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Re-evaluation of the Lower and Middle Palaeolithic of Achenheim (Alsace, France)

Nouvelle évaluation du Paléolithique inférieur et moyen des carrières d'Achenheim (Alsace, France)

ABSTRACT

During their exploitation, the quarries of Achenheim and Hangenbieten (Alsace, France) provided access to an exceptional loess-paleosol sequence, totalling over 40 m in thickness and spanning at least four glacial-interglacial cycles. As early as 1914, E. Schumacher identified thirty stratigraphic units, in which, over the course of almost a century, numerous large faunal remains and lithic artefacts scattered within various levels would be revealed, although only two of these levels were extensively excavated. In particular, the site offers an almost complete key sequence to understand early settlement dynamics in the Rhine valley and particularly the transition between Lower and Middle Palaeolithic, at the boundary between western and central Europe. Nevertheless, data are old and artefacts were recovered by quarry workers and repositioned after their collection. Moreover, while many chronostratigraphic and paleoenvironmental studies have been made during the last decade, the data are dispersed and rarely combined. Due to these biases Achenheim's archaeological data could be disregarded. In the present study, we aim to take a fresh look at the reliability of Achenheim's lithic assemblages. We focus on Lower and Middle Palaeolithic lithic remains, re-examined here in detail. In parallel, their chronostratigraphic position in terms of marine isotope stages, as well as the contemporaneous palaeoenvironmental characteristics, have been checked by combining all available data scattered in many publications concerning older quarries that are no longer accessible or difficult to access. By comparing the archaeological data from this site with the most recent discoveries, both in Alsace and elsewhere in north-western and central Europe, we can show that the lithic industries, though largely incomplete, represent an interesting sample which sheds new light on the succession of lithic technocomplexes of early settlement in the Upper Rhine area. The various technical manifestations identified at Achenheim seem to match the overall techno-typological sequence observed for the Middle and Late Pleistocene of either northwestern or central Europe.

Keywords: Lower Palaeolithic; Middle Palaeolithic; Lithic industries; Loess; Palaeoenvironment; Upper Rhine

Mots-clés : Paléolithique inférieur, Paléolithique moyen, industries lithiques, loess, paléoenvironnement, Rhin supérieur

RESUME

Au cours de leur exploitation, les carrières d'Achenheim et d'Hangenbieten (Alsace, France) ont permis l'accès à une séquence de loess exceptionnelle, totalisant plus de 40 m d'épaisseur et couvrant au moins quatre cycles glaciaires-interglaciaires. Dès 1914, E. Schumacher identifie une trentaine d'unités stratigraphiques, au sein desquelles, pendant près d'un siècle, seront mis au jour de nombreux restes archéologiques, tant fauniques que lithiques. L'importance de cette séquence a suscité l'intérêt de nombreux chercheurs, français, belges, suisses et allemands qui ont mené plusieurs études pluridisciplinaires, notamment environnementales et stratigraphiques durant plusieurs décennies de la fin du XXe siècle. Néanmoins, il ne résulte de ces études publiées tantôt en français, tantôt en allemand, tantôt en anglais, aucune synthèse exhaustive ni

aucun schéma détaillé excepté une vision synthétique des cycles glaciaire-interglaciaire. Il est ainsi difficile d'avoir une lecture globale de la stratigraphie.

De plus, les objets archéologiques ont fait l'objet d'études assez anciennes et méritent d'être réexaminés à l'aune des connaissances actuelles, d'autant plus que leur mode de collecte est éloigné des standards modernes. En effet, excepté deux niveaux ayant fait l'objet de fouilles approfondies, le reste de la collection a été collecté au gré de l'exploitation des carrières, le plus souvent par les ouvriers, mais néanmoins avec un suivi stratigraphique permettant de positionner les objets au sein des ensembles sédimentaires. Il convient ainsi de s'interroger sur la fiabilité de cet ensemble archéologique, afin de savoir quelles informations peuvent en être raisonnablement exploitées. La première question porte sur la validité du positionnement des objets aux bons ensembles sédimentaires. La seconde sur la corrélation des ensembles sédimentaires à une chronostratigraphie précise, permettant alors de les comparer ensuite à d'autres ensembles bien calés des régions voisines. Ces questions sont d'autant plus importantes que le site d'Achenheim se situe dans une région globalement pauvre en sites paléolithiques. Cette lacune archéologique observée dans tout le Rhin supérieur limite toute étude de la dynamique de peuplement à l'échelle européenne.

Dans cet article, nous nous concentrons sur les vestiges lithiques du Paléolithique inférieur et moyen, qui ont fait l'objet d'un réexamen détaillé. Une étude technologique et pétrographique a notamment été réalisée sur les objets de la collection Wernert, représentant un corpus de 860 objets inégalement répartis au sein de plus de 21 unités sédimentaires. Toutes les mentions stratigraphiques rattachées aux objets archéologiques ont été réexaminées et il s'avère que la plupart des objets sont bien attribués à une unité sédimentaire précise. En parallèle, le positionnement chronostratigraphique de ces ensembles sédimentaires a été soigneusement questionné, en combinant toutes les données disponibles dispersées dans la littérature concernant les carrières les plus anciennes qui ne sont plus accessibles. Les caractéristiques paléoenvironnementales ont ainsi été scrupuleusement vérifiées en les comparant notamment aux données disponibles au sein de séquences plus récentes. Suite à ce travail, il a été possible de confirmer ou proposer des rattachements de la plupart des unités sédimentaires à des stades isotopiques marins et ainsi repositionner les ensembles archéologiques dans un cadre chronostratigraphique global, facilitant leur confrontation aux autres sites disponibles de part et d'autre du Rhin.

Le croisement des données archéologiques de ce site avec les découvertes les plus récentes, tant en Alsace qu'ailleurs dans le nord-ouest et le centre de l'Europe, permet de démontrer que l'industrie lithique, quoique largement incomplète, peut être considérée comme un échantillon cohérent pour porter un regard nouveau sur la succession des cultures lithiques des premiers peuplements dans la région du Rhin supérieur. Les diverses manifestations techniques identifiées à Achenheim semblent s'inscrire dans l'évolution techno-typologique globale observée pour le Pléistocène moyen et supérieur, tantôt d'Europe du Nord-Ouest, tantôt d'Europe centrale.

1. Introduction and research questions

Studies on the Middle and Upper Pleistocene of the Upper Rhine and more specifically of eastern France are quite rare. In Alsace (France), ten years of active research led to the discovery of only a few new sites (Griselin et al., 2018; Bachellerie 2021) and to the production of numerous dates (Wuscher, 2021). The number of Pleistocene sequences remains nevertheless too low to achieve the construction of a synthetic regional chronostratigraphy for Lower and

Middle Pleistocene sites and cultures. The chronostratigraphic position, as well as the sedimentological and palaeoenvironmental context, of sites attributed to these periods often lack precision, except only recently for the last climatic cycle concentrating most of the new sections and sites (Wuscher, 2021). The common occurrence of hiatuses does not hinder the recognition of the Eemian and the same major pedological subdivisions of the Weichselian as in northern France (Antoine et al., 2016), but the variety of facies suggests the existence of sub-regional loess domains (Wuscher, 2021). On the German side of the broad Rhine valley, the latest studies date back to the 1960s-1980s (e.g. Bronger, 1966a,b; Khodary Eissa, 1968; Guenther, 1961; Hädrich, 1985, 1987) and only Riegel has been subject to dating by Zöller (1995). Alone and despite all its flaws, the multi-cycle site of Achenheim thus still constitutes the backbone of the chronostratigraphic and archaeological framework for the Lower and Middle Palaeolithic periods in Alsace. Moreover, it can be considered as a key site for understanding the regional Lower-Middle Palaeolithic transition as well as origins of cultural and geographical differences between the Lower and Middle Palaeolithic assemblages of the Rhine valley. Unfortunately, it has not provided new information since 1999.

This situation clearly contrasts to neighbouring regions, where syntheses including recent discoveries and chronostratigraphic updates are regularly published, for example northern France (Antoine et al., 2016, 2021; Hérisson et al., 2016; Loch et al., 2016), Germany (Conard et al., 1995; Bosinski, 2008; Richter, 2016), England (White and Ashton, 2003; Scott, 2011; Parfitt et al., 2010) or Belgium (Van Baelen, 2014; Haesaerts et al., 2016). This gap complicates research on the dynamics of early European settlement by hampering the integration of Alsatian lithic artefacts in the well-documented archaeological frameworks of surrounding provinces. Furthermore, it is unfortunately not possible at present to resume the study of the quarries. The last fieldwork at Achenheim took place in the extension of Hurst quarry twenty-five years ago. The areas of Hurst and Sundhauser ouest quarries are now built over and others are completely overgrown with vegetation, which makes new observations and sampling campaigns difficult or even impossible.

In this context the re-examination of the Achenheim discoveries is of great importance, as they have yielded well-preserved archaeological remains from the Lower Palaeolithic to the Neolithic, distributed throughout an exceptionally long loess-paleosol sequence. However, despite the considerable reputation of Achenheim in the scientific community, the data are not very accessible. The site has been partially studied by various research teams over several decades, although unfortunately this has not provided a meaningful chronostratigraphic synthesis for archaeology. Indeed, since the fundamental thesis of Wernert (1957), the lithic artefacts have only been reviewed by G. Bosinski (1967) and J. Junkmanns (1989) in the context of university studies, later followed by a short synthetic article (Junkmanns, 1995). More recently, Bosinski (2008) re-published only selected data. The latest attempt at integration of archaeological data by Junkmanns (1995) relies at best on the chronostratigraphic framework of Heim et al. (1982). This did not take into account stratigraphic, pedological, chronological and palaeoenvironmental results published afterwards, and the climatic context – interglacial, glacial or early glacial – of most lithic assemblages is not indicated. Lastly, the manual retrieval and stratigraphic assignment of the material by quarry workers have naturally distanced the scientific community from the data. The Achenheim lithic material thus requires re-assessment and integration in an updated chronostratigraphic and palaeoenvironmental framework.

The present study aims not only to provide a first critical synthesis correlating stratigraphic and archaeological data for the Lower and Middle Palaeolithic at Achenheim, but also to evaluate

the reliability of the interpretations based on these lithic finds. In the light of new archaeological observations accompanied by a palaeoenvironmental and chronostratigraphic synthesis, we seek to determine if the archaeological remains of Achenheim allow for a better understanding of the technical evolution of early settlement in the Rhine valley over hundreds of millennia. The focus is on the Lower and Middle Palaeolithic lithic remains. These are the most numerous and are distributed throughout an almost complete sedimentary sequence. Upper Palaeolithic lithic and faunal remains are less abundant but also deserve re-examination and further research.

2. Material and methods

2.1. Site presentation and summary of past chronostratigraphical and palaeoenvironmental studies

The Achenheim site actually includes several quarries located in the neighbouring municipalities of Achenheim and Hangenbieten in the Bruche Valley (France), about 10 km west of Strasbourg (Fig. 1, n°1). Contrary to the recent and active Bossenrott quarry located on the Kochersberg plateau, historical quarries have exploited its eastern slope bordering the left side of the Rhine valley, between the Zorn and Bruche valleys. In comparison with the plateau, these slope landforms favoured thick loess accumulations, paleosol preservation and enhanced the impact of climate cycles on the sedimentary deposits (Vogt, 1978a; Moine & Wuscher, pers. obs.). Several major sedimentary sequences, in which layers of aeolian deposits (loess) alternate with paleosols, have thus been preserved in these quarries.

These loessic sequences were first revealed in the 19th century during loess quarrying to supply nearby brickworks (e.g. Daubrée, 1852; Fig. 2, n°1). Detailed stratigraphic surveys were carried out from 1883 until the 1950s (Schumacher, 1883; Andraea, 1884; Schumacher, 1890, 1914; Forrer, 1920, 1925; Wernert, 1957). The work of Schumacher (1914) and Wernert (1957) particularly contributed to understanding the three-dimensional structure of the Achenheim deposits. The base of the sequence is composed of a terrace consisting of two sandy formations (“*Sables gris rhénans*”/Rhine grey sands and “*Sables rouges vosgiens*”/Vosgian red sands), topped by a sandy loess unit (“*Limon jaune canari*”/canary yellow loam) and a thick brown-red clayey paleosol (“*Limon rouge de plateau*”/plateau red loam). It is superimposed by a thick succession of four loess series (“*Læss ancien inférieur*”/Lower Older Loess, “*Læss ancien moyen*”/Middle Older Loess, “*Læss ancien supérieur*”/Upper Older Loess and “*Læss récent*”/Younger loess) alternating with three major paleosol complexes (Achenheim III, II and I) also called “*lehm*”, the whole of which is capped by the Holocene topsoil. The spatial and temporal connection of the loessic sequence with the underlying terrace deposits is complexified by a tectonic shift, accompanied by an erosion phase at the top of the terrace (Figs. 3 & 4). A Mindel age has always been attributed to the terrace deposits based on the typology of their lithic industries and faunal remains (Wernert, 1957) and on the presence of particular rodent taxa in the “*Sables rouges vosgiens*”, (Chaline & Thévenin, 1972). Furthermore, the “*Limon rouge de plateau*” that tops the terrace deposits was in the past correlated with the Mindel-Riss interglacial (see figure. 1 in Heim et al., 1982) and its characteristics (Fouquaire, 1982) correspond to an interglacial pedogenesis. Though neither directly dated nor bracketed by absolute dates, the chronostratigraphy of the overlying loessic sequence precludes any correlation of the “plateau red loam” with a marine isotope stage (MIS) younger than MIS 11.

From 1980 onwards, a plan to back-fill the extraction sites threatened the Achenheim quarries and motivated new stratigraphic and palaeoenvironmental studies (Heim et al., 1982; Fig. 2, n°3), soon followed by absolute dating, involving thermoluminescence (TL) (Buraczyński & Butrym, 1984; Aitken et al., 1986; Packman & Grün, 1992; Zöller, 1995; Rousseau et al., 1998a,b; Zöller et al., 2004) as well as radiocarbon (Evin et al., 1980; Thévenin, 1980). Lastly, P. Antoine and collaborators presented a new synthetic overview (see Fig. 8 in Antoine et al., 2001) substantially different from previous ones. This new pedostratigraphical succession was accompanied by selected TL dates obtained by Zöller and by the chronostratigraphic interpretation of the Weichselian sequence as exposed in the Hurst quarry extension. Unfortunately, in the absence of a more detailed pedological and sedimentological analysis of the sequence, the uncertain nature of some horizons still hampers precise correlations with older sections *in situ* and with more recently studied and well documented local and regional loess sequences such as Pfulgiesheim, located about 7 km to the NNW (Bachelier et al., 2021) and Nussloch (Germany) located about 100 km to the NE (Antoine et al., 2001, 2009; Moine et al., 2017).

Otherwise, concerning palaeoenvironmental reconstructions based on molluscan assemblages, Wenz (1919) only provides a list of molluscan taxa for a single layer (unit 19) of the Middle Older Loess. As for Mazenot (1963), his palaeoenvironmental interpretations may lack precision. As the exact positioning of his samples throughout thick formations is not mentioned, assemblages from different units may have been mixed. Conversely, Rousseau (1987) combined the data of Puisségur (1978) with many new molluscan samples and reconstructed the precise palaeoenvironmental history of the site. By coupling these results with the absolute dates from the 1980s, Rousseau and Puisségur (1990) linked the reconstructed glacial-interglacial alternation to the MIS succession, correlating Achenheim I, II and III pedocomplexes to MIS 5, 7 and 9 respectively, and supporting the earlier chronological framework proposed by Lautridou et al. (1986).

2.2. Geoarchive reinvestigation

In order to address the problem of the chronostratigraphic and palaeoenvironmental contexts of Achenheim lithic remains, we reviewed the results of geoscientific research in the quarries. The most important studies linked with Wernert's period of activity have been carefully re-evaluated to synthesize and organise sedimentary, malacological and faunistic information given in the synoptic tables 2 and 3, in order to facilitate understanding of the long and complex stratigraphy. Indeed, most of the literature is in German and French and is sometimes only available in university theses, excursion guides or journals with limited circulation, and this can be a rebuttal and a source of confusion unfavourable to the comprehension of the site. The re-evaluation of the attribution of the stratigraphic units to their respective MIS based on sedimentary, malacological and chronological data was necessary to compare the evolutionary trends of the Achenheim archaeological record with those of better documented sites from north-western and central Europe, in order to evaluate the implications of their similarities and discrepancies. This first overview did not *a priori* reveal the necessity for a major revision of both palaeoenvironmental and chronological frameworks, but did improve their combination.

2.3. Absolute chronology

In absence of a synthesis of all dating approaches performed at Achenheim, a compilation was essential to check for any discrepancy between the different methods. Dating results have thus been compiled in a synthetic table with their location and methodological details (Table 1). Dated sections, when known, have been located on the 3D diagram of the site (Fig. 3) and age estimates have been positioned along the synthetic stratigraphy of Lautridou et al. (1985) (Fig. 4). Packman and Grün (1992) obtained ages significantly younger than those of Zöller et al. (1995) for the same samples, especially for the Upper and Middle Older Loess series. Moreover, as loess deposition no longer occurred at the latitude of Strasbourg later than around 15 ka (Wuscher et al., 2021), a general underestimation of their ages cannot be excluded. The same bias probably affects the two youngest ages of Aitken et al. (1986). Despite their good agreement with those of Zöller (1995), the dates by Buraczyński and Butrym (1984) seem affected by methodological flaws (Zöller, 1995). Consequently, here we only used Zöller's dates, published in Zöller (1995), Rousseau et al. (1998a,b) and Zöller et al. (2004), as the chronological framework of the stratigraphy. Ages are presented and discussed together with pedological and palaeoenvironmental data in the section of the corresponding unit.

2.4. Lithic material

2.4.1. Collection of lithic artefacts and associated biases

While faunal remains had been recovered since 1835, the first lithic artefacts were discovered in 1889 (Schumacher, 1890) and others later by Forrer (1925), who also collected faunal remains. The most important contribution is clearly due to Paul Wernert, a geologist who supervised the collection of archaeological material during large scale loess extraction carried out in the Sundhauser, Hurst and Schneider-Schaeffer quarries (Fig. 1 n°2). Then, he wrote his thesis on both faunal remains and lithic tools collected at Achenheim (Wernert, 1957). The material was recovered from the 1910s until the 1950s by naked eye detection and by hand, mostly by quarry workers, i.e. inadequately compared with modern standards. Wernert's method implied "permanent personal control of the work in progress" and "patient and systematic education of supervisors and workers, interesting them in scientific observations and rewarding them with modest rewards". A label indicating the quarry and both the number – based on Schumacher's numbering system – and nature – for example "humoser Lösslehm" or "Lehm brun" (brownish lehm), "Limon rouge argileux" or "roten Lehm" (clayey red lehm), etc. – of the unit of provenance was attached to each piece collected by Schumacher and Wernert.

Despite all these precautions, the various workers may not have always applied the same care to recovering artefacts, an aspect that can hardly be evaluated. This imposes obvious limits to our reinvestigation. Likewise, a significant bias in the number of collected artefacts must also be underlined, since all the pieces, and in particular the smaller ones, were not necessarily recovered. This could partly explain the small number of lithic artefacts for each unit, but also hinders assessment of the density of finds per archaeological layer.

Interestingly, despite the numerous archaeological levels identified at Achenheim, only two have been subject to appropriate archaeological excavation campaigns and in fact produced very few lithic finds. The "sol 74"/soil 74 excavated in 1974 in unit 16 over 200 m² (Figs. 3 & 4) yielded only 92 lithic pieces, revealing a Middle Palaeolithic occupation (Sainty & Thévenin,

1978) and associated with a diversified mammal fauna (Byrne & Prat, 1978; Guérin, 1978; Fig. 2, n°2 & 4). This excavation led to a multi-disciplinary study of the site (Vogt, 1978b, 1979). The “soil 74” was originally attributed to the Younger Loess, i.e. to the Weichselian glaciation, based on its mammal fauna. It was later assigned to the Upper Older Loess at the top of a bedded loamy-sandy formation, i.e. to the end of the Saalian glacial period, based on new field observations (Heim et al., 1982). As for “sol 81”/soil 81, excavated in 1981 (Figs. 3 & 4), it was positioned in unit 20a in the lower part of paleosol complex Achenheim III, capping the Lower Older Loess (Heim et al., 1982; Thévenin, 1982). It contained hearths in addition to bones and a few lithic finds, limited to pebbles (Thévenin, 1982).

2.4.2 Methods of re-examination

Collected over several decades, the archaeological material is quite abundant and mostly recovered by Paul Wernert in the so-called "Wernert collection". Nevertheless, this collection was dispersed during the last century to various curation sites in France. We examined these objects at the Musée National de Préhistoire in Les Eyzies-de-Tayac, at the Musée archéologique de Strasbourg, at the university of Strasbourg and at the home of Paul Wernert's son, in Strasbourg. According to the literature, 1,015 lithic artefacts comprise the Wernert collection (Junkmanns, 1989, 1995). The Lower and Middle Palaeolithic corpus is divided into 21 assemblages. Each assemblage corresponds to artefacts positioned within a unique sedimentary unit. Nevertheless, although all objects from the collections listed above have been re-examined, some of them have not been retrieved. Therefore in this paper we present our observations, occasionally supplemented by J. Junkmanns' observations when we did not find a published object. Use of the Junkmanns data is systematically mentioned.

Lithic remains have been re-examined in the light of the new analytical methods developed after the 1990s, in particular lithic technology (Inizan et al., 1995). In addition, numerous new data on the Lower and Middle Palaeolithic in north-western and central Europe have been published since the end of the 1990s (e.g. Locht et al., 2016; Richter, 2016), shedding new light on the Achenheim remains. The same applies to petrographic studies, where knowledge of the different lithic materials in the Rhine Valley has improved significantly in recent years. This new work on lithics has so far only been partially published in French for a few Middle Palaeolithic levels, as part of a more general synthesis (Koehler et al., 2020).

The selected analytical methods take into account the collection biases. This is why the lithic study does not tackle statistical or economic indices but rather focuses on the qualitative technological and typological data. Each piece was repositioned within the “*chaîne opératoire*”, i.e. operational sequence, highlighting both modes and methods of production. Particular attention was paid to retouched tools, which were observed according to a typological and functional approach. Petrographic analyses were also carried out in order to search for different trends in lithic raw material sourcing strategies (see legend of figure 9 for details).

3. Results

3.1. Unit 30 - MIS 13

Unit 30 is the oldest unit that has yielded archaeological material. It is composed of greyish Rhine sands (SGR on Figs. 3 & 4) of fluvial origin with intercalated silty lenses. Sampled during

several years in the nearby quarry of Hangenbieten, this 3-m-thick unit produced diversified molluscan fauna characteristic of a temperate climate, with shells concentrated in coarser layers (Andreae, 1884). The few faunal remains later found at Achenheim did not contradict this interpretation (Wernert, 1957; Table 2). Based on the minimum number of glacial-interglacial cycles identified in the overlying sedimentary sequence, unit 30 could correspond to an interglacial period not younger than MIS 13. However, several cold environment taxa, which cannot have been contemporary with forest taxa, were found together by Andreae (1884). This observation was confirmed by later sampling at Achenheim (Wernert & Geissert, 1963) but the original climatic attribution was not called into question. Depths of occurrence of the different taxa, which may have highlighted significant changes in the molluscan fauna through time, are unfortunately not recorded, as this unit has always been sampled as a whole. The question remains open whether cold environment taxa were introduced in an interglacial molluscan fauna by gentle reworking from surrounding glacial deposits or if the deposition of the greyish Rhine sands was also contemporary with at least one glacial period. Indeed, two layers of 10-20 cm-sized calcium concretions, similar to loess dolls resulting from interglacial pedogenesis, are shown in the lower half of this unit by Andreae (1884), but neither described nor discussed.

In 1957, a single lithic artefact, a chopper made from a quartzite pebble, was discovered (Wernert, 1962) (Fig. 5, n° 1). It displays two removal negatives at one end, forming a concave cutting edge. However, contrary to the initial observations made by G. Millot, the negatives are very blunt, casting doubt on their anthropogenic character. This could represent the earliest evidence of human presence in Alsace.

3.2. Unit 29 to 21 - MIS 12

E. Schumacher, followed by P. Wernert, went on to describe nine stratigraphic units (units 29 to 21 from bottom to top; Table 2). These layers are composed of silts, more or less loessic in nature (units 29-28), Vosgian red sands (SRV on Figs. 3 & 4) alternating with silts and loams (units 27 to 22) and a canary yellow loam at the top (unit 21; LJC on Figs. 3 & 4). Evidence of cryoturbation is visible in the Vosgian sands and it is also worth noting the absence in these layers of large fauna; the malacofauna, although numerous, is poorly diversified and includes cold climate taxa (Wernert, 1957; Puisségur, 1978). The molluscan fauna of unit 21 only highlight a slight warming and the establishment of a shrub tundra landscape (Puisségur, 1978). These elements reflect a glacial context that we propose to attribute to MIS 12. In the absence of absolute dating for this formation, this is the most parsimonious attribution based on previous chronostratigraphic synthesis (Lautridou et al., 1986).

Apart from the 1913 discovery of a “worked pebble” in unit 28, referred to by Wernert (1957, 1962), the first four units (29-25) are archaeologically sterile. Unit 24, however, yielded a single lithic find, namely a transversal scraper worked from a natural phtanite fragment (Table 2 & Fig. 5 n°2). At first glance, the manmade character of this object is questionable. However, the retouch is direct and occurs on just one edge of the tool where it forms a cutting edge. Following comparisons with other sites in central Europe, the object could be manmade but the presence of only one artefact is questionable. The same question arises for the two lithic artefacts from unit 23. According to J. Junkmanns (1989) these are a large quartz chopper with a very abrupt

frontal removal and an un-retouched phtanite fragment. Unfortunately we were unable to locate and study these items.

3.3. Unit LRP/20e - MIS 11

This red plateau loam (LRP on Figs. 3 & 4), also known as unit 20e (Junkmanns, 1989), overlies the terrace deposits. The brown-reddish clayey-sandy loam has a polyedric structure that includes 29% clay (Fouquoire, 1982). Its characteristics correspond to an interglacial pedogenesis and it has yielded temperate forest fauna and malacofauna (Wernert, 1957; Puisségur, 1978; Table 2). Franc de Ferrière (1937) defines it as a strongly evolved plateau soil with a red, decalcified eluvial clay horizon, featuring massive carbonate concretions (loess dolls), irregular in shape and sometimes flat. He considered it to be the most evolved soil on the site and stated that it is similar to North African soils that developed on calcareous tufa. It can also be linked to the fourth leached brown-type paleosol encountered in other west-European loess-paleosol sequences dated around 400-450 ka. As at Achenheim, this is always described as redder and more clayey than later ones (Antoine et al., 2021), as for example at Ariendorf (Rhineland-Palatinate, Germany; Stremme, 1985; van den Bogaard & Schmincke, 1990), Besigheim (Baden-Wuerttemberg, Germany; Bibus, 2002), Allschwil (Basle-Country, Switzerland; Zollinger, 1991), ferme de Grâce (Picardy, France; Antoine et al., 2020), Saint-Pierre-lès-Elbeuf (Normandy, France; Cliquet et al., 2009) and Op de Schans (Limburg, Netherlands; Meijs et al., 2012). The more intense pedogenesis would result from the exceptionally long duration of interglacial conditions during MIS 11. We can also note the similarity between the Achenheim and Ariendorf sequences, both located in the Rhine Valley, in which the fourth paleosol developed on a first generation of glacial colluvio-aeolian deposits topping the sandy layers of the terrace. In several sites, deposits dated to this interglacial have yielded a diversified malacofauna including many forest taxa, amongst which the extinct taxon *Aegopis (Zonites) acieformis* (Limondin-Lozouet *et al.*, 2020). Currently, this taxon is only known from this interglacial. However, the few shells manually collected at Achenheim by Wernert (1957) are not representative of the contemporary molluscan fauna and Puisségur (1978), though using an adequate protocol, only sampled reworked material derived from the plateau red loam. This could explain why this taxon has not been found in this particular unit at Achenheim. Nonetheless, the species, or at the very least the genus, is present in the succeeding units 20d and 20b (Wernert, 1955, 1957), deposited after (or during) a significant erosion phase of the plateau red loam. Its interglacial character, first established by Wernert (1957), is discussed below. Despite the absence of associated or bracketing absolute dates, all this evidence argues in favour of the correlation of the red plateau loam with MIS 11.

Three lithic artefacts were discovered in the red plateau loam: two large choppers, one in quartzite and another in phtanite, the latter possibly a core (Fig. 5, n° 4; Table 4), and a quartz scraper which has since gone missing.

In 1957, P. Wernert identified the remains of a hearth within this unit; the feature included wood charcoal, reddened soil and the burnt tibia of a horse.

Starting with this unit, all younger units yielded archaeological material.

3.4. Units 20d, 20c & 20b - MIS 11 ?-10

Units 20d to 20b constitute the Lower Older Loess. According to Wernert (1957), these three units contain few faunal remains (Table 2). Unit 20d, a “yellow, clayey fluvial loam”, and unit 20c, a “brownish, intercalated loam”, have only been observed by Wernert (1957). Water infiltration meant that unit 20d could only be explored by machine, thus introducing a bias in the sampling of molluscan remains. Moreover, the eroded microsculpture of *Aegopis* sp. shell material from this unit (Wernert, 1955) suggests their reworking. Then, with only two taxa, including *Helix pomatia*, the malacofauna from unit 20c is by no means representative and raises the question of the origin of the remains of this interglacial taxon. Unit 20b, homogeneous at the top and stratified at the base, is “a loessial loam containing pseudomycelium”. This unit, and especially its base, could well be loessic colluvium, like the two layers of “atypical pseudomycelium-containing loesses” of the Middle Older Loess interpreted as such by Puisségur (1978). Care must therefore be exercised when considering the significance of these three units and the interglacial character suggested by their scarce, biased and possibly reworked malacofaunas; the erosion of the 1 to 4 m-thick red plateau loam (unit 20e) may have indeed lasted over a considerable time.

The sedimentary sequence located in the same stratigraphic position and analysed by Puisségur (1978) is referred to as section 2 (Fig. 3; Table 2). Located 15 m eastward and 5-6 m below its basis, units 20d and 20c are not present in section 2 (Puisségur, 1978), which is similarly structured to unit 20b and yielded almost no fluvial taxa. The choice was thus made to correlate the deposits of section 2 with unit 20b alone, except the top “humic dark loam” equivalent to unit 20a. The malacofauna of section 2 thus reflects a sparse glacial vegetation cover alternating with four interstadial oscillations characterised by steppic vegetation. The state of preservation of the rare fragments of forest taxa found throughout the laminated part of this profile suggests their reworking from older interglacial deposits (Puisségur, 1978), while the few fragments of temperate molluscan taxa found at the top of the homogeneous yellowish loessic loam may derive from burrows in-filled with material from the overlying paleosol (cf. 3.5). While the attribution of unit 20b to MIS 10 seems most likely, the assignment of units 20d and 20c to the early glacial period of MIS 11 and MIS 10, i.e. around 390 and 370 ka (Railsback et al., 2015), is merely hypothetical.

As regards the lithic finds, four artefacts, made from quartz and phtanite, are associated with unit 20d. They consist of a chopper, a scraper made from natural debris and two flakes with natural surfaces and smooth butts, suggesting that the cores were not prepared (Fig. 5 n°3 & Fig. 6 n° 1). An artefact found in unit “20c/d” can also be included. Bearing denticulated retouches, it attests to more elaborate and efficient knapping. Indeed, the negatives on its upper surface and its prepared butt suggest that it was probably detached from a prepared core (Fig. 6, n° 2).

Thirteen lithic artefacts were retrieved from unit 20c. These include flakes, cores and choppers (Table 4), mostly of quartz, quartzite and phtanite. They reflect simplified modes of production but suggest a certain organization in the management of debitage, with priority given to of the debitage surfaces and striking platforms (Fig. 6, n° 3 and 4).

Unit 20b yielded forty lithic artefacts, mainly of quartz, quartzite and phtanite. The lithic industry is dominated by flake production, predominantly using simple methods of flaking, without prior preparation of the volume of the core. Nevertheless, eight flakes attest to a more

productive type of debitage with possible preparation of the flaking surface, some of which might be described as “Levallois” or “Prepared Core Technology” (Fig. 6, n° 5 to 9). Indeed, several negatives on their upper face show the preparation of the flaking surface prior their detachment. Moreover, some butts are prepared. Likewise, three scrapers display more regular retouch than in the preceding units (Fig. 6, n° 10 & 11). Three worked pebbles have also been identified. Finally, two objects can be ascribed as “unifaces”, i.e. unifacially worked handaxes. These are clearly more carefully made and show greater technical skill than artefacts present in the underlying units (Fig. 7 n° 1).

3.5. Unit 20a - the end of MIS 9

Unit 20a consists of a truncated reddish-brown soil at the base, above which lies a dark brown clayey loam with humus-rich horizons (Heim *et al.*, 1982; Table 3). The malacofauna from the humic horizons suggests quite a marked steppic character and indicates significant warming (Puisségur, 1978), although not to interglacial level. The very small proportions of the humid forest taxon *Perforatella bidentata* indicate the localised presence of trees. These characteristics prompt us to attribute this unit to a climate of early glacial type, at the MIS 9-8 transition.

Otherwise, Heim *et al.* (1984; section B, unit 5) described a non-calcareous brown clayey-sandy loam with large reddish spots previously detected by Heim *et al.* (1982) between units 20b and 20a. Associated pollen analyses reflect forest vegetation (Heim *et al.*, 1984). Combined with the presence of *Helix pomatia* in unit 20a (Wernert, 1957), even reworked, these elements indicate interglacial conditions, most likely corresponding to MIS 9.

The reinvestigation of sections supervised by A. Thévenin at the beginning of the 1980s led him to undertake a small excavation in 1982. Within unit 20a he uncovered the remains of a number of hearths (Thévenin, 1982) in a level designated “soil 81”, which geomorphological analyses attribute to this unit (Heim *et al.*, 1982).

As regards lithic remains, 76 artefacts were recorded, the vast majority of which were made from Vosgian rocks, except three flint flakes (Table 4; Fig. 9). Two of the six cores found have Levallois debitage, according to Boëda’s (1994) definition (Fig. 7, n° 5 & 6). Indeed, these cores are shaped out by two asymmetrical convex surfaces that define a plane of intersection. Their debitage surface shows several centripetal negatives that shape lateral and distal convexities. Likewise, three flakes also fall within the Levallois concept of debitage by virtue of their size, the sign of preparation of the volume prior to their detachment, and evidence for preparation of the butts, which can be dihedral or faceted in shape (Fig. 7, n° 3). This, coupled with the presence of scrapers, leads us to suggest that this unit already belongs to the Middle Palaeolithic. Nevertheless, it should be noted that the retouch on the flakes remains minor (Fig. 7, n° 2 & 4). Moreover, worked pebbles are still occasionally present in this relatively late period. Similarly, certain cores show an absence of preparation prior to the detachment of flakes. Some of them, more intensively exploited, suggest an SSDA (“*système par surface de débitage alternée*”) type of exploitation, according to the definition of Hubert Forestier (1993). Several flakes are produced on different surfaces of the block, without preparation.

3.6. Unit 20’’ - MIS 9/8

Unit 20'' marks the beginning of the "Middle Older Loess" (Wernert, 1957). It is described as a thick complex of sandy formations and brownish beds, which becomes increasingly sandy at its base (Heim *et al.*, 1982). The malacofauna is indicative of a contrasted climate in terms of warmth and humidity and of a steppic type of vegetation (Puisségur, 1978) that may have developed during an early glacial stage of the MIS 9-8 transition, possibly between 320 and 280 ka during the succession of isotopic substages 9d-9a *sensu* Railsback et al. (2015).

As regards lithic material, 46 artefacts made from various local rocks have been recorded (Table 4). While the two cores indicate limited exploitation of pebbles, with few evidence of preparation or hierarchical organisation, certain flakes reveal more elaborate preparation and thus confirm the trend already noted concerning the stratigraphic development towards Levallois flaking concepts (Fig. 8, n° 1 to 3). Finally, two plunging flakes attest to the maintenance of the convexities of cores during debitage.

3.7. Unit 20'' and 20' - MIS 8

Unit (20'') is composed of yellow loess and its molluscan and faunal remains reflect glacial conditions, while overlying unit 20', described as an atypical loess (Schumacher, 1914; Werner, 1957) and then as a "more typical loess" (Heim *et al.*, 1982), consists of loessic colluvium (Franc de Ferrière, 1937; Puisségur, 1978). The replacement of cold-climate by forest taxa throughout unit 20' highlights a transition towards interglacial conditions subsequently recorded (see 3.7). TL ages of 228 ± 19 and 222 ± 20 ka obtained for units 20'' and 20' respectively (Fig. 4) would date them to MIS 7. However, chronostratigraphic distinctions are not possible beyond 200 ka with the regenerative TL method on fine-grain material (Zöller, 1995). Moreover, the loessic nature of both units is obviously incoherent with an attribution to MIS 7e or MIS 7c-a, characterised by Bt horizons (see figure 9 in Antoine et al. (2021) and references therein). They are also definitely too thick (4-5 m) to correspond to the intermediate loessic layer contemporaneous of MIS 7d when distinct. All these points rather support the attribution of units 20'' and 20' to MIS 8.

In terms of lithic industry, units 20'' and 20' produced 60 and 117 artefacts respectively (Table 4). The artefacts recorded from unit 20'' reflect a predominance of Levallois debitage, which tends to be preferential and very well controlled (Fig. 8, n° 4 to 6). Some of the retouched tools are also particularly well made; retouched points appear. The recorded artefacts also include simple scrapers and a few rare denticulated tools. Most of the retouched tools are made from good quality raw materials such as flint, chalcedony and phtanite, collected in pebble form, probably in the immediate vicinity of the site.

In contrast, the lithics from unit 20' show that elongated, blade-like elements were sought after (Fig. 8, n° 8 & 9); the debitage technique shows little Levallois influence and flakes tend to be quite thick. The retouched objects tend to be sub-quadrangular with carefully executed retouch and are interpreted as simple, straight-edged scrapers (Fig. 8 n° 7). Noteworthy are two objects that could attest to bifacial production; one is made of flint from the Lörrach region, nearby Basel, about 100 km south of Achenheim (Fig.8, n° 10, Table 5 and Fig. 9 & 10). Also worthy of note are two prismatic, volumetric, semi-turning blade cores (Fig. 8, n° 8). However, they show little visible evidence for preparation of the volume (absence of crests).

3.8. Units 20 to 18 - MIS 7

The nature of unit 20, i.e. a humic brown loam, confirms the climatic transition begun in unit 20'. As was the case for unit 20', unit 19, originally described as an atypical loess, is reinterpreted by Puisségur (1978) as a loessic colluvium and by Heim et al. (1982) as a sandy loam deposit resting on an erosion level. Unit 18 is composed of red-brown loam and is interpreted as a Bt of truncated leached brown soil (Heim *et al.*, 1982). The malacofauna indicates a warm temperate climate associated with a certain degree of humidity (Puisségur, 1978). The three units are therefore attributed to MIS 7 in spite of the TL age of 190 ± 16 ka obtained in unit 19 (Zöller et al., 2004; Fig. 4), which may, like older ones, be somewhat underestimated.

Concerning the lithic industry, these units have produced the largest numbers of artefacts of the entire sequence: 90 objects for unit 20, 98 for unit 19 and 147 for unit 18 (Table 4). The large number of finds, together with the presence of production waste, suggests that debitage took place on site. The lithic industry is very similar in all three units. The majority of objects are made from good quality raw materials (phtanite and flint; Fig. 9) and this is particularly true for Levallois blanks and retouched objects. Of particular note in units 19 and 18 are three flakes and a core of flint with sub-primary cortex, the source of which is more than 100 km away (Table 5; Fig. 10).

The retouched tools are predominantly triangular in form: Mousterian points and convergent scrapers (Fig. 11 n° 1, 7, 8 & 9), along with a few simple, denticulated scarpers, all made from quite thick, carefully worked blanks (Fig. 11, n° 6). It is also worth noting that the sizes of the finished retouched artefacts (flakes and objects) are slightly larger (around 55 mm of length) than those recorded in the older units 20' and 20 (Fig. 12). As regards the modes of production, Levallois debitage is very common and involves preferential or recurrent unipolar and centripetal methods (Fig. 11, n° 4 & 5). Also worthy of mention is the presence of a well-exploited rhyolite blade core, which appears to show evidence for the creation of a frontal crest and perhaps also a dorsal crest (Fig. 11, n° 10).

3.9. Units 17a, 17 and 16 - MIS 6

Units 17a, a thin loess layer, and unit 17, sandy-loam formations or bedded sands (Heim *et al.*, 1982), mark the beginning of the "Upper Older Loess" (Schumacher, 1914). Unit 16 is a 4 m-thick typical loess with intercalated zones of rubefaction (Schumacher, 1914; Wernert, 1957; Heim *et al.*, 1982, Table 3). It discordantly overlies the "*Formations limoneuses litées*" (unit 17), i.e. cryoturbated bedded loamy formations with syngenetic frost cracks, and which includes here a hydromorphic loamy horizon (pseudo-gley). This facies corresponds to the "bedded formations" with syngenetic frost cracks described in Belgium and northern France in the same stratigraphic position in loess sequences of the penultimate glacial period (Heim et al., 1982). The "soil 74" archaeological level is situated at the top of this sequence in the lower half of unit 16 (Heim *et al.*, 1982).

These levels yielded very few faunal remains, both in terms of individuals and species (Wernert, 1957). It should also be noted that the loess contains very few and small terrestrial molluscs (Wernert, 1957; Puisségur, 1978). These observations clearly attest to a very cold glacial

environment that can be attributed to MIS 6 with the support of all TL ages from these three units (Fig. 4; Table 1).

Likewise, very few lithic artefacts have been recorded in these units: 5 objects in unit 17a, 10 in unit 17/17' and 12 in unit 16 (Table 4). Proportionally, these units have yielded fewer objects of flint and chalcedony than the older units (Fig. 9). Retouched tools are proportionally numerous and they display regular, fine retouch (Fig. 13, n° 1, 3 & 4). Levallois debitage appears to dominate with an emphasis on centripetal/unipolar management to produce quadrangular or roughly oval flakes (Fig. 13, n° 2). Apart from two cores, there is very little evidence for *in situ* debitage. Contrary to other units, the very few lithic and bone finds, together with a higher proportion of retouched tools, could suggest ephemeral occupation.

3.10. Unit 15 - MIS 5e (only?)

From the top of the Upper Older Loess to the base of the Younger Loess series, Schumacher (1914) distinguished three units: unit 15 ending the Upper Older Loess and units 14 to 13 at the base of the Younger Loess. Later, Wernert (1957) merged them on his synthetic profile, although he roughly distinguished unit 15 from units 14-13 in his description (Table 3). Heim et al. (1982) described unit 15 as a thick red-brown loam representing the lower part of a Bt horizon of truncated leached brown soil. The two ages between 85 and 70 ka obtained for the base of this Bt horizon (Table 1) are considered underestimations (Rousseau et al., 1998b). According to figure 22 of Fouquaire (1982), this Bt horizon attributed to MIS 5e is only preserved at the bottom of a large palaeogully in the Hurst quarry extension (Fig. 3), whereas unit 15 is present up to the southern slope on Schumacher's profile. Thus, either unit 15 of Schumacher includes the interglacial paleosol and basal overlying horizons interpreted as steppe soils and attributed to the Weichselian Early Glacial (Fouquaire, 1982; Sommé *et al.*, 1986), or at the time of Schumacher's observation, when the palaeogully was cut more to the north-east by the north-south-oriented main Hurst quarry wall (Fig. 3), the large palaeogully may have been less incised and the Bt horizon preserved also on its sides.

Due to decarbonation, the sediment is void of molluscan remains, but pollen samples indicate the presence of a gallery forest, surrounded by open vegetation on the plateau, evolving towards a mixed forest possibly contemporaneous with the climatic optimum (Heim et al., 1984).

The lithic finds from unit 15 are labelled "red loam", suggesting that they derive from the Bt horizon rather than from the overlying brown steppe soil B-horizon, i.e. unit 10 of Fouquaire (1982). The lithics from units 14-13 come from the overlying succession of humic horizons attributed to the Weichselian Early Glacial (cf. 3.11). We therefore believe that the distinction between unit 15 (= Bt horizon-steppe soil B horizon) and units 14-13 (= humic horizons) is broadly valid for the lithics.

Schumacher (1914) clearly located his "*Kulturschicht*", i.e. the occupation level with hearths, at the interface between his units 15 and 14. In such a position it probably just precedes the deposition of unit 14, otherwise it would have been eroded. The material thus most likely dates to the Weichselian Early Glacial.

The lithic material from unit 15 is composed of 51 pieces, mainly of phanite. Of the 12 retouched pieces, most are single or double scrapers with straight or convex cutting edges (Fig.

14, n° 2, 3 & 4). Two small flakes display very abrupt retouch. One of them is made of flint from a source located 70 km to the south-west of the site (Table 5; Fig. 10). One bifacial piece is referred to in the literature as a “*Faustkeil*” (Junkmanns, 1989). However, the poor quality of the raw material used makes the object difficult to interpret (Fig. 14, n°5). Our observations prompt us to re-characterise this object as a “scraper with bifacial retouch”.

As regards the modes of production, most of the cores can be categorised as Levallois, three of which can be interpreted as recurrent centripetal and one as bipolar (Fig. 14, n° 6). In general, they point to exhaustive debitage. One volumetric blade core has also been recorded (Fig. 14, n°1). It shows quite elaborate (rear and lateral crests, removal of opposing bladelets) and relatively exhaustive exploitation, with several phases of re-sharpening of the striking platform.

We note the reduced size of the artefacts (approximately 41 mm in length) compared to the underlying units (Fig. 12).

3.11. Units 14-13 - MIS 5d-a?

Units 14 and 13 originally distinguished by Schumacher (1914) were further merged by Wernert (1957) into a blackish humic loam, mostly decalcified and partly reworked (Table 3) and later by Heim et al. (1982) into a pedocomplex described as a dark-brown loamy formation, reaching a substantial thickness (4 m) in the large palaeogully of the Hurst quarry extension, where several successive humic soil horizons developed. Lautridou et al. (1985) finally describe a formation of bedded humic loams including pedogenesis and sedimentation. According to the profiles of Fouquoire (1982), Heim et al. (1984) and Rousseau et al. (1998b), their lateral extension seems limited to the deepest and central part of the large palaeogully along the southern wall of the Hurst quarry extension. Palynological analyses indicate a shift from a “conifer-dominated forest” to a “degraded forest environment”, which suggests that unit 14 was deposited during an Interglacial-Early Glacial transition (Heim et al., 1984). The malacofauna contemporary with the second phase indicates cool and humid conditions (Puisségur, 1978) and a dry grassland environment (Rousseau, 1987). Pedosedimentary characteristics imply cold and humid periglacial conditions during the reworking phase, alternating with short dry phases enabling the deposition of reddish loamy beds (Fouquoire, 1982).

Later, the description of the base of unit 14 was detailed in the Hurst quarry extension. A black humic horizon interpreted as a grey forest soil (Van Vliet-Lanoë, 1984; Sommé et al., 1986; Antoine et al., 2001), which is supported by a pollen analysis (Sommé et al., 1986), underlies a (light) grey silty horizon interpreted as a thin loess deposit (Rousseau et al., 1998a,b). In between, but only on the northern wall of the quarry, there is a brown loamy horizon (Rousseau et al., 1998b) interpreted as an isohumic steppe soil (Antoine et al., 2001). The horizon at the base of unit 14 represents at least the basal black soil (Fig. 4).

On the one hand, taking into account pedological features, Antoine et al. (2001) concluded that the black humic and brown loamy horizons are contemporaneous with the end of the Early Glacial, i.e. MIS 5a. On the other hand, the (light) grey silty horizon has been dated at 64.9 ± 6.9 ka on the southern wall (Rousseau et al., 1998a; Zöller et al., 2004) and at 52.4 ± 4.9 ka on the northern wall (Rousseau et al., 1998a). This second date has been considered as a “minimum age owing to the apparent secular disequilibrium in the 238-uranium decay chain” (Rousseau et al., 1998a) and was no longer considered by Zöller et al. (2004). According to the age of 64.9 ± 4.7 ka obtained in the lower part of unit 9 about 1 m above the

upper limit of unit 13, the absence of significant age decrease throughout this 5-m-thick formation suggests a rapid colluvial infilling of the bottom of the large gully exposed in the western extension of the Hurst quarry (Fig. 3). Such a colluvial event is documented in several sequences from western Europe (Antoine et al., 2016), and may be contemporaneous with an interstadial of MIS 4, e.g. Greenland Interstadial 18 around 64 ka (Rasmussen et al., 2014). As already noticed by Schumacher (1914), the reworking led to the mix of material from both Early Glacial humic soils and overlying loess units. This could explain the apparent discrepancy between pollen- and mollusc-based palaeoenvironmental interpretations. Indeed, pollen may have preferentially been reworked within pellets of humic soils whereas molluscs, more fragile, may preferentially be contemporary with the reworking phase. Thus, whereas the material collected in unit 14 and coming from humic horizons very probably dates to the Early Glacial (MIS 5a), a doubt persists for the chronostratigraphical attribution of artefacts collected in unit 13 (or “13-14”), which could be of Weichselian Early Glacial to Middle Pleniglacial (MIS 4) age.

However, most of the artefacts from unit 14 come from humic horizons whereas the few ones from unit 13 (or “13-14”) are not precisely located in the stratigraphy. If the three basal layers distinguished by Rousseau et al. (1998b) resemble typical early glacial paleosols (e.g. Antoine et al., 2016), overlying bedded sediments have a more suspicious colluvial nature that would require new field observations.

In total, 64 lithic artefacts have been attributed to unit 14 and only 3 to unit 13 (or “13-14”) (Table 4). More than a third, mostly retouched artefacts, are made of flint or chalcedony (Fig. 9). Some of the flint, including a core, was sourced more than 100 km to the south-south-east of the site (Table 5, Fig. 10). The lithic industry is dominated by scrapers, many of which are convergent (Fig. 15, n° 1 to 5). Levallois debitage is common and tends to be preferential, recurrent centripetal or bipolar (Fig. 15, n° 7). We observe that there was an emphasis on the production of triangular pieces with a convergent extremity which at times can be quite pointed. They all display careful retouch. Other tools are quadrangular and are retouched, sometimes partially, along one edge.

3.12. Units 12 to 7 - MIS 4 & 3

Often grouped together in the descriptions, units 12 to 9 are difficult to dissociate, and thus difficult to correlate with the Weichselian Lower and Middle Pleniglacial. A leached loam level probably corresponds to unit 12, while more recent loesses are attributed to units 11 and 10, and perhaps 9, which formed under cold climatic conditions (Heim et al., 1982; Table 3).

Detailed malacological analyses only exist for unit 9. In section 4, samples 11 to 13 have revealed a tundra environment with cold and humid conditions (Puisségur, 1978), but interstadial given the high number of molluscs. Though only partially presented, the contemporary malacofauna from the top of section 7 and the base of section 8 appears to fit this interpretation (Heim et al., 1984). Rousseau (1987) reconstructs a “damp cold grassland” that, in the upper half of the unit, shifts to a “scarce vegetated environment with moist conditions [with] only a few rare bushes (...) (proto-tundra)”.

Available ages are too few and too imprecise to position the MIS 4-3 limit within unit 9 (Fig. 4). According to the stratigraphic scheme of Antoine et al. (2001), this limit should occur in the

lower part of unit 9 between ages 64.9 ± 4.7 and 41.5 ± 3.9 ka. Here the calcareous loess changes to weathered loess, i.e. brown loess, about 3.5 m below the level of deep thin frost wedges, which would fit with the chronostratigraphical framework established for the Nussloch loess-paleosol sequence. For the same reason, it is still not possible to position precisely the MIS 3-2 transition in relation to the base of the “*Læss de couverture*”/“Cover Loess” (units 6-2). As proposed by Antoine et al. (2001), based on comparison with reference records from surrounding regions, the base of the Cover Loess probably better corresponds to the Weichselian Middle-Upper Pleniglacial transition. This would imply placing the MIS 3-2 limit somewhere in the lower part of the Loess Cover. Radiocarbon dating performed on shell and earthworm granule samples (Evin et al., 1980) about 2 m below the level of deep thin frost wedges (Table 1; Fig. 4) provided calibrated ages around 35-29 ka for the youngest and 40-38 ka for the oldest. The associated $\pm 3-5$ ka errors due to old measurements prevents us from concluding in favour of one or the other hypothesis.

Nineteen lithic artefacts were retrieved from an unspecified unit between units 12 and 9 (Table 4). These include five Levallois flakes, mainly of flint and chalcedony, which reveal careful debitage with preferential or recurrent exploitation (Fig. 15, n° 11 & 12). Two retouched objects can be classified as convergent scrapers and one in particular stands out due to its large size (Fig. 15, n° 8). Two Levallois cores, one recurrent and the other preferential (Fig. 15, n° 9 & 10), are also remarkable due to their large size (around 57 mm in length; Fig. 12).

Lastly, it is also tempting to assign five artefacts to the Middle Palaeolithic: two discoid cores, two pseudo-Levallois points and a simple convex scraper with reverse retouch, found in units 6/7. Unit 7 is a reddish-coloured soliflucted zone filling in a shallow gully of local extension embedded in unit 8, a layer of brownish soliflucted sandy loam (Schumacher, 1914; Wernert, 1957). They were later bracketed by TL ages of 34.1 ± 4.3 (top of unit 9) and 24 ± 2.7 ka (unit 6) in the Hurst quarry (Fig. 3; Zöller et al., 1995). Radiocarbon ages of 24900 and 35200 BP have also been obtained at the top of unit 9 (Evin et al., 1980; Table 1), but both methods cannot be compared since the relative position of their samples in unit 9 is not precisely known. Otherwise, this time interval includes the end of the Weichselian Middle Pleniglacial marked by the last arctic brown soil of the last glacial dated between 35 and 39 ka at Nussloch (Germany) (Moine et al., 2017) and at Havrincourt (France) (Antoine et al., 2014). At Nussloch, this time interval is also characterised by several erosion-infilling cycles recorded in a large thermokarst infilling dated between 35800-31800 BP (Antoine et al., 2001). Thus, according to the nature, morphology and position of unit 7 (see the stratigraphic profile of Schumacher (1914)), we cannot exclude here the reworking of Middle Palaeolithic material from the Achenheim I complex, locally eroded higher up the slope.

4. Comparisons of Achenheim lithic assemblages with north-west and central European sites

4.1. First traces of human occupation during an interglacial (MIS 13?)

Although tenuous, lithic and faunal finds are present within the various levels that can be assigned to the Lower Palaeolithic at Achenheim. Unit 30, which produced just one lithic artefact, has been correlated at the earliest with an interglacial phase, MIS 13. The artefact, a worked pebble, is very rudimentary and questionable. If we consider the available data for the Rhine Valley, the earliest evidence for worked tools comes from the Middle Rhine during an

interglacial period that corresponds either to MIS 15 or MIS 13, for example at Kärlich G and Miesenheim (Bosinski, 2008; Rocca, 2013) – their chronological attributions remaining uncertain – and from the “Lower sand” of Mauer (Vollbrecht, 1997; Bahain et al., 2015) (Fig. 16, Table 6). The lithic finds are scarce and consist of a few small flakes and pieces that could be interpreted as pebbles or cores, some of which are also questionable.

4.2. Sparse settlement between MIS 12 and 9, a progressive evolution in modes of production with no evidence for the Acheulean

In the terrace deposits above, the Vosgian sand (units 29 to 22), including traces of severe cold conditions, and the oldest loessic deposits, i.e. the canary yellow loam (unit 21), marking an interstadial phase, have been tentatively attributed to MIS 12. The very few archaeological remains from these units generally take the form of worked pebbles and simple flakes, some of which are questionable manmade objects. Assuming that these units underwent roughly the same recovery and observation procedures as the overlying interglacial units, we can thus wonder if the rarity of archaeological finds might reflect a quasi-absence of human occupation during MIS 12. Indeed, this was one of the most severe glaciations of the last million years (see Koutsodendrīs et al., 2019 and references therein). This echoes the few other traces of human occupation dated to MIS 12 in the Rhine Valley, or in central and north-western Europe (Nicoud, 2011), where the evidence is also limited to rudimentary flakes and worked pebbles or cores as in Kärlich H (Bosinski, 2008) (Fig. 16; Table 6).

The red plateau loam (unit 20e) is correlated with the interglacial contemporary to MIS 11. It also contains very few lithic finds, consisting of worked pebbles or cores and a few flakes. In the Rhine valley, we can mention the site of Kärlich-Seeufer, with its lithic industry attributed to MIS 11 or 9 (Gaudzinski, 1996; Bosinski, 2008). This lithic industry contains a majority of flake debitage production on quartz and quartzite cores using simplified methods of exploitation, but there are also three “unifaces” (Rocca, 2013). During MIS 11, we observe an increased density of sites in northern France with Cagny-la-Garenne and Cagny-Cimetière (Lamotte & Tuffreau, 2001; Nicoud, 2011) and in England with Barnham and Boxgrove (Ashton et al., 2005; Nicoud, 2011) for example (Fig. 16). In contrast to the Rhine valley sites, they contain bifacial artefacts that are generally qualified as Acheulean.

Three of the Achenheim units (20d, 20c and 20b) can be correlated with MIS 10, although some material contemporary with MIS 9 might be included in burrows at the top of unit 20b. Lithic remains become more numerous in these units and we observe an evolution in the modes of production. While there are still worked pebbles, the debitage of flakes develops progressively towards more elaborate concepts which can be compared to “Prepared Core Technology” (White et al., 2011). Scrapers also appear alongside large unifaces with relatively carefully executed invasive retouch. While in the Rhine valley no other site can be clearly assigned to MIS 10 (Fig. 16), they are several in northern France: for example, Saint-Pierre-lès-Elbeuf IV (Cliquet et al., 2009; Nicoud, 2011) and Ferme de l'Épinette (Lamotte et al., 2001) (Fig. 16). Here the industries are also often characterised by simple flake production, which is associated with bifacial objects that are often categorised as “Acheulean” (Lamotte et al., 2001; Nicoud, 2011). The lack of Acheulean elements throughout the entire Achenheim sequence must be noted. Indeed, apart from two “unifaces”, bifacial tools are absent. The latter would have been

quite visible to the workers and observations were made on a very large area. Their absence at Achenheim thus rather reflects an archaeological reality than a bias in the collection method.

4.3. The appearance of Levallois debitage methods at the end of MIS 9

Unit 20a at Achenheim has been correlated with the end of MIS 9. It reveals the first evidence for a well-controlled Levallois reduction technique. There are no comparable examples recorded in the Rhine valley or in Germany. Currently, the German sites recently reattributed to MIS 9 (Geyh and Müller, 2005; Richter, 2016) have evidence for the production of small flakes and worked pebbles or cores, in line with earlier occupations, as at Karstein (Bosinski, 2008), Schöningen (Serangeli and Conard, 2015) or Neumark (Brühl & Laurat, 2010) (Fig. 16; Table 6). However, in some west European sites, Levallois debitage appears at the end of MIS 9, but always in association with other modes of production that are more typical of the Lower Palaeolithic, just as we observe in unit 20a at Achenheim. This is the case at Purfleet (White and Ashton, 2003) and Etrécourt-Manancourt (Hérisson et al., 2016) (Fig. 16). Levallois debitage is also attested in southern France at the end of MIS 9 at Orgnac 3 (Moncel et al., 2011) and in level 2 of Petit-Bost (Bourguignon et al., 2008). Lastly, we must mention Belgian sites that have produced evidence for a fully Mousterian industry, such as Kesselt-Op de Schans (Van Baelen, 2014) and Mesvin IV (Soriano, 2000) (Fig. 16).

Thus, Achenheim can be considered as a new example for the appearance of Levallois debitage during MIS 9 within a Lower Palaeolithic substrate. It also supports the idea of a progressive evolution of Middle Palaeolithic modes of production within a Lower Palaeolithic substrate, whether Acheulean or not (White & Ashton, 2003; Bolton, 2015).

4.4. Numerous occupations during the Saalian

Three of the Achenheim units can be assigned to MIS 8 (20''', 20'' and 20'). All of the occupations appear to have taken place under interstadial conditions, or at least not under pleniglacial conditions. The industry is clearly Mousterian and we observe a high degree of variation in the modes of production, which are well-controlled. The Levallois debitage is common and the tools are mainly well-made scrapers, with a majority of triangular objects. Of note is the appearance of volumetric blade debitage in unit 20', although shaping is minimal. Also worth highlighting is the possible presence of two fragments of bifacial pieces (distal extremity), the flint for which comes from a source 100 km to the south of the site.

In the Rhine valley and more generally in western Europe, few sites can be assigned to MIS 8, a fact that certain authors attribute to the severity of the prevailing climate (Hérisson et al., 2016; Fig. 16; Table 6). In the Rhine valley and in Germany in general, Levallois debitage appears for the first time during MIS 8, as at Ariendorf (Bosinski, 2008) or perhaps at Markkleebberg (Wiśniewski, 2014), although the latter site could also be attributed to MIS 6 (Richter, 2016). The expansion of Levallois debitage during MIS 8 can also be observed in north-western Europe where “it now constitutes the common basis of Middle Palaeolithic lithic assemblages” (Locht, 2005). Furthermore, just as in unit 20' at Achenheim, other technical systems appear such as the debitage of blades from prismatic cores already described at Saint-Valéry-sur-Somme (de Heinzelin & Haesaerts, 1983) and Le Rissori (Hérisson et al., 2016) (Fig. 16).

Three of the Achenheim units are attributed to MIS 7 (units 20 to 18). They contained the largest quantities of lithic finds, with a greater diversity of raw materials, some of which were brought to the site from considerable distances, sometimes up to 100 km. This fact, coupled with the large number of retouched tools and their relatively varied forms, might suggest occupations that were of longer duration, or at least more varied. Furthermore, the industry resembles the “*Moustérien de type Ferrassie*”, in which Levallois debitage dominates and is present in all its forms. Scrapers are numerous as are Mousterian points and it is worth noting once more the presence of prismatic blade cores although this time they are more elaborate (unit 20). Lastly, the artefacts are also larger than the material in the underlying and overlying units.

These data perfectly match observations made more widely in central and north-western Europe for this period during which, with the exception of Belgium and Germany, we observe a considerable rise in the number of sites (Hérisson et al., 2016). Several discoveries can be assigned to MIS 7 in the Rhine valley at Rheindahlen (Bosinski, 2008) or in the Meuse valley at Maastricht-Belvedere (van Kolfschoten et al., 1993) (Fig. 17; Table 7). The lithic industries attest to a predominance of Levallois debitage, which is sometimes associated with well-controlled volumetric blade debitage and numerous scrapers, a significant number of which are convergent. These industries resemble material grouped together under the term “*Moustérien Ferrassie*” in the northern half of France at the same time; they share the same technical characteristics, including an increase in blank size (Locht, 2018), just as has been observed in the Achenheim units.

Achenheim could thus be an additional milestone in the general adoption of Levallois debitage and the care taken in the production of large scrapers and Mousterian points during MIS 7. Interpretations can unfortunately not be pushed farther.

Three of the Achenheim units (17, 17a and 16) are attributed to the end of MIS 6. They produced rather few archaeological finds, whether lithic or faunal, and there are very few traces of on-site debitage. Most artefacts, often extremely well made, were brought on site as finished objects. It should be noted that the excavation of soil 74, also dated to the end of MIS 6 (Buraczyński and Butrym, 1984; Fig. 4), also revealed very few lithic artefacts. All this evidence probably reflects a short-term camp, with the import of finished tools (Koehler et al., 2020). We therefore believe that the difference in the number of objects collected in Achenheim for the MIS 6 units cannot only be explained by the method of collection. The same is true for other sites in the Rhine valley dating to MIS 6, whether in Alsace – the recent excavation at Ernolsheim-sur-Bruche (Bachelier et al., 2021) – or in Rhineland-Palatinate, such as Ariendorf (Richter, 2016), Tönchesberg 2A (Conard, 1992) Schweinkopf and Wannan (Justus, 2000, Bosinski, 2008). These sites contain very few lithic finds, which indicates expedient *in situ* modes of production in association with the importation of well-made finished objects, often of flint (Fig. 17; Table 7). The frequent proximity between lithics and concentrations of bones suggests that these sites were hunting camps.

Outside the Rhine valley, publications indicate that in the northern half of France sites become rarer in MIS 6 (Hérisson et al., 2016), and were potentially occupied for shorter periods of time. On the contrary, numerous cave sites attest to more varied forms of occupation in the south of France (Soriano, 2005; Hérisson et al., 2016). Although its dating still remains uncertain (Richter, 2016), the site of Markkleeberg in central Germany may be one of the rare sites belonging to MIS 6 in central Europe to have yielded a significant quantity of lithic material of a relatively diverse nature (Schäfer et al., 2003).

4.5. Difficulties of attribution for MIS 5

Composed of a brown-red loam, unit 15 is assumed to be mostly correlated with the Eemian (MIS 5e). The methods of lithic production are still Levallois and scrapers remain numerous. There are, however, fewer convergent tools. The difference essentially lies in the reduced size of the artefacts compared to the underlying layers.

In western Europe and in the Rhine valley, sites assigned to the Eemian in the strictest sense are rare, and even rarer in loess contexts. Apart from Levels A and B at Wallertheim (Conard et al., 1996), the few recorded sites have been uncovered in tufa or peat contexts, as in France at Caours (Locht, 2018) and Waziers (Hérisson, et al., 2017) (Fig. 17; Table 7). Lithic artefacts reflect modes of production that are often quite simple but they can also be associated with Levallois and discoid techniques. The artefacts also tend to be quite small. They are generally found in association with significant quantities of faunal remains.

In contrast, central Europe contains over 30 sites attributed to MIS 5e. They tend to be preserved in travertines or lake contexts (Wenzel, 1998; Richter, 2016). They reveal various modes of production, but authors also draw attention to the reduced size of the artefacts, particularly during the second phase of the Eemian, evoking a “microlithic character” (Richter, 2016, p. 114).

Access to raw materials could be more limited in the Eemian due to the denser forest cover. In Achenheim, the small size of the unit 15 artefacts might support their chronostratigraphic attribution to the Eemian. Nevertheless, loess contexts tend to yield very few sites that can be strictly assigned to the Eemian, the stable conditions not being conducive to the burial of remains and the surface horizon of these soils having often been eroded during subsequent climatic deterioration (MIS 5d and/or 5b) (Locht, 2018).

Unit 14 is correlated with a humic level attributed to the Weichselian Early Glacial (MIS 5d-a). Unfortunately the chronology is imprecise and this prevents comparisons with other assemblages from north-west and central Europe whose chronostratigraphic positions are generally more precise. The lithic finds from Achenheim reveal an industry mainly based on flint, some of which came from distant sources (over 100 km to the south). The modes of production are dominated by Levallois debitage, which is present in various modalities, and retouched tools are dominated by triangular objects (Mousterian points) and scrapers with careful retouch. This unit can be compared to most of the MIS 5d-a sites in western Europe and in the Rhine valley (Fig. 17; Table 7). For G. Bosinski (2008), the increase in the number of discoveries in the Rhine valley from MIS 5c onwards provides an opportunity to identify technical traditions. In particular he identifies the “Rheindahlien of the MIS 5c”, characterised by the presence of Levallois debitage associated with the production of blades and bladelets. These sites can be compared to their contemporary counterparts on the western bank of the Rhine, which are grouped together under the term “North-West Technocomplex” because of the presence of Levallois points and blade debitage (Conard & Adler, 1996; Locht, 2002; Depaepe, 2007; Koehler, 2012). Until now these sites share the particularity of all being situated on the left bank of the Rhine.

In central Germany, a small number of sites are attributed to the Weichselian Early Glacial. They reveal a very different lithic industry, characterised by a dominance of discoid productions, limited Levallois debitage, few points and no blade debitage (Richter, 2016).

4.6. Rare evidence for occupations during MIS 4 and 3: different from remains discovered on the east bank of the Rhine?

Very few archaeological remains have been recorded for units 13 to 9, which are attributable to MIS 4 and, possibly, MIS 3. They stand out, however, due to the presence of very large Levallois elements, such as a large scraper made from a Levallois flake and a large preferential Levallois core. Although the small numbers mean that we must exercise care when making comparisons, certain observations can nonetheless be made.

In north-western and central Europe, very few occupations have been recorded for MIS 4, probably because of the harshness of the pleniglacial conditions and of the rarity of sedimentary records of this period (Antoine et al., 2001; 2014, and Fig. 17; Table 7). However, from MIS 3 onwards, we observe a spectacular rise in site numbers in Germany (Richter, 2016). According to J. Richter, all of the sites recorded for MIS 3 in central Europe belong to the “Mousterian with a Micoquian Option”, by virtue of the combined presence of plano-convex “*keilmesser*”, small bifaces and leaf-shaped pieces alongside “Mousterian” tools produced using the Levallois debitage concept (Fig. 17). While caution should be exercised, these elements differ quite significantly from those observed at Achenheim.

We must look to the northern half of France to find technical affinities. Here, very few sites have been recorded, probably as a result of poor conditions for the preservation of archaeological levels (Locht, 2018). Generally speaking, the build-up of loess is fairly weak for this period (Antoine et al., 2003, 2014) and the erosion processes are quite pronounced (Haesaerts et al., 2016). These sites were often discovered in test pits and were not always subjected to extensive excavation, due to the sparsity of lithic finds. Some sites display a clear increase in the size of Levallois flakes: these objects attest to careful, often preferential, Levallois debitage and the flakes produced were often transformed into large scrapers (e.g. at Savy, Attilly and Gauville; Loch, 2018; Fig. 17; Table 7). This “could be explained by new access to better quality and larger blocks of raw material” (Locht, 2004, p. 21).

5. Conclusion

This contribution is a first attempt to combine archaeological data with their stratigraphic, chronological and palaeoenvironmental contexts for the Achenheim site, previously dispersed in different publications. Thirty-one units of the Achenheim-Hangenbieten quarries are correlated with the time span between MIS 13, at the latest, and MIS 4/3. Of these, twenty-one units contain archaeological assemblages that can be attributed to the Lower and Middle Palaeolithic. Although these data are incomplete due to their mode of recovery, their attribution to marine isotope stages and their comparison with other west- and central European sites enables an interesting hypothesis to be proposed (Fig. 18). When compared to available data for the Rhine valley and for north-western Europe, the various technical manifestations identified at Achenheim, positioned within the MIS framework, seem to be linked to other better documented technical manifestations. They could fit with the overall techno-typological development observed for the Middle and Late Pleistocene, either of north-western Europe (Hérisson et al., 2016; Loch et al., 2016) or of central Europe (Richter, 2016). This finding is all the more worthy of attention since the recovery of archaeological material at the site spans several decades. Consequently, though biased, the lithic assemblages from Achenheim can be

considered relevant for examining the evolution of lithic production modes in the Upper Rhine. This is a first step for further investigations. A new assessment of the faunal assemblage retrieved from these levels will undoubtedly provide insights regarding chronostratigraphy and human behaviour in the near future. Though the molluscan record provides robust evidence for glacial-interglacial alternation, it can be argued that below the Achenheim II pedocomplex the sequence still lacks a reliable chronology. Obtaining reliable ages beyond 250 ka with luminescence dating remains too challenging (e.g. Murray et al., 2014; Wacha et al., 2021), but several dating methods offer some perspectives such as amino-acid racemization (Oches & McCoy, 2001) and Electron Spin Resonance (ESR) (Schellmann, 2020) applied on terrestrial gastropod shells, or ESR on fluvial quartz and ESR/U-Th on mammal teeth (e.g. Bahain et al., 2015; Serin-Tuikalepa et al., 2020). Though more difficult than ever to perform, new fieldwork on the site of Achenheim has never seemed so essential.

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Figures and Tables captions

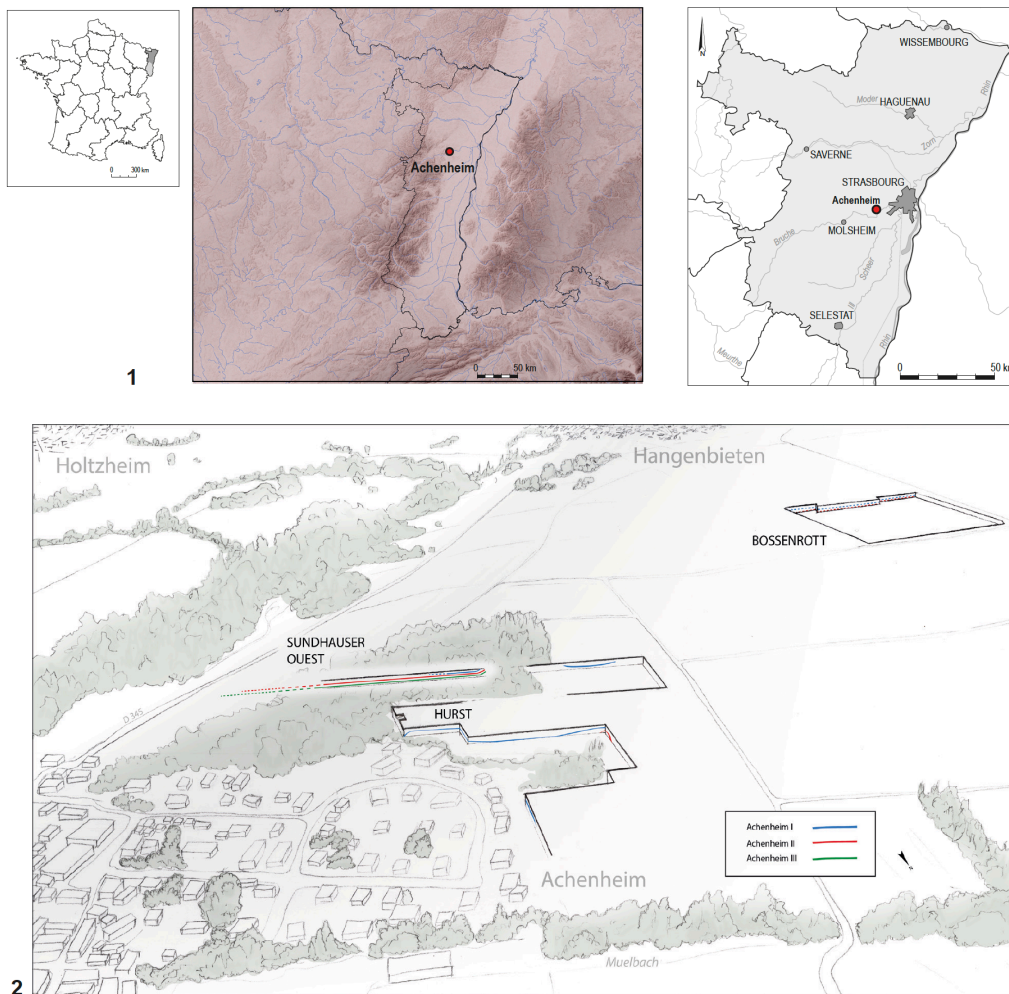


Fig.1 – Location of Achenheim quarries

1: geographic position; 2: perspective view of the quarries (drawing: M. Chosson)

Fig. 1 – Localisation des carrières d'Achenheim

1 : position géographique ; 2 : vue en perspective des différentes carrières (dessin : M. Chosson)



1



2



3



4

Fig. 2 – History of research on the Achenheim quarries

1: View of Achenheim, Hurst quarry in 1912/1913, with a dark Mousterian layer (Forrer, 1920); 2: archaeological surveys during quarry exploitation (J. Sainty, SRA Grand Est archives); 3: Achenheim Hurst, units 1 to 5 (J. Sommé); 4: Sol 74 excavation (J. Sainty, SRA Grand Est archives)

Fig. 2 – Historique des recherches dans les carrières d'Achenheim

1: Vue de la carrière Hurst à Achenheim, en 1912/1913, avec une couche, sombre, moustérienne (Forrer, 1920) ; 2 : fouilles archéologiques menées pendant l'exploitation de la carrière (J. Sainty, archives du SRA Grand Est) ; 3 : Achenheim Hurst, unités 1 à 5 (J. Sommé) ; 4 : fouille du Sol 74 (J. Sainty, archives du SRA Grand Est)

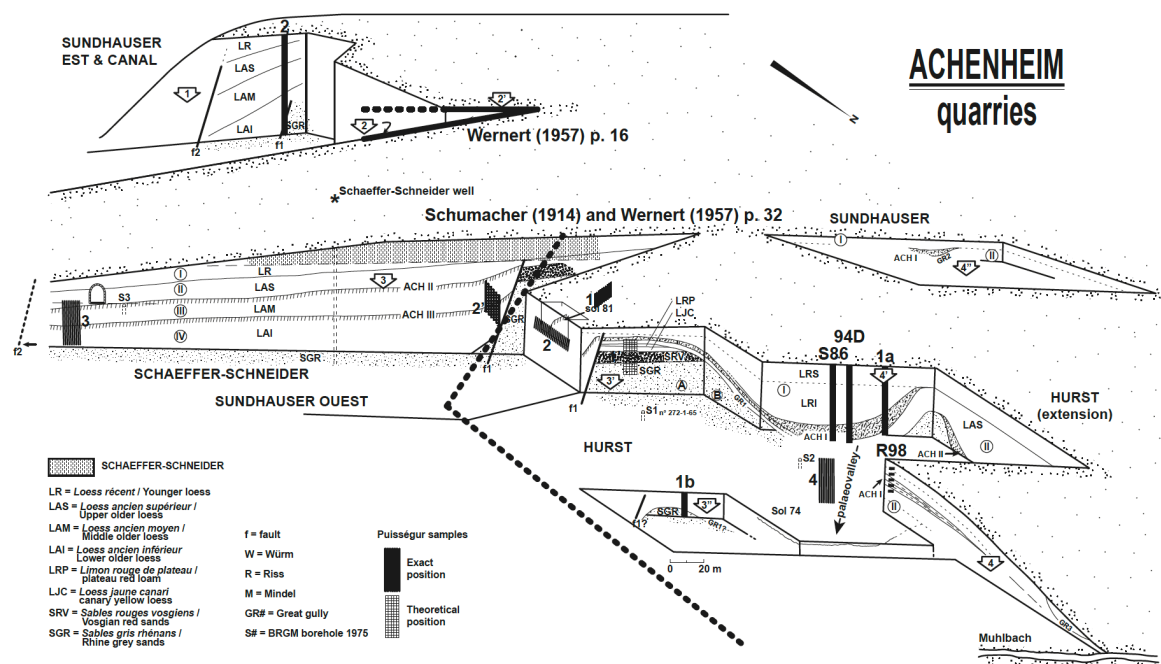


Fig. 3 – Synthesis of stratigraphic sections (after Thévenin and Marnot-Houdayer, 1987, modified). TL-dated profiles 1a, 1b and 2 are located after Buraczyński and Butrym (1984). Dated profile S86 that provided TL samples dated by Aitken et al. (1986), Packman and Grün (1992) and Zöller (1995) is located after Rousseau et al. (1998b). Dated profile R98 is located after Rousseau et al. (1998a). Not precisely located by Zöller et al. (2004), dated profile 94D, i.e. “1994 dredgehole”, has been arbitrarily positioned in the middle of the southern wall of the Hurst quarry. Samples radiocarbon dated by Thévenin (1980) and Evin et al. (1980) come from the southern wall of the Hurst quarry, but their exact location is not indicated even by Sommé et al. (1986). The Schumacher-Wernert profile has been positioned according to the position of the wall crossing the quarries on the IGN map of 1950. Only the position of its central part, i.e. in the Sundhauser ouest quarry, differs from that proposed by Thévenin and Marnot-Houdayer (1978) on their figure 3, who placed it on the south-eastern wall (at the place of downward arrowed label 3). Their position seems awkward as the wall would have been observed in a reversed way, i.e. from the west instead of the east.

Fig. 3 – Synthèse des profils stratigraphiques (d’après Thévenin et Marnot-Houdayer, 1987, modifié). Les profils 1a, 1b et 2 datés par TL sont localisés d’après Buraczyński et Butrym (1984). Le profil S86 qui a fourni des échantillons TL datés par Aitken et al. (1986), Packman et Grün (1992) et Zöller (1995) est localisé d’après Rousseau et al. (1998b). Le profil R98 est localisé d’après Rousseau et al. (1998a). Non précisément localisé par Zöller et al. (2004), le profil 94D, i.e. « 1994 dredgehole », a été placé arbitrairement au milieu de la paroi sud de la carrière de Hurst. Les échantillons datés au radiocarbone par Thévenin (1980) et Evin et al. (1980) proviennent de la paroi sud de la carrière Hurst, mais leur emplacement exact n'est pas indiqué même par Sommé et al. (1986). Le profil Schumacher-Wernert a été positionné d’après la position du front de taille traversant les carrières sur la carte IGN de 1950. Seule la position de sa partie centrale, c'est-à-dire dans la carrière Sundhauser ouest, diffère de celle proposée par Thévenin et Marnot-Houdayer (1978) sur leur figure 3, qui l'ont placée sur le front de taille sud-est (à la place de l'étiquette fléchée vers le bas 3). Leur position semble problématique car le front de taille aurait été observé de manière inversée, c'est-à-dire de l'ouest au lieu de l'est.

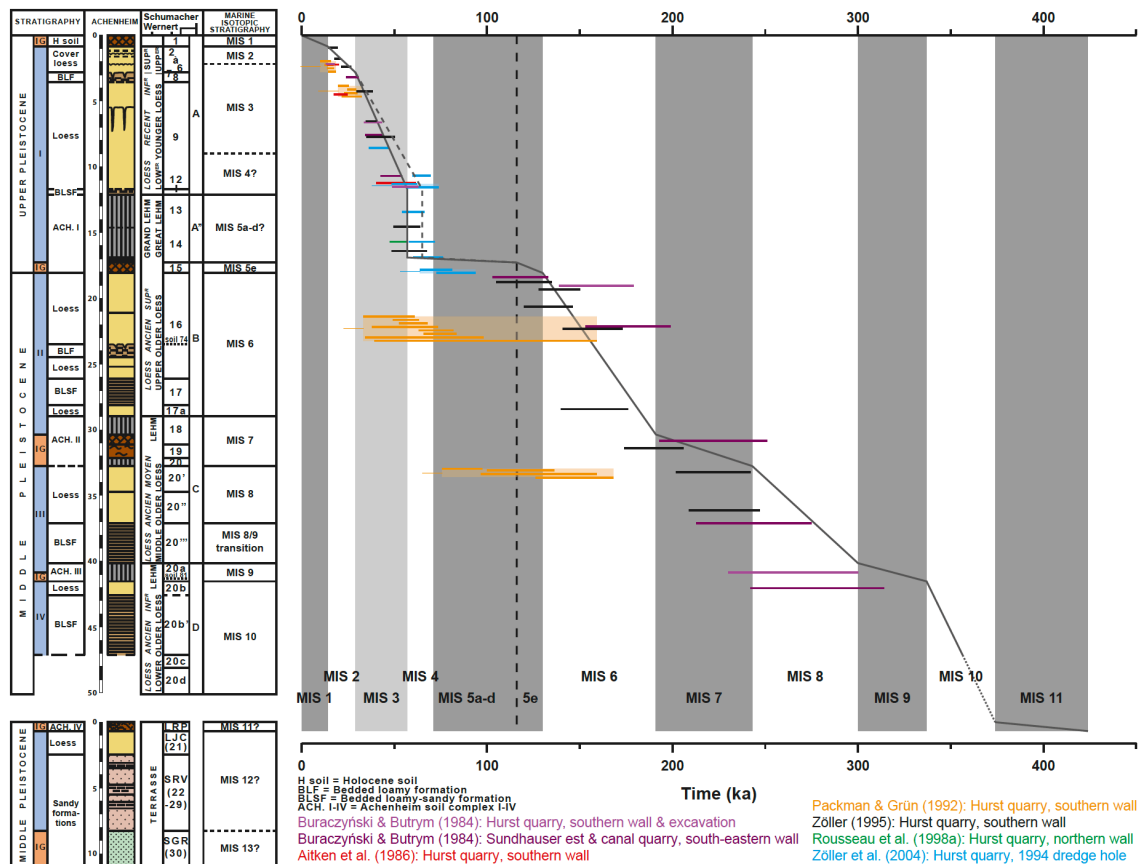


Fig. 4 – Luminescence chronology of Achenheim loess-paleosol sequences.

Agés are listed in table 1 and dated profiles located on figure 3. Samples dated by Aitken et al. (1986), Packman and Grün (1992), Zöller (1995) and Zöller et al. (2004) have been located on the synthetic stratigraphy of Lautridou et al. (1985) based on a scheme present in Zöller (1995). Rousseau et al. (1998a) provide a correlation scheme that enabled the location of their new dated sample. Only the position of samples dated by Buraczyński and Butrym (1984) remains more approximate within each glacial/interglacial ensemble as they only provide their own stratigraphies. Radiocarbon ages are imprecisely located at the top and in the middle of unit 5 of Sommé et al. (1986), i.e. of the loess unit located below the horizon of deep thin cracks, and at the top of Achenheim I pedocomplex. Coherent with bracketing luminescence ages, but hard to calibrate owing to their asymmetric uncertainties, the fourth uppermost ages have not been included in the figure. Ages provided by the different methods applied on samples dated by Packman and Grün (1992) have been vertically distinguished. The broken line indicates depth vs. time relationship deduced from all available data. The dashed broken line is hypothetical owing to a possible hiatus in the sequence. It represents an older but less probable chronological alternative for the base of the palaeo-gully infilling. The interglacial part of MIS 5, i.e. MIS 5e, has been distinguished on the right of a vertical dashed line.

Fig. 4 – Datations des séquences de loess-paleosol d'Achenheim

Les âges sont répertoriés dans le tableau 1 et les profils datés situés sur la figure 3. Les échantillons datés par Aitken et al. (1986), Packman et Grün (1992), Zöller (1995) et Zöller et al. (2004) ont été localisés sur la stratigraphie synthétique de Lautridou et al. (1985) basée sur un schéma présent dans Zöller (1995). Rousseau et al. (1998a) proposent un schéma de corrélation permettant de localiser leur

nouvel échantillon daté. Seule la position des échantillons datés par Buraczyński et Butrym (1984) reste plus approximative au sein de chaque ensemble glaciaire/interglaciaire car ils ne fournissent que leurs propres stratigraphies. Les âges radiocarbone sont localisés de manière imprécise en haut et au milieu de l'unité 5 de Sommé et al. (1986), c'est-à-dire de l'unité de loess située au-dessous de l'horizon à fentes fines et profondes, et au sommet du pédocomplexe Achenheim I. Cohérents avec les âges par luminescence les encadrant, mais difficile à calibrer en raison de l'asymétrie des incertitudes associées, les quatre âges supérieurs n'ont pas été reportés sur la figure. Les âges fournis par les différentes méthodes appliquées sur les échantillons datés par Packman et Grün (1992) ont été distingués verticalement. La ligne brisée indique la relation profondeur-temps déduites de toutes les données disponibles. La ligne brisée en tirets est hypothétique en raison d'un éventuel hiatus dans la séquence. Elle représente une alternative chronologique plus ancienne mais moins probable pour la base du remplissage du paléo-vallon. La partie interglaciaire du MIS 5, c'est-à-dire le MIS 5e, a été distinguée à droite de la ligne pointillée verticale.

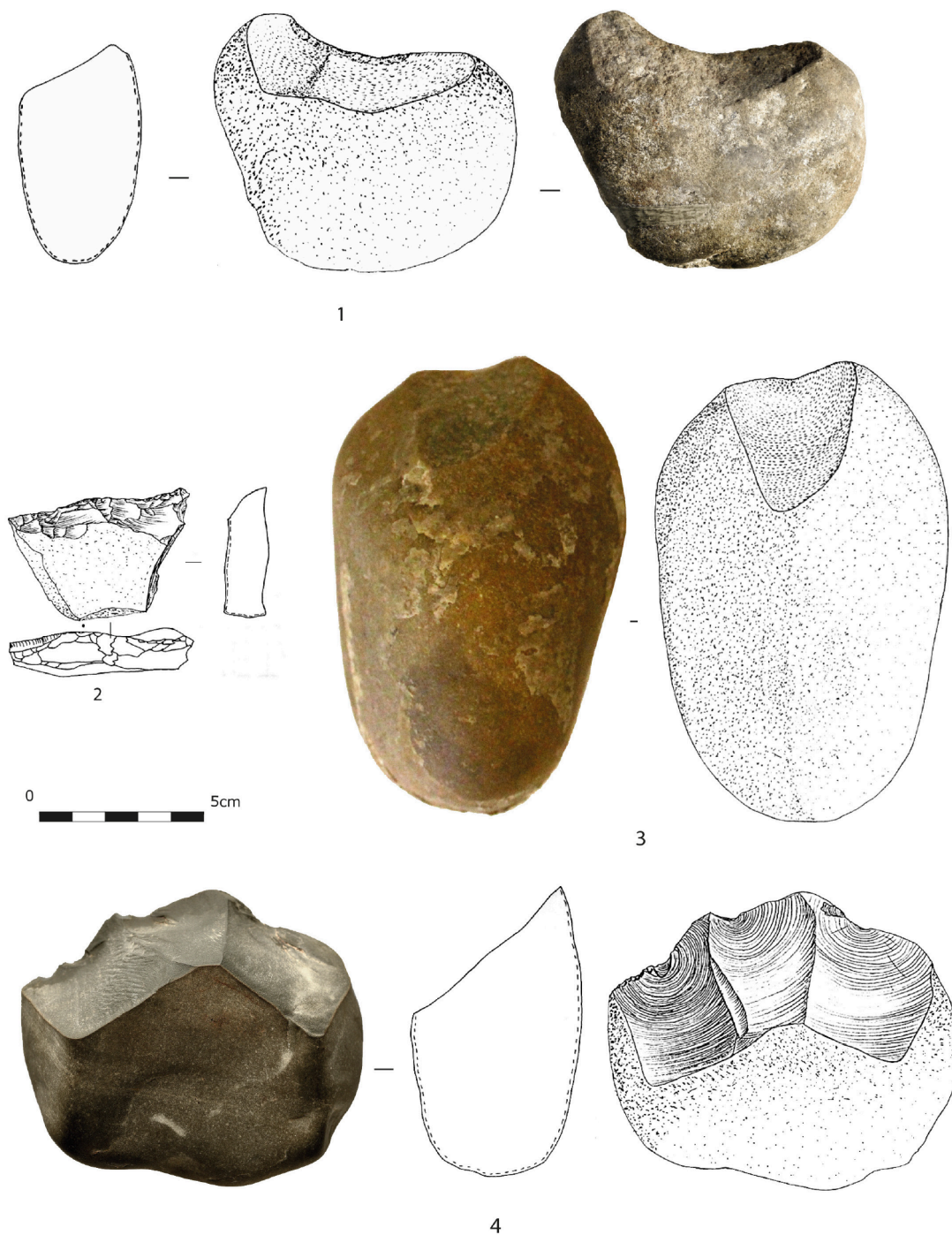


Fig. 5 – Lithic remains from Lower Paleolithic units (units 30 to 20d) (drawings: J. Junkmanns; photographs: Musée archéologique de Strasbourg and H. Koehler)

1: chopper, unit 30, quartzite; 2: scrapers? unit 24; 3: chopper, unit 20d, quartzite; 4: chopper or core, unit 20e

Fig. 5 – Objets lithiques des unités du Paléolithique inférieur (unités 30 à 20d)

1 : chopper, unité 30, quartzite ; 2 : racloirs ? unité 24 ; 3 : chopper ou nucléus, unité 20e ; 4 : chopper, unité 20d, quartzite

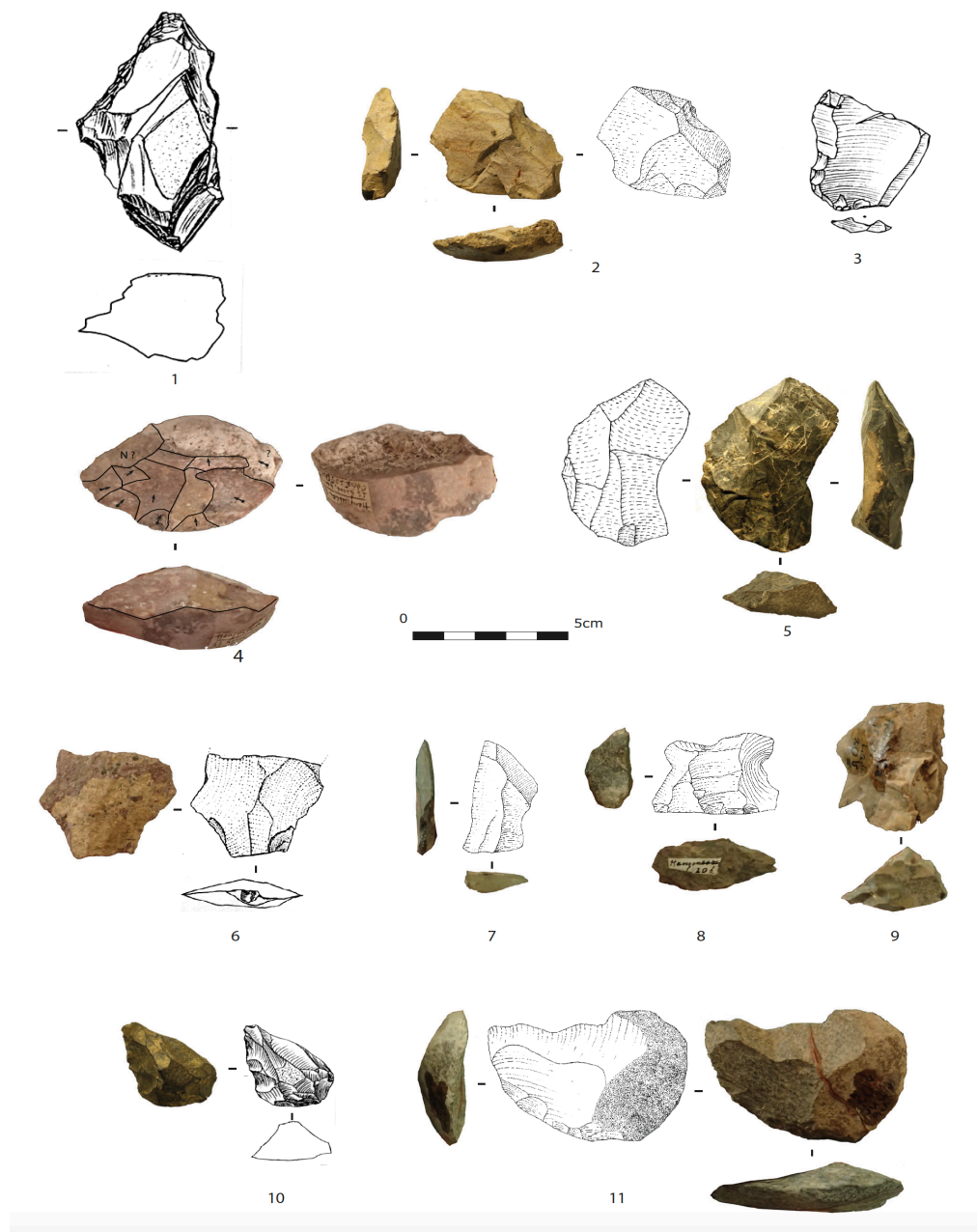


Fig. 6 – Lithic remains from Lower Paleolithic units (units 20d to 20b) (Drawings: J. Junkmanns & H. Koehler, photographs: H. Koehler)

1: unit 20d: scraper on natural debris, phtanite; 2: unit 20c/d: flake, unknown material
 3: unit 20c: flake, phtanite; 4: strate 20c, core, quartzite; 5 à 9: unit 20b, flakes from “prepared core technology” (5, 7 & 8: phtanite; 6: rhyolite and 9: flint); 10: unit 20b, scrapers (phtanite); 11: unit 20b, scraper (grauwacke)

Fig. 6 – Objets lithiques des unités 20d à 20b, Paléolithique inférieur

1 : unité 20d : racloir sur casson naturel, phtanite ; 2 : unité 20c/d : éclat, matière première indéterminée ; 3 : unité 20c : éclat, phtanite ; 4 : unité 20c, nucléus, quartzite ; 5 à 9 : unité 20b, éclats de “prepared core technology” (5, 7 & 8 : phtanite ; 6 : rhyolite et 9 : flint) ; 10 : unité 20b, raclours (phtanite) ; 11 : unité 20b, racloir (grauwacke).

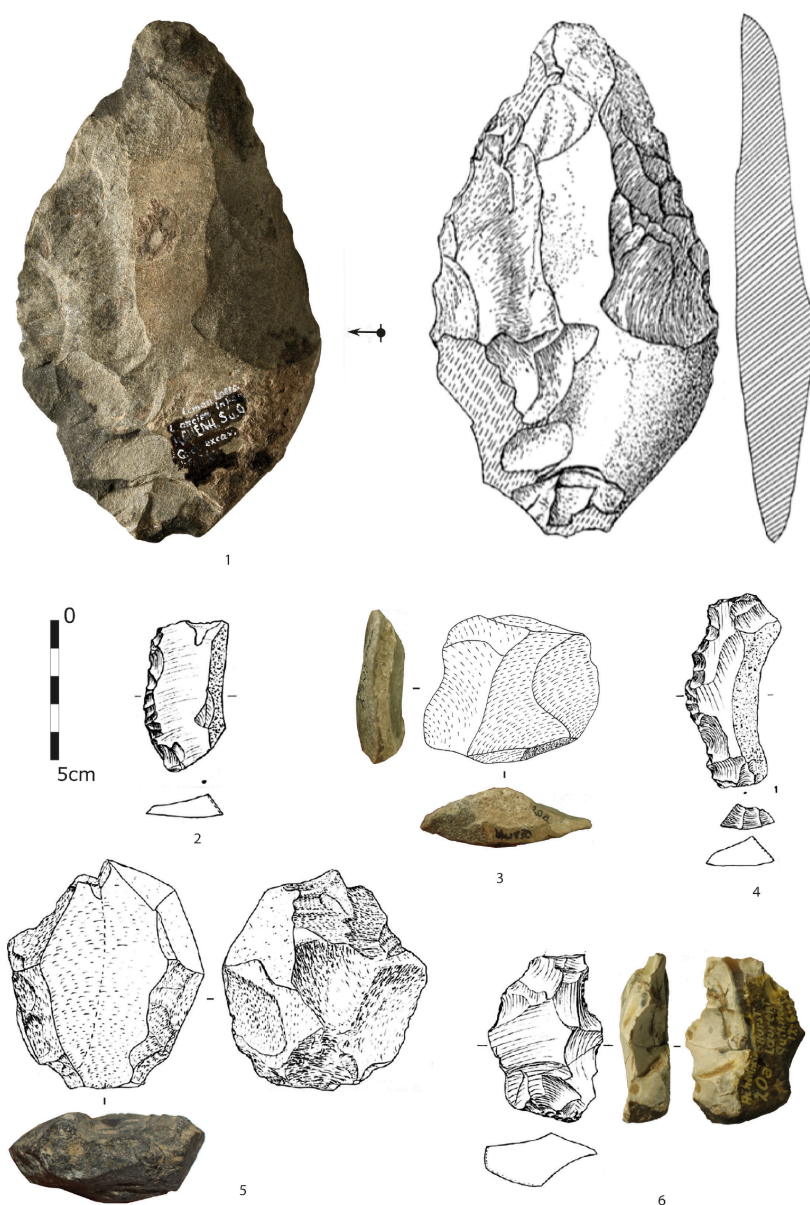


Fig. 7 – Lithic remains from end of Lower Paleolithic and beginning of Middle Palaeolithic (units 20b and 20a) (Drawings: J. Junkmanns & H. Koehler, photographs: H. Koehler)

1: unit 20b (end of Lower Palaeolithic); 2 to 6: unit 20a (beginning of Middle Palaeolithic)

1: uniface, greywacke; 2: retouched éclat débordant, phanite; 3: Levallois flake, quartzite; 4: retouched blade, greywacke; 5: Levallois core, undefined rock; 6: Levallois core, flint

Fig. 7 - Objets lithiques de la fin du Paléolithique inférieur et du début du Paléolithique moyen (unités 20b et 20a)

1 : unité 20b (fin du Paléolithique inférieur) ; 2 à 6 : unité 20a (début du Paléolithique moyen)

1 : uniface, grauwacke ; 2 : éclat débordant retouché, phanite ; 3 : éclat Levallois, quartzite ; 4 : lame retouchée, grauwacke ; 5 : nucléus Levallois, roche indéfinie ; 6 : nucléus Levallois, silex

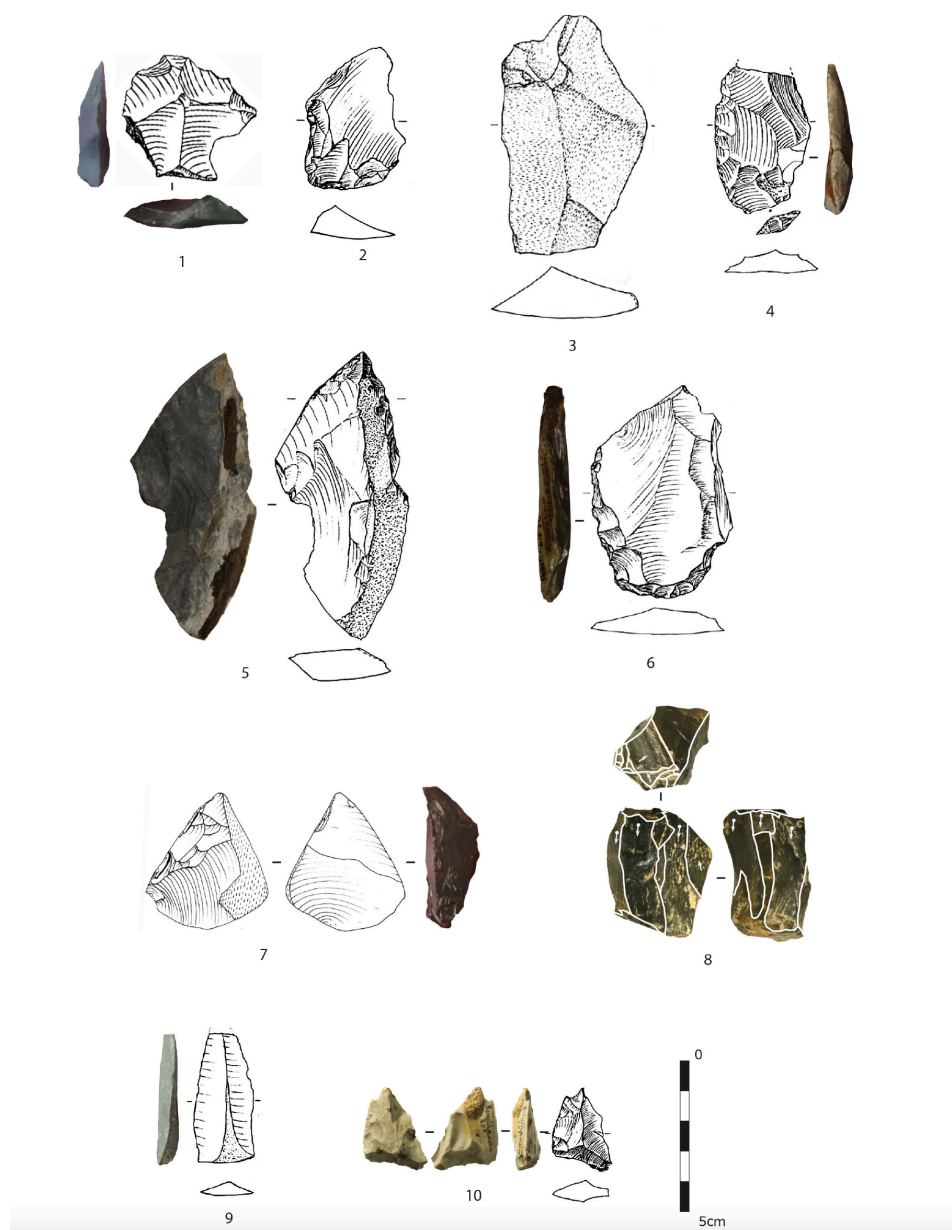


Fig. 8 – Lithic remains from units contemporaneous from MIS 8 (units 20''' to 20') (Drawings: J. Junkmanns & H. Koehler, photographs: H. Koehler)

1 to 3: unit 20'''; 4, 5 & 6: unit 20''; 7 to 10: unit 20'

1: Levallois flake, flint; 2: Levallois flake, other rock; 3: elongated flake, greywacke; 4: scraper on Levallois flake, calcédoine; 5: convergent scraper, phtanite; 6: denticulé, phtanite; 7: simple scraper, phtanite; 8: blade core, phtanite; 9: blade, phtanite; 10: distal fragment of bifacial piece?, flint from Lössrach

Fig. 8 – Objets lithiques des unités contemporaines du SIM 8 (unités 20''' à 20')

1 à 3 : unité 20''' ; 4, 5 & 6 : unité 20'' ; 7 à 10 : unité 20'

1 : éclat Levallois silex ; 2 : éclat Levallois autre roche ; 3 : éclat allongé, grauwacke ; 4 : racloir sur éclat Levallois, calcédoine ; 5 : racloir convergent, phtanite ; 6 : denticulé, phtanite ; 7 : racloir simple, phtanite ; 8 : nucléus laminaire, phtanite ; 9 : lame, phtanite ; 10 : fragment distal de pièce bifaciale ? silex de Lössrach

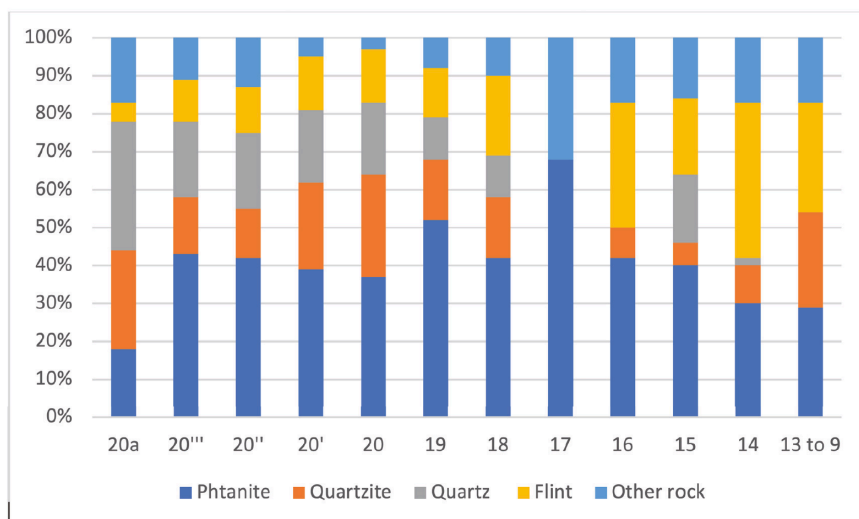


Fig. 9 – Different raw material frequencies in Middle Palaeolithic lithic industries

Among the macroscopic characteristics that can help to specify the type of deposit exploited, the state of the cortex, when present, is particularly effective. Indeed, primary deposits are characterised by fresh cortex or easily identifiable natural surfaces. On the other hand, secondary deposits are characterised by modified cortex or natural surfaces. For nodules, these modifications can range from a slight dissolution to the creation of a true neocortex or its total ablation, resulting in a 'clawed' surface characteristic of (natural) fluvial transport. For the natural surfaces, the changes generally correspond to a progressive abrasion of the micro-reliefs according to increasing distance. In Alsace, the different types of deposits are well marked: the (rare) primary deposits present fresh cortex, the colluvial deposits, which are always limited in extent and single-phased, are indicated by cortex that has undergone a more or less intense chemical action but little mechanical wear, and the fluvial deposits, which essentially correspond to the alluvial deposits of the Rhine and Bruche rivers, present strongly rolled elements. Eventually, a more detailed analysis of the fluvial elements would perhaps make it possible to specify which exact type of alluvium was exploited; however, the fairly recent history of the Rhine makes it possible to eliminate many of them, and such a study would consequently not provide any significant precision.

Fig. 9 – Fréquence des différentes matières premières dans les unités du Paléolithique moyen

Parmi les caractéristiques macroscopiques qui peuvent aider à préciser le type de gisement exploité, l'état du cortex, lorsqu'il est présent, est particulièrement efficace. En effet, les gisements primaires se caractérisent par des cortex frais ou des surfaces naturelles facilement identifiables. D'autre part, les gisements secondaires sont caractérisés par des cortex ou des surfaces naturelles modifiés. Pour les nodules, ces modifications peuvent aller d'une légère dissolution à la création d'un véritable néocortex ou à son ablation totale, aboutissant à une surface « griffée » caractéristique du transport fluvial (naturel). Pour les surfaces naturelles, les changements correspondent généralement à une abrasion progressive des micro-reliefs en fonction de l'éloignement. En Alsace, les différents types de dépôts sont bien marqués : les (rares) dépôts primaires présentent des cortex frais, les colluvions, toujours d'étendue limitée et monophasées, sont signalées par des cortex ayant subi une chimie plus ou moins intense. Mais peu d'usure mécanique, et les dépôts fluviaux, qui correspondent essentiellement aux alluvions du Rhin et de la Bruche, présentent des éléments fortement laminés. A terme, une analyse plus détaillée des éléments fluviaux permettrait peut-être de préciser quel type exact d'alluvions a été exploité ; cependant, l'histoire assez récente du Rhin permet d'en éliminer beaucoup, et une telle étude n'apporterait par conséquent aucune précision significative.

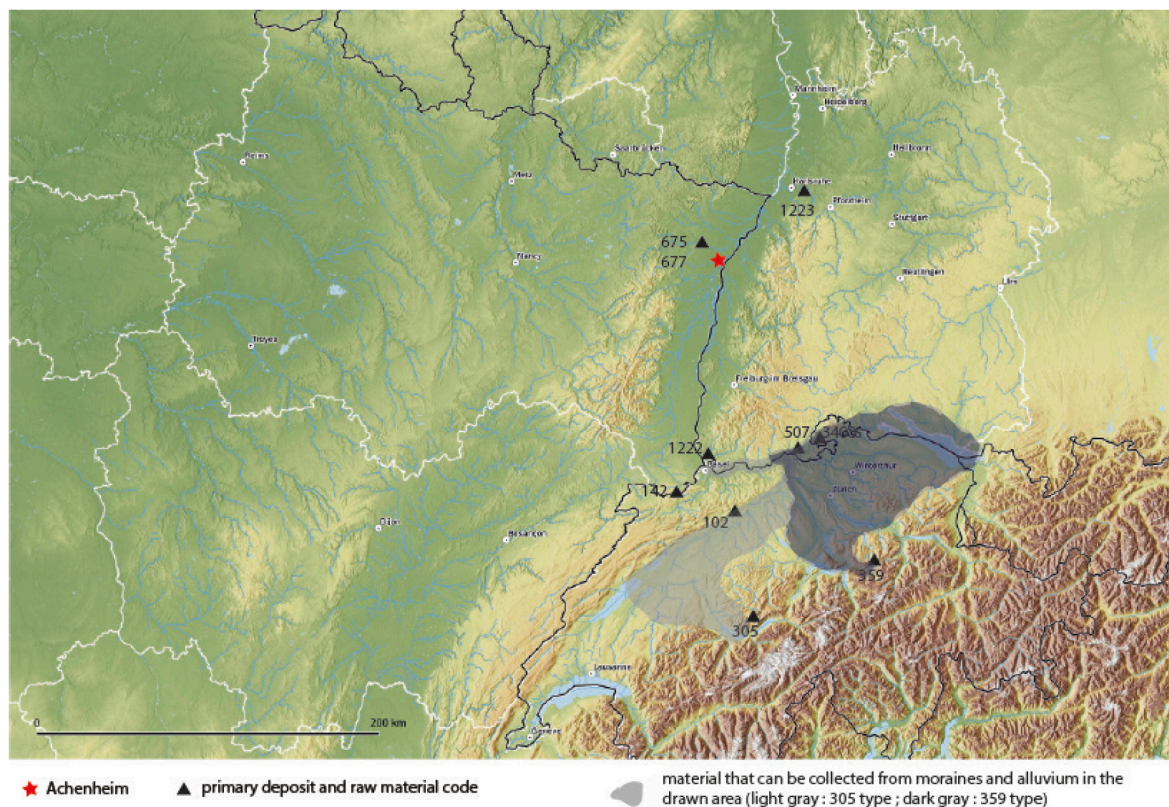


Fig. 10 – Map of origin of allochthonous raw material (J. Affolter)

The code in the map is explained in table 5

Fig. 10 – Carte de provenance des matières premières allochtones (J. Affolter)

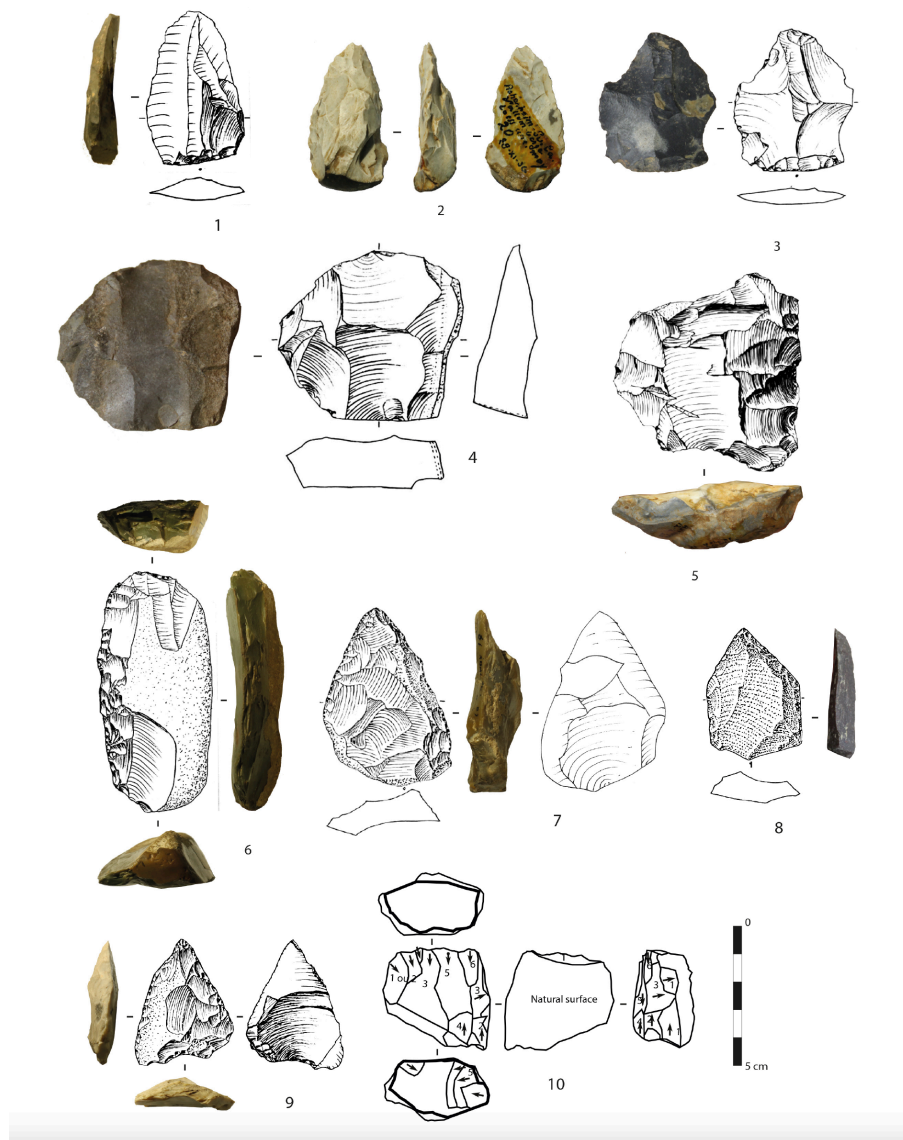


Fig. 11 – Lithic remains from unit 20 to 18 (MIS 7)

(Drawings: J. Junkmanns & H. Koehler, photographs: H. Koehler)

1, 2 & 4: unit 20; 3 & 5: unit 19; 6 to 10: units 19-18

1: convergent Levallois flake, phtanite; 2: double scrapers with ventral retouches, flint; 3: Levallois flake, flint from Oberiberg (90 km); 4: bipolar Levallois core, flint; 5: Levallois core, flint; 6: scraper, phtanite; 7: convergent scraper with ventral retouches, flint; 8: convergent scraper, quartzite; 9: convergent scraper with ventral retouches, calcédoine; 10: blade core, rhyolite

Fig. 11 – Objets lithiques des unités 20 à 18 (SIM 7)

1, 2 et 4 : unité 20 ; 3 et 5 : unité 19 ; 6 à 10 : unités 19-18

1 : éclat Levallois unipolaire convergent, phtanite ; 2 : racloir double à retouches bifaciales, silex ; 3 : éclat Levallois, silex d'Oberiberg (90 km) ; 4 : nucléus Levallois bipolaire, silex ; 5 : nucléus Levallois, silex ; 6 : racloir, phtanite ; 7 : racloir convergent à retouches bifaciales, silex ; 8 : racloir convergent, quartzite ; 9 : racloir convergent à retouches bifaciales, calcédoine ; 10 : nucléus laminaire, rhyolite

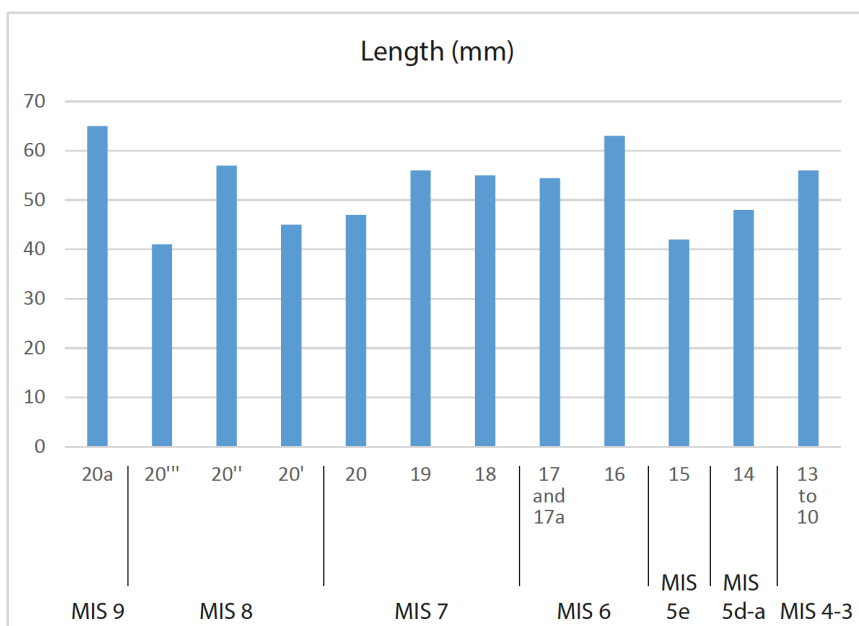


Fig. 12 - Average lengths (in mm) of lithic artefacts

Fig. 12 – Longueur moyenne (en mm) des artefacts lithiques

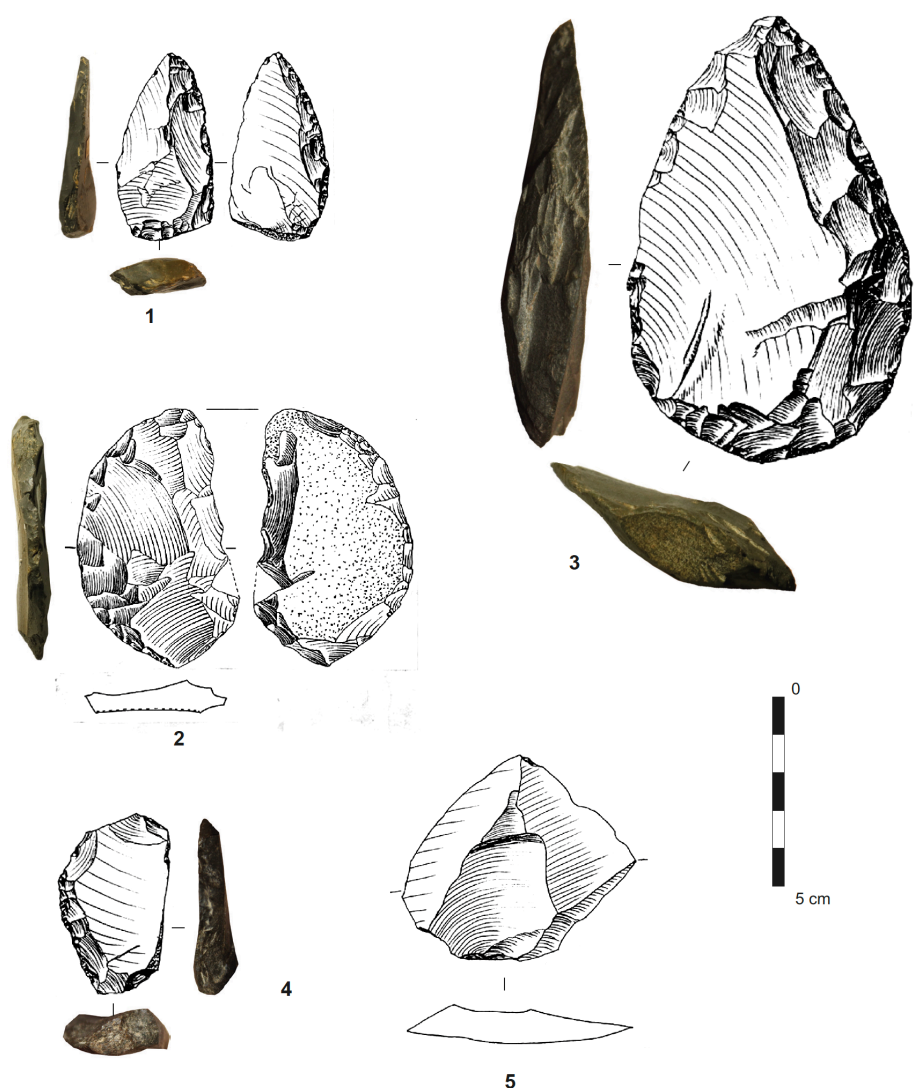


Fig. 13 – Lithic remains from units 17 and 16 (MIS 6)
(Drawings: J. Junkmanns, photographs: H. Koehler)

1 to 3: unit 17/16; 4: unit 17; 5: unit 16

1: ventral retouch scraper, phtanite; 2: centripetal Levallois core; phtanite; 3: convergent scraper, phtanite; 4: scraper, flint; 5: point, phtanite

Fig. 13 – Objets lithiques des unités 17 et 16 (SIM 6)

1 à 3 : unité 17/16 ; 4 : unité 17 ; 5 : unité 16

1 : racloir à retouche ventrale, phtanite ; 2 : nucléus Levallois récurrent centripète, phtanite ; 3 : racloir convergent, phtanite ; 4 : racloir, silex ; 5 : pointe, phtanite

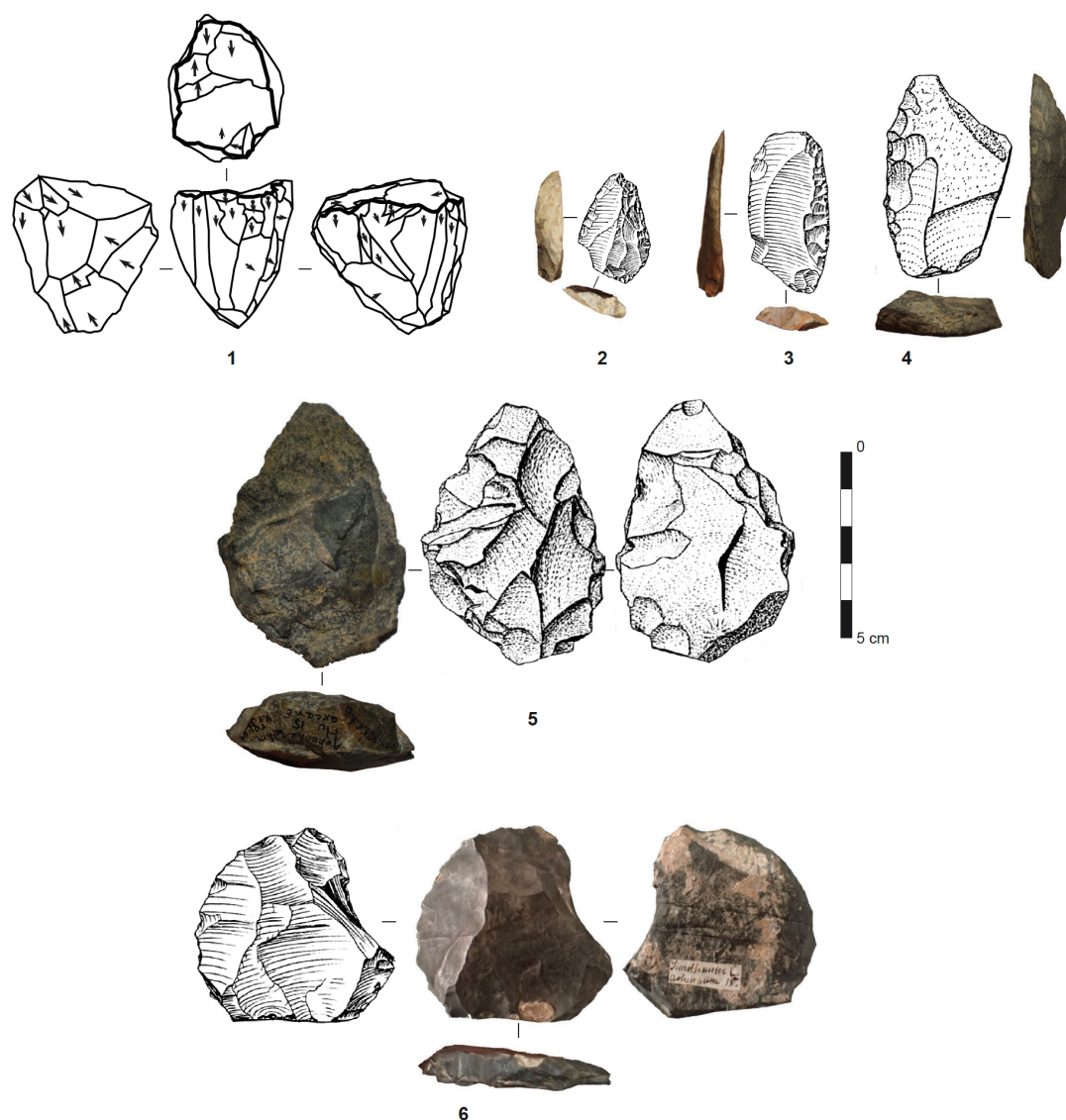


Fig. 14 – Lithic remains from unit 15 (MIS 5e)

(Drawings: J. Junkmanns & H. Koehler, photographs: H. Koehler)

1: blade core, phtanite; 2: scraper, flint; 3: scraper, flint; 4: scraper, greywacke; 5: scraper with bifacial retouch, Hornstein; 6: bipolar Levallois core; phtanite

Fig. 14 – Objets lithiques de l'unité 15 (MIS 5e)

1 : nucleus laminaire, phtanite ; 2 : racloir, silex ; 3 : racloir, silex ; 4 : racloir, grauwacke ; 5 : racloir à retouches bifaciales, Hornstein ; 6 : nucléus Levallois bipolaire, phtanite

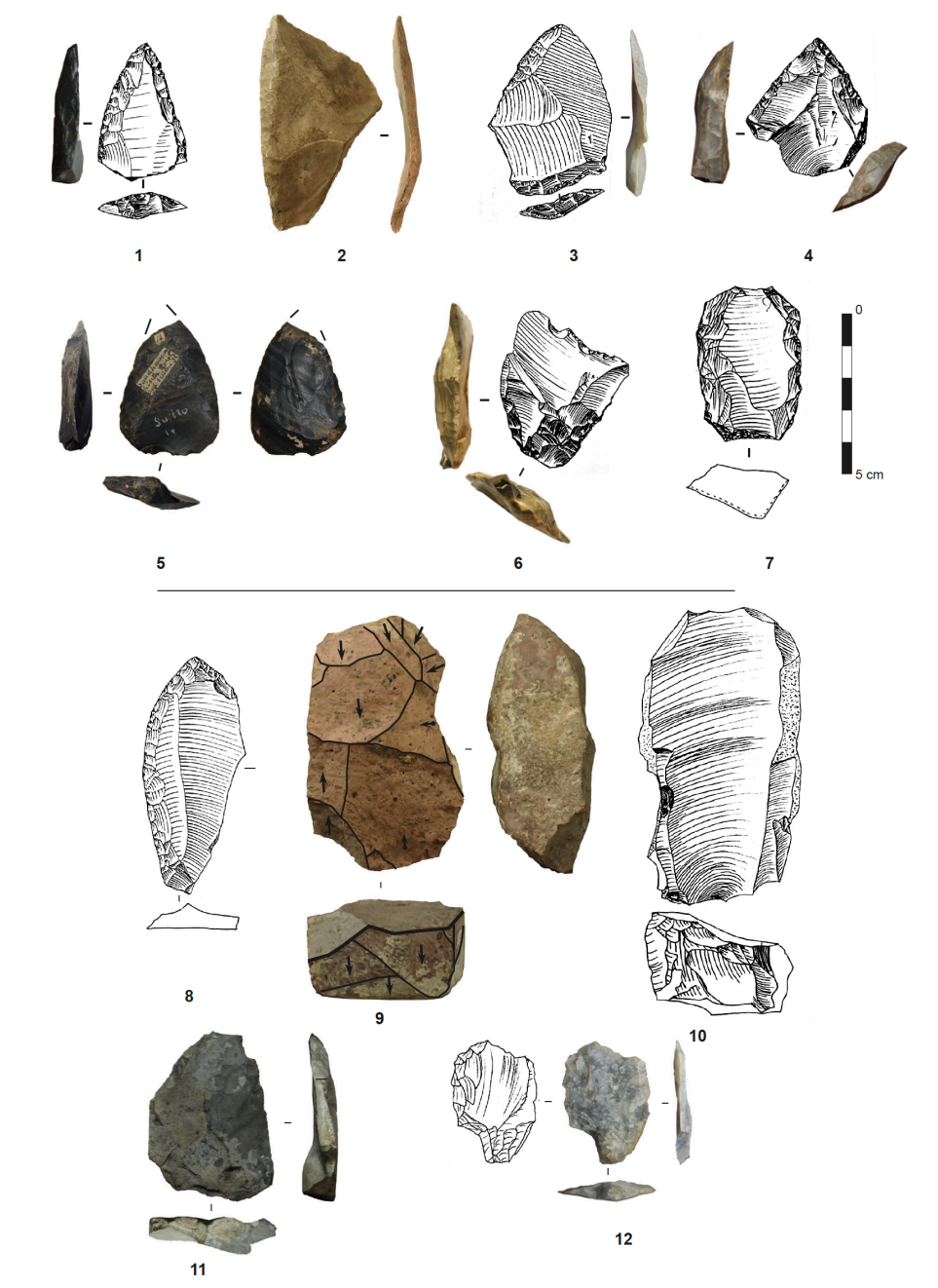


Fig. 15 – Lithic remains from units 14 to 9 (MIS 5d-a and MIS 3?)

(Drawings: J. Junkmanns, photographs: H. Koehler)

1 to 7: units 14-13 (MIS 5d-a); 8 to 12: units 13-9 (MIS 4-3)

1: Mousterian point, flint from Simmenthal; 2: scraper, flint from Olten; 3: scraper, flint from Oberiberg; 4: Mousterian point, calcedoine; 5: scraper with bifacial retouch, phtanite; 6: scraper, flint from Ewattingen; 7 bipolar Levallois core, phtanite; 8: scraper, unknown material; 9: bipolar Levallois core, rhyolite; 10: preferential Levallois core, Hornstein; 11: retouched Levallois flake, chert; 12: Levallois flake, flint

Fig. 15 – Objets lithiques des unités 14 à 9 (SIM 5d-a et SIM 3 ?)

1 à 7 : unités 14-13 (SIM 5d-a) ; 8 à 12 : unités 13-9 (MIS 4-3)

1 : pointe moustérienne, silex de Simmenthal ; 2 : racloir, silex d’Olten ; 3 : racloir, silex d’Oberiberg ; 4 : pointe moustérienne, calcédoine ; 5 : racloir à retouche bifaciale, phtanite ; 6 : racloir, silex d’Ewattengen ; 7 : nucléus Levallois bipolaire, phtanite ; 8 : racloir, matériel indéterminé ; 9 : nucléus Levallois bipolaire, rhyolite ; 10 : nucléus Levallois préférentiel, Hornstein ; 11 : éclat Levallois retouché, chert ; 12 : éclat Levallois, silex

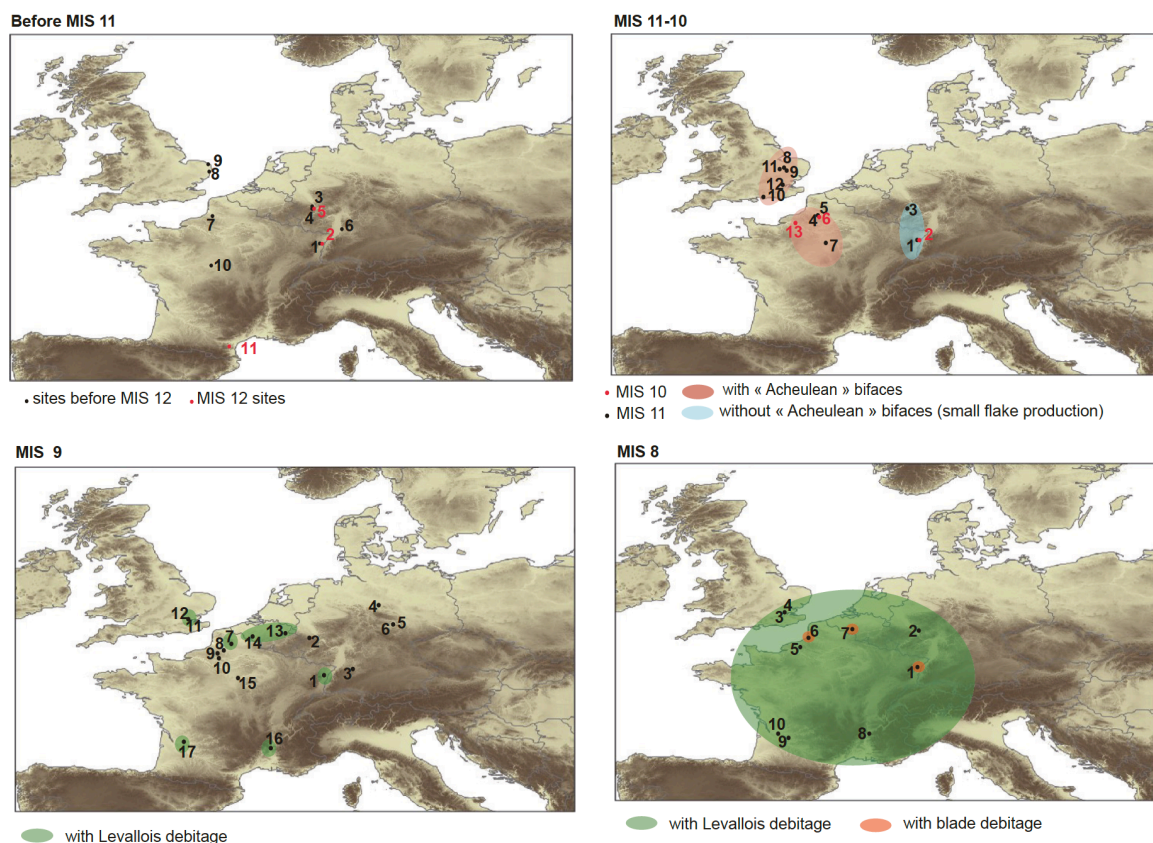


Fig. 16 – Maps of sites used for comparison of MIS 13 to MIS 8 lithic industry in North-west Europe (H. Koehler & S. Diemer)

Sites are listed in table 6

Fig. 16 – Cartes des sites utilisés pour les comparaisons des industries lithiques des SIM 13 à 8 en Europe du Nord-Ouest (H. Koehler & S. Diemer)

Les sites sont listés dans le tableau 6

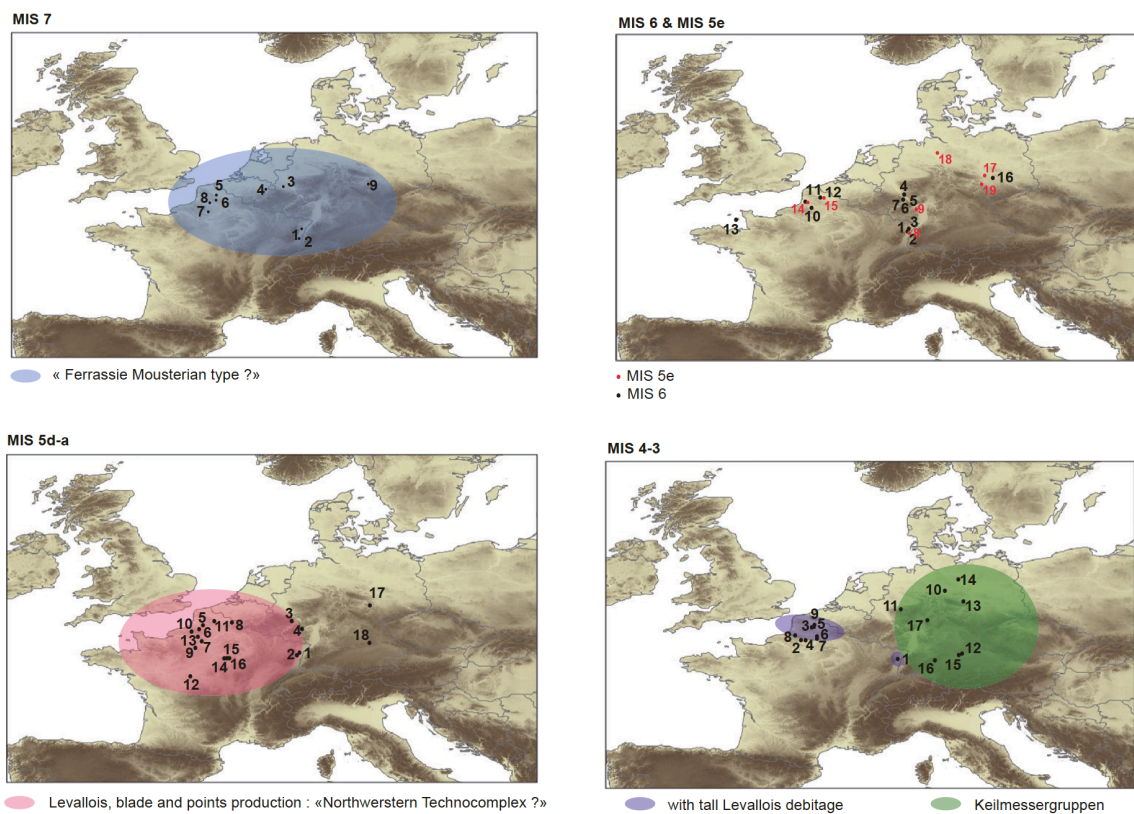


Fig. 17 – Maps and list of sites used for comparison of MIS 7 to MIS 3 lithic industry in North-west Europe (H. Koehler & S. Diemer)

Sites are listed in table 7

Fig. 17 – Cartes des sites utilisés pour les comparaisons des industries lithiques des SIM 7 à 3 en Europe du Nord-Ouest (H. Koehler & S. Diemer)

Les sites sont listés dans le tableau 7

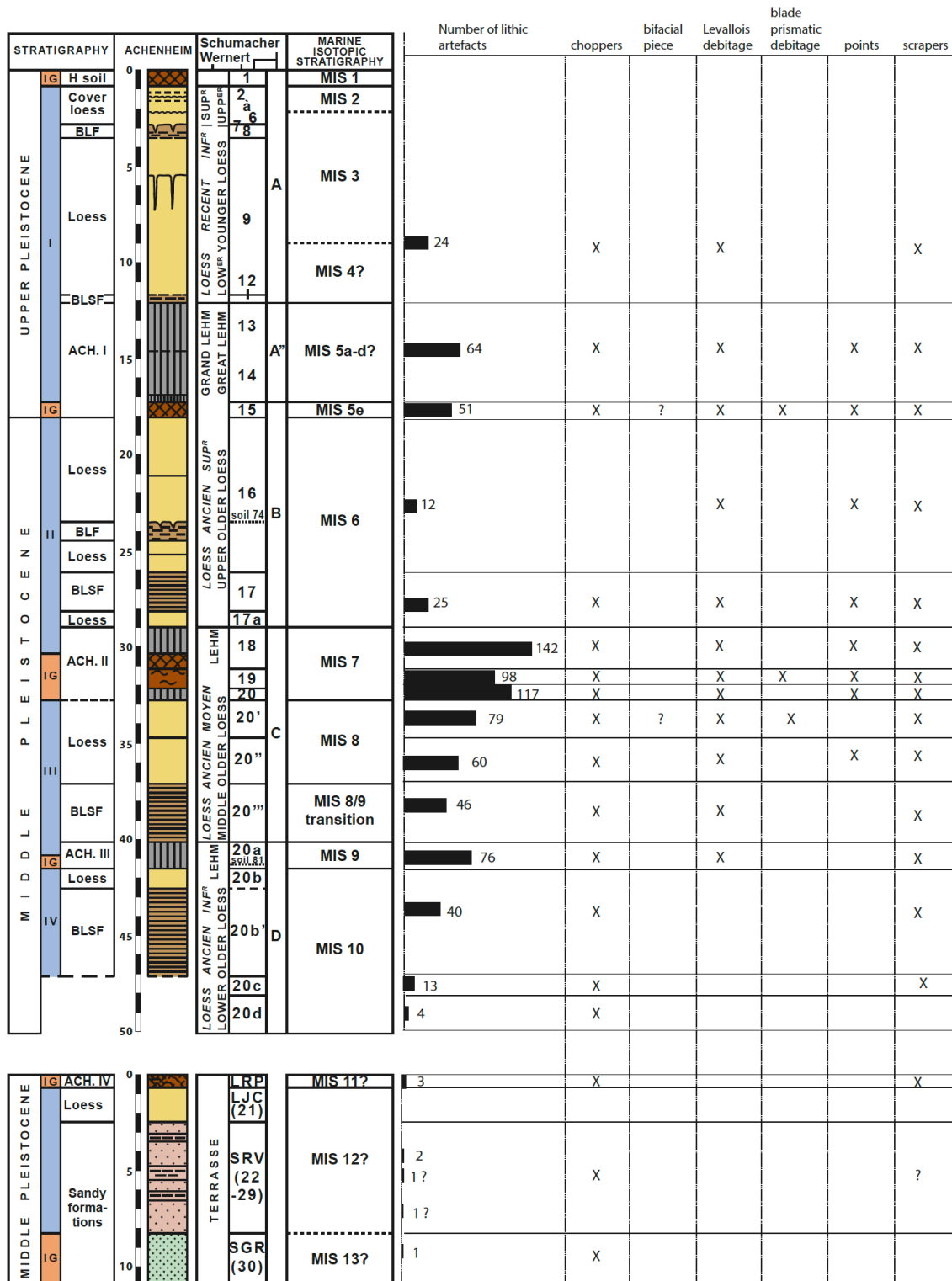


Fig. 18 – Synthetic profile of Achenheim, with lithic industries (H. Koehler & O. Moine, after Heim et al., 1982, modified)

Fig. 17 – Profil synthétique d'Achenheim, avec les industries lithiques

Table 1 – Compilation of all absolute ages obtained in the various loess-paleosol sequences from the Achenheim quarries

Tableau 1 – Compilation de tous les âges numériques obtenus dans les différentes séquences des carrières d'Achenheim

Strata	Stratigraphy		Sedimentary descriptions		Malacofauna		Fauna	MIS
	Lautridou et al. (1985)	Schumacher (1914)	Wernert (1957)	Puisségur (1978)	Schumacher (1914) / Wernert (1957)	Puisségur (1978)		
20b	Lower older loess 4 th glacial period	Lower Older Loess. Atypical. (20a and b. in the south-western part of Achenheim not yet reached, but farther north detected)	LOESSIC SILT with pseudomycellium, homogeneous at the top and laminated at the base. Layer fewly fossiliferous.	P2, S15-16 : yellowish loessic silt with black burrows filled in with sediment from the upper layer (20a) (16) and yellowish loessic silt without burrows (15) P2, S7-14 : alternation of dark clayey levels and light horizons ; these latter more or less varved in appearance. A few small loess dolls in 9 and various detritic materials divers in 11. Russian interstadial with gully erosion C2, P3-6: alternation of light and dark horizons with small carbonated grains and clayey aggregates. Lehmrockelsand C2, P1-2: dark yellow horizon (1) overlaid by a brown horizon (2); a few residue, small mangan and iron oxyde concretions	[W] <i>Helix pomatia</i> , <i>Clausilia</i>	P2, S15-16: cold species <i>Vallonia tenuilabris</i> , <i>Columnella columella</i> and <i>Pupilla alpicola</i> , abundant in 15 almost disappeared in 16, as well as <i>Succinea oblonga</i> . <i>Vallonia costata</i> and <i>Vallonia pulchella</i> more and more numerous. <i>Perforatella bidentata</i> appears. Transition toward a warming phase P2, S7-14: similar molluscan fauna. Level 8 is poorer in individuals; it reminds sample 6. Levels 11 and 13 seem to have deposited under slightly less cold climate P2, S6: absence of <i>Vallonia tenuilabris</i> and <i>Columnella columella</i> . Warming P2, S3-5: same molluscs than in 1 and 2 but with <i>Vallonia tenuilabris</i> , <i>Columnella columella</i> and <i>Pupilla alpicola</i> . Cooling P2, S12: <i>Pupilla muscorum</i> association with <i>Trochicola hispida</i> and a lot of <i>Succinea oblonga</i> . Very cool climate.	<i>Cygnus musicus</i> , det. Schaub, 1, (Birds of prey) swallowing wads, <i>Carnis vulpes</i> , 1, <i>Meles taxus</i> , probably from burrows dig from overlying black loam. <i>Hyena crocuta</i> , archaic form, 1, <i>Citellus rufescens</i> , several, <i>Arctomys marmota</i> , 2, <i>Arvicola</i> sp., 1, (Under-termed rodents in swallowing wads. <i>Equus robustus</i> cf. <i>mosbachensis</i> and <i>taubachensis</i> , several, <i>Equus (Asinus) hydruntinus</i> , 1, <i>Equus hemionus</i> ?, 1, <i>Rhinoceros cf. etruscus</i> , 1, <i>Rhinoceros mercki</i> , 1, <i>Cervus elaphus</i> , rare, <i>Capreolus capreolus</i> , 1, large bovid, 1	MIS 10 + mix with MIS 9 at the top (burrows)
20c			Hardened, ferritized and fossiliferous INTERLAYERED DARKISH LOAM		[W] <i>Helix pomatia</i> , <i>Clausilia</i>		<i>Ursus arctos</i> , 1 ind., <i>Ursus cf. spelaeus</i> , 1 ind., (<i>Hyena</i>), typically gnawed bones. <i>Felis spelaea</i> , 1 ind., <i>Citellus rufescens</i> , 1 ind., <i>Equus robustus</i> cf. <i>mosbachensis</i> , several ind., <i>Rhinoceros mercki</i> , 1 ind., <i>Cervus elaphus</i> , rare, <i>Cervus euryceus</i> , 1 ind., <i>Bison schoetensacki</i> , 1 ind., large bovid, 1 ind., <i>Elephas cf. antiquus</i> , 1 ind.,	MIS 10 (interstadial)
20d			Basal YELLOW FLUVIAL CLAYEY LOAM, laminated and horizontal over its entire extent currently exploited. Its thickness does not exceed 2 m. Layer fewly fossiliferous		[W] <i>Helix pomatia</i> , quite common, <i>Arianta arbusorum major</i> , rare, <i>Cepaea nemoralis</i> , <i>Aegopsis</i> sp., several ind., <i>Fruiticicola fruticum</i> , <i>Succinea oblonga</i> var. <i>schumacheri</i> , <i>Limnea</i> , different species, <i>Planorbis</i> , different species, <i>Planidium</i>	<i>Ursus</i> , 1 ind., (<i>Hyena</i>), typically gnawed or crushed bones, <i>Rhinoceros mercki</i> , 1 ind., <i>Equus robustus</i> cf. <i>mosbachensis</i> , 1 ind., <i>Cervus elaphus</i> , large, 2 ind., <i>Cervus eustephanus</i> ?, 1 ind., <i>Cervus euryceus</i> , 2 ind., <i>Capreolus capreolus</i> , 1 ind., large bovid, 1 ind.,	MIS 10 (interstadial at the top)	
20*	Terrace (Cover loam) 4 th interglacial period (Achenheim N)	Sandy loess loam. Cover older sandy loess (locally deeper horizon if the Middle Older Loess?)	RED PLATEAU LOAM from 1 to 4 m thick (...), red loam eluvial soil according to Franc de F. erniere.	P1, S8 : brown grey horizon made of allocthonous materials, i.e. reworked from the red plateau loam	[W] <i>Helix pomatia</i> , several ind., <i>Arianta arbusorum major</i> , 1 ind., <i>Arianta arbusorum</i> , medium-sized, several ind., <i>Cepaea nemoralis</i> , 2 ind., <i>Fruiticicola fruticum</i> , <i>Urnio</i> sp., 1 ind.	(Hyaena), gnawed or crushed bones, <i>Ursus cf. spelaeus</i> , <i>Ursus arctos</i> , 1 ind., <i>Meles taxus</i> , 1 ind., <i>Citellus rufescens</i> , rare (2 or 3 ind.), <i>Arctomys marmota</i> , 1 ind., <i>Arvicola terrestris</i> , 2 ind., <i>Equus robustus</i> , rare, <i>Cervus elaphus</i> (cf. <i>eustephanus</i>), 1 ind., <i>Cervus elaphus</i> , archaic type, 3 ind., <i>Capreolus capreolus</i> , 3 ind., <i>Bison prisacus</i> , very large, 1 ind., <i>Elephas cf. antiquus</i> , 1 ind.	MIS 11 interglacial	
21	Terrace (6 th glacial period)	Laminated loess partly bright yellow	RED SANDS AND superimposed CANARY YELLOW SOLIFLICTED SANDY LOESS. It is thicker and at the terrace level of the red loam, with the overlying sandy older loess, very rare bone remains (...). They may have been introduced from the overlying layer by mixing from cryoturbation.	P1, S« canary sandy loess » : formation not directly visible in profile 1 as probably eroded but locally well-developped 30 m southwards; canary sandy loess; characteristic aggressive yellow color. Mix of loess and fine sand.	[S] Next to land small shells: freshwater molluscan fauna. First completely extinct (false) (<i>Columnella columella</i>) and 5 genus extinct in Alsace: [W] <i>Medium-sized Helix arbusorum</i> and <i>Helix nemoralis</i>	P1, S8 : scarce molluscan fauna but with forest (3 species and 14% of individuals) and half-forested (3 species and 33% of individuals) taxa including <i>Helicigona lapicida</i> , <i>Helicodonta obvolva</i> , <i>Cochlicodina laminata</i> , <i>Cepaea</i> and <i>Helicigona lapicida</i> . Interglacial context.	MIS 12 (interstadial)	
22		Laminated loess with Vosgian sand (and Vosgian loam) beds	RED SANDS AND superimposed CANARY YELLOW SOLIFLICTED SANDY LOESS. It is thicker and at the terrace level of the red loam, with the overlying sandy older loess, very rare bone remains (...). They may have been introduced from the overlying layer by mixing from cryoturbation.	P1, S7: brown grey horizon made of allocthonous materials, i.e. reworked from the red plateau loam	[S] Next to land small shells: freshwater molluscan fauna. First completely extinct (false) (<i>Columnella columella</i>) and 5 genus extinct in Alsace: [W] <i>Medium-sized Helix arbusorum</i> and <i>Helix nemoralis</i>	P1, S8 : scarce molluscan fauna but with forest (3 species and 14% of individuals) and half-forested (3 species and 33% of individuals) taxa including <i>Helicigona lapicida</i> , <i>Helicodonta obvolva</i> , <i>Cochlicodina laminata</i> , <i>Cepaea</i> and <i>Helicigona lapicida</i> . Interglacial context.	MIS 12 (interstadial then glacial)	

Strata	Stratigraphy Lautridou et al. (1985)	Sedimentary descriptions			Malacofauna		Fauna	MIS	
		Schumacher (1914)	Wernert (1957)	Puisségur (1978)	Schumacher (1914) / Wernert (1957)	Puisségur (1978)			
23	Terrace (5 th glacial period)	Finely laminated light yellowish to whitish muddy loess. To the top and in the middle plate-shaped calcareous concretions. In sieving residuals fine calcareous grains in sieving residue	STRATUM OF WHITISH RHYME MUD AND OF SANDY-LOESSIAL SILT with an hardened calcareous bed at the top	C1: P4: Vespers sand with intercalations of silty beds. Agglomerations of fine sand stained with iron oxide in the residue. Large, flat sandstone concretions at the base	P1, S4: molluscan fauna similar to 2 and 3 but less abundant with rather numerous <i>Pupilla alpicola</i> and fragments of aquatic species. Cold and still humid climate		Wernert (1957)	MIS 12	
24			C1: P2-3: greenish marls. Residue mainly composed of small concretions and agglomerations of fine sand (Vosgian and Rhine)	C1: P1: variegated yellow and green marl, with large flat concretions. Aggregated siliceous sand platelets in the residue	P1, S3: less <i>Columella columella</i> , numerous <i>Trochulus hispidus</i> and a few aquatic molluscs. Still cold but less humid climate P1, S2: <i>Columella columella</i> association with numerous <i>Valonia tenuilabris</i> very few <i>Trochulus hispidus</i> and <i>Succinea oblonga</i> represented by its elongated morph. Swamp area, very cold and humid climate P1, S1: <i>Pupilla</i> association with <i>Valonia costata</i> , <i>Trochulus hispidus</i> , <i>Succinea oblonga</i> . Rather cold climate			MIS 12	
25-27		Vosgian sand, including some loess especially at the top and bottom. With (dark yellow) thin plate sandy loess dolls	RED VOSGIAN SANDS strongly soliflucted at the contact with underlying Rhine sediments. These cryoturbation features since 1883	C1: pink Vosgian sands with very thin beds of green marls vertes	[W] Poorer molluscan fauna, especially quantitatively, than that of basal Rhine sands and characterised by cold climate species <i>Valonia tenuilabris</i> , <i>Vertigo pigraea</i> , <i>Columella columella</i> , <i>Stagnicola palustris</i> , <i>Gyraulus riparius</i> , <i>Gyraulus rosmaessleri</i> , <i>Valvata macrostoma</i>			MIS 12	
28		Vosgian mud : Light reddish fine loessic mud carbonate-free - Between Achenheim and Hangenbieten replaced by Rhine mud : Light grey plastic marl	RHINE MUDDS soliflucted, marly and grey, with ferritized vegetal imprints and freshwater molluscs					<i>Cervus elaphus</i> , rare, <i>Cervus sp.</i> 1 ind., <i>Equus cf. hemionus</i> , 1 ind., <i>Rangifer tarandus</i> , 1 ind., <i>Cervus sp. juv.</i> , 1 ind., <i>Cervus elaphus</i> , rare, <i>Cervus sp.</i> 1 ind., det. Schumacher, <i>Capreolus capreolus</i> , 1 ind., large bovid, 1 ind., <i>Elephas</i> , 1 ind.	MIS 12
29		Loessial mud, yellowish, carbonated. - Between Achenheim and Hangenbieten : yellowish to brownish sand-loess mud	YELLOW LOESSIAL MUDDS		[W] Freshwater molluscan fauna. Neither vertebrate remains, nor human Pas de vestiges humains			MIS 12	
30	5 th interglacial period (+ glacial period?)	Older Rhine sand. With layers of Rhine mud and sandy Rhine mud	RHINE SANDS, (...) grey, rich in quartz and calcareous grains and including ochreous spheric concretions	C1: grey green Rhine sands	[S] Terrestrial (48) and freshwater (31) mollusc species, whose 3 (not 4 as originally thought) extinct species, and 12 species nowadays extinct in Alsace. * <i>Semilimax kochii</i> , <i>Discus alherdaei</i> , <i>Columella columella</i> , <i>Segmentina sandbergeri</i>			Castor fiber, 1 ind., <i>Rhinoceros etruscus</i> , 1 ind., (signalé par Freundenberg), <i>Squalius leuciscus</i> 1 ind., récolte Andraée	MIS 13 (+ MIS 14?)

Table 2 – Synthesis of sedimentary descriptions, malacofauna and fauna taxa for each unit of Achenheim quarry and proposal of MIS correlations for Lower Palaeolithic.

Tableau 2 – Synthèse des descriptions sédimentaires et des taxons malacologiques et faunistiques pour chaque unité des carrières d'Achenheim et proposition de corrélation des unités à un SIM pour les niveaux du Paléolithique inférieur

Strata	Stratigraphy	Sedimentary descriptions				Maliaco fauna		Fauna	MIS
		Schumacher (1914)	Wernert (1957)	Heim et al. (1982)	Puisségur (1978)	Schumacher (1914) / Wernert (1957)	Puisségur (1978)		
9	Younger loess 1 st glacial period	Younger Loess. Formation quite homogeneous in its upper part. Untypical towards the bottom, similar to sandy loess (loamy, sandy and granular laminations)	WHITISH TYPICAL LOESS poorly fossiliferous	Several loesses rich in molluscs, with a typical yellowish loess overlying spotted brownish clayey loesses	P1, S13: light yellow loess whose colour probably results from a redox phenomena or the underlying level. Except shells the residue is almost null P1, S11-12: "very soft" greenish loess. Residue almost entirely composed of shells	[W] <i>Succinella oblonga</i> , <i>Trochilus hispidus</i> , <i>Pupilla muscorum</i>	Extremely abundant fauna P1, S13: <i>Pupilla muscorum</i> absent, but 12.20% of <i>Pupilla alpicola</i> P1, S11-12: considerable quantity of <i>Columnella columella</i> and <i>Pupilla alpicola</i> ; their number decreases in 12 <i>Columnella columella</i> associations. Very cold and humid climate (lundra). Probable dependency of cold species proportions to the humidity degree	Schumacher (1914) / Wernert (1957) [W] <i>Equus cf. przewalskii</i> , 1, <i>Equus hemionus?</i> , <i>Rangifer tarandus</i> , several	MIS 3
10	Great loam / Younger oes transition	Younger sandy Loess	SANDY YOUNG LOESS	In present [1982] profiles, the sandy and gravelly loess (10 and 11), observed laterally towards the valley by Schumacher, lack		[W] <i>Succinella oblonga</i> , <i>Pupilla muscorum</i> , <i>Vertigo genesii</i> , <i>Columnella columella</i> , <i>Clausilia rugosa parvula</i> , <i>Yonilia pichnella</i> , <i>Planorbis marginatus</i>		[S] between strata 9 and 13-14: horse, mammoth, reindeer, ground squirrel, bison	MIS 4-3
11	1 st glacial period	Loessic sand with gravel layers (Brook gravel)	WASHED-OUT LOAM from the loam of the Older Loess	Laminated silty-sandy formations with small syngenetic frost cracks				[W] (Hyena) typically gnawed bones, <i>Arctomys marmota</i> , several, <i>Citellus rufescens</i> ; numerous, idem E. Schumacher, <i>Microtus arvalis</i> det. Schumacher, <i>Rhinoceros tichorhinus</i> ; several, <i>Equus germanicus</i> , common, <i>Equus hemionus</i> ?, 3, <i>Cervus elaphus</i> ; rare, <i>Cervus euryceros</i> ; 6, <i>Rangifer tarandus</i> ; quite common, <i>Bison prisus</i> , <i>Elephas primigenius</i> ; numerous	MIS 4-3
13-14	Upper older loess (Great loam)	Loessic loam with an increasing breccialike mix of (humic) loess and (younger) loess	WEATHERING LOAM OF THE OLDER LOESS	Dark brown silty ensemble that strongly thickens in the small fossil gully of the Hurst quarry (4 m) where develop several successive humic soil horizons				[W] <i>Canis lupus</i> 1, <i>Ursus cf. arctos</i> 1, <i>Meles taxus</i> 1, <i>Hyena</i> , coproliths and enwed bones, 1, <i>Arctomys marmota</i> , 1, <i>Citellus rufescens</i> 1, <i>Arvicola amphibius</i> , 2, <i>Rhinoceros tichorhinus</i> , rare, <i>Equus germanicus</i> , quite common, <i>Equus asinus hydruntinus</i> , rare (det. Stehlin), <i>Cervus elaphus</i> ; several, <i>Cervus euryceros</i> , 6, <i>Rangifer tarandus</i> L., rare, <i>Cervus capreolus</i> , 1, <i>Capra</i> sp., 1, <i>Bison prisus</i> , 1, <i>Elephas primigenius</i> , rare	MIS 5d-a
15	Upper older loess (Great loam) 1 st interglacial period (Achenheim I)	Upper Older Loessic loam (Upper Loam). Decalcified loam cover of the Older loess. Formed partly on already reworked, partly on not altered, initial deposit of Older Loess	TYPICAL UPPER OLDER LOESS with four intercalated rubefaction zones. Fauna very impoverish in both individuals and species. Bones (...) very rare small loess terrestrial molluscs, (...) 4 m thick fossiliferous unit in which occur beautiful cryoturbation phenomena	Brown reddish non calcareous loamy horizon with a prismatic structure and clayey coating, unevenly preserved, and that constitutes the lower half of a truncated brown leached soil Bt horizon	[S] Locally like A' [12-14] with (some-) times numerous shell remains from A [2-9] initiated in root tubules or burrows			[S] Very sparse bone remains [W] <i>Arvicola terrestris</i> , 1, <i>Citellus rufescens</i> , rare, <i>Equus germanicus</i> , 1, small equidae or <i>Equus hemionus</i> , 1, <i>Rangifer tarandus</i> , 7, <i>Cervus euryceros</i> , 1, <i>Elephas primigenius</i> , 1,	MIS 5e
16	Upper older loess 2 nd glacial period	Upper Older Loess. Formation more or less very typical at the top, with a whitish and a reddish Zone (Banded Loess)	VERY SOLIFLUCTED BASAL SANDY LOESS AND RED SAND LENS. Straw yellow color	Yellowish and yellow brownish loess series, 3 to 4 metres thick, (...) very calcareous typical loess, weakly altered (pseudomycellium) Unconformity	[S] Very sparse shells			[S] Very sparse bone remains [W] <i>Arvicola terrestris</i> , 1, <i>Citellus rufescens</i> , rare, <i>Equus germanicus</i> , 1, small equidae or <i>Equus hemionus</i> , 1, <i>Rangifer tarandus</i> , 7, <i>Cervus euryceros</i> , 1, <i>Elephas primigenius</i> , 1,	MIS 6
17 (17)		Upper Older Loess. Untypical formation, similar to sandy loess, with more or less granular and sandy laminations		Dark brownish laminated silty sandy or sandy formations with sporadic gravel and pebble lenses and very thick (3 m), facies and laminations more regular than in unit 16. Truncate lower layers (19) according to reworked by the loess. By a reddish sandy bed with rare pebbles	[S] Shells more common, mostly whorl fragments [W] Molluscs, shell fragments, rather large, probably reworked by solifluction, from older units			[S] Bone remains a little more common than in loess 16. Marmot remains observed several times in 17a [W] <i>Talpa</i> , det. Nehring, 1, <i>Canis lupus</i> , 1, very large, <i>Mustela putorius</i> , det. Nehring, 1, <i>Chellus rufescens</i> , 1, <i>Arctomys marmotta</i> , rare, <i>Lepus timidus</i> , det. Schumacher, <i>Equus germanicus</i> , rare, <i>Equus asinus hydruntinus</i> , 1, <i>Arvicola terrestris</i> , 1, <i>Citellus rufescens</i> , 1, <i>Rangifer tarandus</i> , 1, <i>Elephas 1</i> (indeterminate tusk fragment), <i>Arius boschas</i> , det. Nehring, 1	MIS 6
17a		(granular loess), partly humic In general, lighter (more whitish), homogeneous loess							

Strata	Stratigraphy	Schumacher (1914)	Sedimentary descriptions	Heim et al. (1982)	Puisségur (1978)	Schumacher (1914) / Wernert (1957)	Malacofauna	Fauna	MIS
18-18'	Lautridou et al. (1985) Middle older loess (Loam) 2 nd interglacial period (Achenheim II)	Schumacher (1914) Middle Older Loessloam (Middle Loam). More or less calcareous loam cover of the Middle Loess	Wernert (1957) RED BROWN LOAM, sometimes sulfoclated at the top. Rather rich fossiliferous layer of the lower part of the layer with ferruginous concretions	Heim et al. (1982) Brownish humic loam with protoconas Brown reddish non calcareous silty clayey (E) truncated brown leached soil (E) horizon	P3, S11: brown red loam. Residue almost null composed essentially of quartz and MgO grains	Schumacher (1914) / Wernert (1957) [S] Marmot, red deer, cave hyena, beaver, bovid (<i>Bos primigenius</i>) [W] Talpa, 1. <i>Canis lupus</i> , medium-sized, 1. <i>Canis vulpes</i> , several, <i>Meles taxus</i> , 1. <i>Arctomys marmota</i> , numerous, <i>Arvicola terrestris</i> , several, <i>Castor fiber</i> , 2. <i>Eulus granaeolus</i> , rare, <i>Eulus talpae</i> , 1. <i>Eulus sylvaticus</i> , 1. <i>Eulus elaphus</i> , rare, <i>Rhinoceros indeterminate</i> , rare, <i>Cervus elaphus</i> , rare, <i>Cervus euryceros</i> , rare, <i>Cervus capreolus</i> , rare, large bovid, rare, <i>Elephas cf. primigenius</i> , rare	P3, S11: very poor fauna: 4 species and 14 individuals for 10 litres of sample. However, it fits very well in the spectra series	[S] Marmot, red deer, cave hyena, beaver, bovid (<i>Bos primigenius</i>) [W] Talpa, 1. <i>Canis lupus</i> , medium-sized, 1. <i>Canis vulpes</i> , several, <i>Meles taxus</i> , 1. <i>Arctomys marmota</i> , numerous, <i>Arvicola terrestris</i> , several, <i>Castor fiber</i> , 2. <i>Eulus granaeolus</i> , rare, <i>Eulus talpae</i> , 1. <i>Eulus sylvaticus</i> , 1. <i>Eulus elaphus</i> , rare, <i>Rhinoceros indeterminate</i> , rare, <i>Cervus elaphus</i> , rare, <i>Cervus euryceros</i> , rare, <i>Cervus capreolus</i> , rare, large bovid, rare, <i>Elephas cf. primigenius</i> , rare	MIS 7
19		Middle Older Loess. Untypical formation. More or less rich in granules and sandy, as well numerous small secondary carbonates (calcareous milky tubules, fibres, etc.) partly similar to morlar. Upward a lot of (sometimes large, often root-shaped elongated) loess coils	UNUSUAL LOESS with pseudomycellum and a rich fauna of thermophilous and hygrophilous forest molluscan according to W. Wenz: high clay and fine sand content according to J. Franc de Ferrière	Silty-clayey deposit with large molluscs (<i>Ariaria arbusorum</i> , <i>Cepaea</i>) (...) overlying an unconformity erosion	P3, S9-10: light brown clayey silt with pseudomycellum. (In the middle) a fine layer with several small sandy beds. Rather weak residue composed almost entirely of quartz, feldspars, mica, orthite and iron oxide grains. Formation sans doute redoussée, comme le prouve le litage (central), mais la distance de transport est faible car les coquillages sont en assez bon état. Il ne s'agit pas d'un loess mais d'une colluvion de pente	[S] Strikingly abundant molluscan fauna: <i>Ariaria arbusorum</i> (partly unusually large), <i>Cepaea nemoralis</i> , <i>Friticolia fruticum</i> , <i>Helicospira singula</i> , <i>Helicospira obvolvata</i> and <i>Helicospira obvolvata</i> [W] According to Schumacher and Wenz: <i>Ariaria arbusorum</i> major, giant forms, <i>Cepaea nemoralis</i> , <i>Friticolia fruticum</i> , <i>Helicospira obvolvata</i> , <i>Helicospira lapidosa</i> , <i>Evomphalia fringilla</i> , <i>Aton</i> , <i>Unio</i>	P3, S9-10: fauna abundant enough to ensure their significance. Open-forest association, but shells more abundant in the lower half. Warm temperate climate. The giant size of <i>Ariaria arbusorum</i> , and the presence of <i>Helicospira obvolvata</i> and <i>Friticolia fruticum</i> suggest a certain degree of humidity	[W] <i>Canis lupus</i> , medium-sized, rare, <i>Canis vulpes</i> , rare, <i>Hyena crocuta</i> , several, in addition coproliths and gnawed bones, <i>Meles taxus</i> , several, <i>Arvicola terrestris</i> , 1. <i>Arctomys marmota</i> , numerous, burrow skeleton remains, <i>Castor fiber</i> , rare, <i>Eulus roboratus</i> , <i>Asinus hydruntinus</i> , rare, <i>Rhinoceros mercki</i> , rare, <i>Rhinoceros cf. etruscus</i> , rare, <i>Sua scrofa</i> , 1. <i>Cervus elaphus</i> , numerous, <i>Capreolus capreolus</i> , numerous, <i>Bison schoetensacki</i> , <i>Brama bernicla</i>	Fin MIS 8 / transition MIS 8-7
20	Middle older loess 3 rd glacial period	Middle Older Loess. Humic, with granular lamination, deposits strongly loamy (poorly calcareous) loess	BROWN HUMIC SILT with sulfoclated pockets or calcareous nodules, especially in bones	Thin brownish humic silt (sometimes truncated by an arosion level)	P3, S8: brown humic silt, rather weak residue, some shells are often covered by MgO dendrites. A little quartz	[S] Single <i>Ariaria arbusorum</i> (large), <i>Cepaea nemoralis</i> [W] <i>Ariaria arbusorum</i> major, <i>Cepaea nemoralis</i> , numerous	P3, S8: the molluscan association indicate a very open forest. The residue is very rich in shells, a little <i>Unio</i> , <i>Stuzarella oblonga</i> appears here for the last time	[S] <i>Rhinoceros (Rhinoceros mercki type?) vulpes</i> , 1. (<i>Hyena</i>), coproliths and gnawed bones, <i>Canis arctos</i> , rare, <i>Citellus rufescens</i> , rare, <i>Arctomys mercki</i> , several, <i>Castor fiber</i> , rare, <i>Equus robustus</i> , <i>Asinus hydruntinus</i> , several, <i>Equus hemionus</i> ? 1, <i>Rhinoceros elaphus</i> , several, <i>Equus eustephanus</i> ? 3, <i>Cervus euryceros</i> , numerous, <i>Alcea alcea</i> ? 1, <i>Bison schoetensacki</i> , several, <i>Bos primigenius</i> , several, <i>Capra ibex</i> , 1, <i>Elephas antiquus</i> , 1, birds: 1 egg shell <i>Arisea</i> ?	MIS 8 (inter-stade)
20'		Untypical loess, somewhat granular, with very abundant calcareous milky tubules and fibres. Also with many thicker calcareous tubes downwards	Light yellow UNUSUAL CAL LOESS, with large pseudomycellum, silt rather calcareous than aeolian according to Wernert. Loess very fossiliferous with bones and shells of large molluscs	Silt with a more typical loess facies	P3, S6-7: thick yellowish clayey silt with, in its median part, calcareous grains. The residue is quite archaeologically composed of ortholiths and granules. Rather than a "light loess" as suggested by Wernert, it would be loessic colluvium (cf. 9 and 10)	[S] Larger <i>Helix germanica</i> (<i>Cepaea nemoralis</i>) quite common [W] <i>Ariaria arbusorum</i> , <i>Cepaea nemoralis</i>	Molluscan fauna mark a transition off during the warm season and accumulate colluvium on the low slope. It also explains the huge quantity of slugs (36.5 %) and the large number of granules	[W] <i>Canis lupus</i> , medium form, 1. <i>Canis vulpes</i> , 1. <i>Ursus arctos</i> , 1. <i>Ursus schreiteri</i> , Diem (cf. <i>arvensis</i>), 1. <i>Meles taxus</i> , 1. <i>Citellus rufescens</i> , several, <i>Equus robustus</i> , <i>Taubauch-La Micoque type</i> , several, <i>Equus asinus hydruntinus</i> , several, <i>Equus hemionus</i> ? 2, <i>Rhinoceros elaphus</i> , several, <i>Rhinoceros cf. etruscus</i> , several, <i>Equus eustephanus</i> ? 1, <i>Rhinoceros mercki</i> , several, <i>Rhinoceros cf. etruscus</i> , several, <i>Cervus elaphus</i> , numerous, <i>Alcea alcea</i> ? 1, <i>Bison schoetensacki</i> , several, <i>Bos primigenius</i> , several, <i>Capra ibex</i> , 1, <i>Elephas antiquus</i> , 1, birds: 1 egg shell <i>Arisea</i> ?	MIS 8 (inter-stade)

Strata	Stratigraphy	Sedimentary descriptions				Malacofauna		Fauna	MIS
		Schumacher (1914)	Wernert (1957)	Heim et al. (1982)	Puisségur (1978)	Schumacher (1914) / Wernert (1957)	Puisségur (1978)		
20''	Lautridou et al. (1985) Middle older loess 3 rd glacial period		YELLOW LOESS WITH THICK NODULAR CONCRETIONS. Layer weakly fossiliferous. Bones (...) are distributed over the entire thickness of the sediment reaching up to 2.5 m; they are most of the time included in large calcareous dolls on which occasionally adhere fragments of large Helicidae	Silt with a more typical loess facies	P3, S4-5: loess, light yellow in its lower part, dark yellow at the top (...) [with] rather large dolls (Ø 6 to 8 cm) [in the middle] whose origin is hard to determine. The residue is weak and included several concretions of hardened loess (upper half) P3, S3 : light greenish loess. Several rather large dolls. Concretions of hardened loess in the residue. Shells often encrusted with MgO		P3, S5: lower percentage of "cold" elements (<i>Pupilla loessica</i> and <i>Pupilla alpicola</i>) than in S1, and several <i>Valonia costata</i> and <i>21 Pupilla sterti</i> . Climate is still cold but less humid P3, S4: fauna similar to 3, but more abundant. Higher percentages of <i>Succinea oblonga</i> and <i>Pupilla alpicola</i> . Climate is still very cold and humid P3, S3 : quite rich in individuals but poor in species (6 in addition to the single fragment of <i>Arriaria</i>). Typical <i>Pupilla</i> association (<i>Pupilla muscorum</i> , <i>Pupilla loessica</i> , <i>Pupilla alpicola</i>) which alone represent 85 % of the total population. Climate is very cold humid	[M] <i>Ursus arctos</i> , 1, <i>Meles taxus</i> , 1, (<i>Hyaena</i>), gnawed bones, <i>Citellus rufescens</i> , several, <i>Equus cf. germanicus</i> , rare, <i>Equus robustus</i> , <i>Taubach-La Micoque</i> type, several, <i>Equus asinus hydruntinus</i> , 1, <i>Equus hemionus?</i> , 1, <i>Cervus elaphus</i> , 1, <i>Capreolus capreolus</i> , 1, <i>Cervus euryceros</i> , 1, <i>Bison priscus</i> , 1, <i>Elephas cf. primigenius</i> , with spaced lamellae, 1, <i>Elephas trogontherii</i> , 1	MIS 8
			BLACKISH SLOPE AND RUNOFF SILT, stratified and laminated, constituting a thick colluvial fan. Bones remains are rare	Thick complex of sandy and brownish laminated formations, more and more sandy downward and whose facies is compatible to that of layer 17	P3, S1-2: runoff silt with intercalated beds of carbonated grains silty grains, called "Lehmbröckelsand" in Central Europe. This formation generally follows an interglacial or an important warming and corresponds to a contrasted climate both in terms of heat and humidity		C3, P1-2: fauna abundant in species but rather poor in individuals. Mix of steppe and xerophilous species (<i>Helicella striata</i> , <i>Chondrula tridens</i> , <i>Euomphalia strigella</i>), with also palustral and aquatic ones (<i>Pupilla alpicola</i> , <i>Ariscus leucostriatus</i>). Coldness marked by <i>Pupilla alpicola</i> and <i>Valonia tenuilabris</i> but attenuated by <i>Valonia costata</i> and <i>Valonia pulchella</i> . Rather cold and contrasted climate	[M] <i>Ursus arctos</i> , 1, <i>Meles taxus</i> , 1, (<i>Hyaena</i>), typically gnawed bones, <i>Felis minuta</i> , 1, <i>Citellus rufescens</i> , very common, <i>Arvicola</i> sp., 1, <i>Equus robustus</i> , <i>Taubach-La Micoque</i> type, quite common, <i>Equus asinus hydruntinus</i> , 1, <i>Rhinoceros cf. mercki</i> , 1, <i>Cervus elaphus</i> , 2, <i>Capreolus capreolus</i> , 1, <i>Bison schoentensacki</i> , 1, <i>Elephas cf. primigenius</i> , 1	MIS 8 / MIS 9
20a	Lower older loess (Loam) 3 rd interglacial period (Achenheim III)	Lower Older Loessloam (Lower Loam)	HUMIC DARK LOAM, surface paleosol. Very fossiliferous in vertebrate remains. Bones from the top of the layer, very fossilized, wear few concretions, are dark brown, impregnated by calcite and covered by manganese spots or dendrites. Bones from basal parts are often covered by brownish concretions that sometimes agglomerate fragments of large shells	Dark brown clayey loam, weakly or not calcareous, (...) with several humic horizons and, at the base, the root of a brown reddish truncated soil	P2, S17-18: brown dark horizon. Very weak residue only composed of granules and MgO grains. Below: very dark horizon, several small wood charcoal		P2, S17-18: except 3 <i>Valonia tenuilabris</i> 18, no cold species. Rare <i>Succinea oblonga</i> . Clear steppe association with <i>Helicella striata</i> , <i>Chondrula tridens</i> and some small-size <i>Valonia pulchella</i> . Numerous slugs and calcareous granules [earthworm granules] indicate a soil	[M] <i>Talpa</i> , <i>Ursus arctos</i> , rare, <i>Ursus cf. deningeri</i> , 1, <i>Meles taxus boddaerti</i> , very large, 1, <i>Citellus rufescens</i> , 1, <i>Equus robustus</i> cf. <i>mosbachensis</i> , and <i>Micoque-Taubach</i> type: many, <i>Eulippus</i> v. <i>Reich</i> , (?), horse with long thin limbs, several, <i>Equus cf. asinus hydruntinus</i> , several, <i>Equus hemionus?</i> , 2, <i>Equus germanicus</i> , rare, <i>Equus elaphus</i> , several, <i>Rhinoceros mercki</i> , rare, <i>Rhinoceros cf. etruscus</i> , rare, <i>Sus scrofa ferus</i> , 1, <i>Cervus elaphus</i> , common, <i>Cervus euryceros</i> , 1, <i>Capreolus capreolus</i> , rare, <i>Bison priscus</i> , 1, <i>Bos primigenius</i> , 1, large bovid, rare, <i>Elephas antiquus</i> , 2, <i>Elephas trogontherii</i> , 7	Fin MIS 9

Table 3 - Synthesis of sedimentary descriptions, malacofauna and fauna taxa for each unit of Achenheim quarry and proposal of MIS correlations for the Middle Palaeolithic

Tableau 3 – Synthèse des descriptions sédimentaires et des taxons malacologiques et faunistiques pour chaque unité des carrières d’Achenheim et proposition de corrélation des unités à un SIM pour les niveaux du Paléolithique moyen

	Unit	Chopper	Core	Unretouched flake	Retouched tools	Undetermined	Total
Middle Palaeolithic	12-9	3	3	11	3	4	24
	13 or 13-14	1	0	1	1	0	3
	14	4	11	25	21	3	64
	15	5	7	24	8	7	51
	16			7	3	2	12
	17/17' & 17a	1	2	12	9	1	25
	18-18'	8	22	68	31	13	142
	19	11	15	37	20	15	98
	20	4	14	55	26	18	117
	20'	8	15	35	10	11	79
	20''	8	5	22	13	12	60
	20'''	8	2	22	2	12	46
	20a	17	6	13	9	32	76
Lower Palaeolithic	20b	6	3	18	4	9	40
	20c	2	1	3	1	6	13
	20d	1	0	2	1	0	4
	20e	2	0	0	1	0	3
	23	1	0	1	0	0	2
	24	0	0	0	1 ?	0	1 ?
	28	0	0	0	0	1 ?	1 ?
30	1	0	0	0	0	1	

Table 4 – Type and count of lithic industry from Lower and Middle Paleolithic units

Tableau 4 – Type et effectif de l’industrie lithique des unités du Paléolithique inférieur et moyen

Unit	Type	Raw material	Raw material code (J. Affolter)	Origin	Km from Achenheim	Direction	Remarks
13-14	Retouched blade	Flint	3403	Neunkirch/Neuweghalde	120	SE	
14	Simple scraper on elongated flake	Lydite	675	Vosges (Lydite)	10 - 20	W	
14	Mousterian point on flake	silex	305	Simmenthal; alluvions du Rhin	90	S	
14	Retouched Levallois flake	silex	507	Ewattingen/ lit de la Wutach	102	SE	
14	Blade	silex	142	Pleigne/Löwenburg	128	SSW	
14	Fragment of flake with reverse retouch	silex	1223	Schönberg bei Freiburg i. Br. (MCVC)	70	SW	
14	Simple scraper on flake	silex	102	Olten/Chalchofen	137	SSE	
14	Elongated flake with retouch	silex	102	Olten/Chalchofen	137	SSE	
15	Levallois core	Lydite	675	Vosges (Lydite)	10 - 20	W	pebble
15	Discoidal flake with notches	silex	1223	Schönberg bei Freiburg i. Br. (MCVC)	70	SW	pebble
17	Simple scraper on éclat débordant	silex	305	Simmenthal; alluvions du Rhin	90	S	
18	Levallois core	silex	305	Simmenthal; alluvions du Rhin	90	S	pebble
19	Cortical flake with notches	silex	142	Pleigne/ Löwenburg	128	SSW	subprimary cortex
19	Centripetal Levallois flake	silex	359	Oberiberg; alluvions du Rhin	90	S	pebble
19	Core ?	silex	507	Ewattingen/ lit de la Wutach	102	SE	
20'	Fragment of bifacial piece ?	silex	1222	Lörrach/tranchée autoroute (MFTB)	104	S	
20b	Flake with naturel surface	silex	507	Ewattingen/ lit de la Wutach	102	SE	

Table 5 – Origin of allochthonous raw materials (J. Affolter)

Tableau 5 – Origine des matières premières allochtones (J. Affolter)

MIS	N°	Sites	MIS	Artefacts	References	
Before MIS 11	1	Achenheim, stratum 30	MIS 13	1 chopper	Wernert, 1957, Junkmanns, 1989	
	2	Achenheim, strata 24 & 23	MIS 12	Very few artefacts, small flakes and choppers	Wernert, 1957, Junkmanns, 1989	
	3	Miesenheim 1	MIS 13	Choppers or small flakes cores & small flakes artefacts	Bosinski, 2008 ; Rocca, 2013	
	4	Kärlich, G	MIS 15 or 13	Choppers or small flakes cores & small flakes	Bosinski, 2008, Rocca, 2013	
	5	Kärlich, H	MIS 12	few artefacts, choppers or small flakes, one small biface (Fäustkeil) ?	Vollbrecht 1997 ; Bosinski, 2008	
	6	Mauer, lower sand	MIS 15	Human bones	Vollbrecht 1997 ; Wagner et al., 2011 ; Bahain et al., 2015	
	7	Moulin Quignon	MIS 16	Flake debitage and acheulean bifaces	Antoine et al., 2019	
	8	Pakefield	MIS 19	Flake debitage	Parfitt et al., 2010, Nicoud 2011	
	9	Happisburgh	MIS 19	Microdebitage, few bifacial pieces	Nicoud 2011, Voinchet et al., 2015	
	10	La Noira	MIS 16/15	flake debitage and "Large Cutting Tools" (bifacial pieces), early Acheulean	Moncel et al., 2013	
	11	Caune de l'Arago, Tautavel	MIS 12	choppers and small flakes, bifaces	de Lumley et al. 2004	
	MIS 11-10	1	Achenheim, stratum 20e	MIS 11	Very few artefacts, small flakes and choppers	Wernert, 1957, Junkmanns, 1989
		2	Achenheim, strata 20d, 20c et 20b	MIS 10	Flake debitage, choppers or cores	Wernert, 1957, Junkmanns, 1989
3		Kärlich-Seeufer	MIS 11	Small flakes, choppers, simple bifacial pieces	Bosinski, 2008, Rocca, 2013	
4		Cagny-la-Garenne II (12 lithic series)	MIS 11	Acheulean bifacial pieces, choppers, flake debitage, scrapers, notches & denticulés	Lamotte & Tuffreau, 2001 ; Nicoud, 2011	
5		Cagny-Cimetière	MIS 11	Few artefacts (series K1 to K10), flake debitage and acheulean bifaces	Tuffreau & Lamotte, 2001, Nicoud, 2011, Tuffreau et al., 1997 ; Lamotte et al., 2001	
6		Ferme de l'Épinette, MS et Cagny, C0 & MS	MIS 10	Flake debitage, « acheulean » bifaces	Tuffreau et al., 1997 ; Lamotte et al., 2001	
7		La Celle	MIS 11	Few artefacts, bifacial pieces	Limondin-Lozouet et al., 2006	
8		Barnham I et IV	MIS 11	Flake debitage, one biface	Ashton et al., 1998, Nicoud, 2011	
9		Elveden-Area III	MIS 11	Flake debitage, bifacial pieces	Ashton et al., 2005 ; Nicoud, 2011	
10		Boxgrove Q1/A/4b-c ; Q2/GTP17/4b-c ; Q1/B/4b	MIS 13 or 11	A lot of acheulean bifaces and rare flake debitage	Roberts et Parfitt, 1999 ; Nicoud, 2011	
11		High Lodge B-C-D-E	MIS 13-9	Flake debitage and bifacial pieces	Ashton et al., 1992 ; Nicoud, 2011	
12		Swanscombe Barnfield Pit L.G.4-1 ; Pit Midden ; Pit Top L.G. ; B.L.L. ; K.F.I. ; L.L. ; L.M.G	MIS 11	Flake debitage, notches and rare biface	Conway et al., 1996, Nicoud, 2011	
13		Saint-Pierre-les-Elbeuf, IV	MIS 10	Flake debitage, « acheulean » bifaces	Cliquet et al., 2009, Nicoud, 2011	

MIS	N°	Sites	MIS	Artifacts	References	
MIS 9	1	Achenheim, 20a	MIS 9	Flake debitage, Levallois debitage, scrapers, choppers	Wernert, 1957, Junkmanns, 1989	
	2	Karstein	MIS 9	Small flake debitage, notches, choppers	Bosinski, 2008	
	3	Steinheim	MIS 9	Human bones	Adam, 1954	
	4	Schöningen, 12-B, 12-II & 13-II-4	MIS 9	Small flake debitage, notches, choppers	Serangeli and Conard, 2015	
	5	Memleben	MIS 9	Small flake debitage, notches, denticulés	Mania, 1997 ; Rocca, 2013	
	6	Wangen	MIS 9	Small flake debitage, notches, denticulés	Mania, 1997 ; Rocca, 2013	
	7	HUD d'Ericourt-Manancourt, secteur 2	MIS 9a	Bifaces, flake debitage, minor Levallois débitage	Hérisson et al., 2016	
	8	Cagny-l'Épinette (11-12)	MIS 9/8	Flake debitage and bifaces, notches, denticulés	Lamotte & Tuffreau, 2001 ; Nicoud, 2011	
	9	Clairy-Saulchoix	MIS 9/8	Flake debitage and bifaces, notches, denticulés	Nicoud, 2011	
	10	Plachy-Buyon	MIS 9/8	3 bifacial pieces	Locht et al., 1995	
	North-West Europe	11	Purfleet, Bed 6	MIS 9	Proto-Levallois debitage, acheulean bifaces	White and Ashton, 2003
		12	Purfleet Bed 8	MIS 9	Levallois debitage	White and Ashton, 2003
		13	Kesselt Op de Schans niveau 3	MIS 9	Major Levallois débitage	Van Baelen, 2014
		14	Mesvin IV	MIS 8 or 10 ?	Major Levallois débitage, scrapers	Soriano, 2000; Haesaerts et al. 2019
		15	Soucy, niveaux 5-II, 5-1, 3-P, 1, 5-0, 3-5, 2	MIS 9	Flake production and « acheulean » bifaces	Lhomme, 2007, Nicoud, 2011
		16	Ognac 3, niveaux 6 et 5, 4a, 3 & 2	MIS 9	Levallois, discoïde and SSSA debitage, pebble tools, acheulean bifaces	Moncel et al., 2011
	MIS 8	17	Petit-Bost niveau 2	MIS 9	Levallois, discoïde and Quina debitage ; acheulean bifaces,	Bourguignon et al., 2008
1		Achenheim, 20 ⁱⁱⁱ , 20' & 20	MIS 8	Levallois debitage, prismatic blade debitage, scrapers, mousterian points, and bifacial pieces ?	Wernert, 1957, Junkmanns, 1989	
2		Ariendorf 1	MIS 8	Major Levallois debitage, scrapers	Bosinski, 2008	
3		Northfleet à Backer's Hole, niveau Coombe Rock	MIS 8	Major Levallois debitage, scrapers	Scott, 2011	
4		West Thurrock Lion Pit Tramway Cutting Bed 1	MIS 8	Major Levallois debitage, scrapers	Scott, 2011	
5		Pucheuil level A/C	MIS 8	Major Levallois debitage, scrapers	Delagnes and Ropars, 1996	
6		Saint-Vallery-sur-Somme	MIS 8	prismatic blade debitage	de Heinzelin & Haesaerts 1983	
7		Rissori IV, IIIA et IIIB	MIS 8 (or 7)	prismatic blade debitage	Hérisson et al., 2016	
8		Payre-Rompon, levels F & G	MIS 8	Levallois, discoidal and Quina debitage, acheulean bifaces	Moncel, 2008	
9		Les Bosses	MIS 8	Levallois, discoidal and Quina debitage, acheulean bifaces	Jarry et al., 2007	
10	Cambre-Brune 2, level VIII	MIS 8	Levallois, discoidal and Quina debitage, acheulean bifaces	Brenet, 2011		

Table 6 – List of sites from MIS 13 to 8 mentioned in figure 16

Tableau 6 – Liste des sites des SIM 13 à 8 mentionnés dans la figure 16

N°	Sites	MIS	Artefacts	References
Rhine Valley	Achenheim, 20, 19 & 18	MIS 7	« Moustérien de type Ferrassie » : Levallois & laminar debitage, scarpers and points	Wernert, 1957, Junkmanns, 1989
	Uffheim	MIS 7a	2 lithic artefacts : blade and chopper	Griseilin dir, 2018
	Rheindahlen, B3, B2, & B1	MIS 7	« Moustérien de type Ferrassie » : Levallois & laminar debitage, scarpers and points	Bosinski, 2008
	Maastricht-Belvedere, unité IV	MIS 7 or 9	« Moustérien de type Ferrassie » : Levallois debitage, scarpers and points	Van Kolfsochten et al., 1993
	Blaiche-Saint-Vaast, H, IIA, E & DO	MIS 7e	« Moustérien de type Ferrassie » : Levallois debitage, scarpers and points	Hérisson, 2012
	Etricourt-Manancourt, secteur 2, LRS & LGS	MIS 7c-a	Levallois & discoidal debitage	Hérisson et al., 2016
North-West Europe	Therdonne, N3	Late MIS 7a	« Moustérien de type Ferrassie » : Levallois & laminar debitage, scarpers and points	Hérisson 2012
	Montières-les-Amiens	Late MIS 7a ?	« Moustérien de type Ferrassie » : Levallois & laminar debitage, scarpers and points	Tuffreau et al., 1981
Central Germany	Weimar-Ehringsdorf, Lower travertin	MIS 7	Levallois Debitage, unifacial and bifacial scrapers and points.	Hadlle & Pawlik, 2010
	Achenheim, 17, 17a & 16	MIS 6	Few lithic industry, Levallois debitage, points, short-term camp	Wernert, 1957, Junkmanns, 1989
Rhine Valley	soil 74 of Achenheim	End of MIS 6	Few lithic industry, simple flake debitage, short-term camp	Sainty & Thévenin, 1978 ; Buraczynski et Butrym, 1984 ; Koehler et al., 2020
	Emolsheim-sur-Bruche	MIS 6 ?	Few lithic industry, simple flake debitage, short-term camp	Bachelletie, 2021
	Ariendorf, niveau 2	MIS 6	Few lithic industry, simple flake debitage, short-term camp	Richter, 2016
	Wannen	MIS 6	Few lithic industry, simple flake debitage, short-term camp	Justus 2000 ; Schäfer 1990, Schäfer et al. 2003 ; Bosinski, 2008
	Schweinkopf	MIS 6	Few lithic industry, simple flake debitage, short-term camp	Justus 2000 ; Schäfer 1990, Schäfer et al. 2003 ; Bosinski, 2008
	Tönchesberg, 2A	MIS 6	simple flake debitage, short-term camp	Conard, 1992
	Achenheim, 15	MIS 5e	Levallois flake, scarpers, smaller industry	Wernert, 1957, Junkmanns, 1989
	Wallertheim A & B	MIS 5e	simple flake debitage, smaller industry	Conard et al 1995
	Plachy-Buyon, niveau N2	MIS 6	Unipolar Levallois debitage and discoidal debitage	Locht, 2018
	Abbeville Menchecourt, sondage 12	MIS 6	Discoidal debitage	Locht, 2018
	Havrincourt, niv. J	MIS 6	Few lithic industry : One blade and one mousterian point	Hérisson and Goval, 2013
	La Cotte de St. Brelade 5	MIS 6	Levallois, discoidal and blade prismatic debitage, bifaces	Scott et al., 2014
	North-West Europe	Caours, NC, N1 to N4	MIS 5e	Discoidal & Levallois industry
Waziers		MIS 5e	Few small pieces	Hérisson, et al., 2017
Central Germany	Markkleeberg	MIS 6 or 8	Levallois, discoidal and simple unipolar debitage.	Richter, 2016
	Neumark-Nord 1 & 2/2	MIS 5e	Levallois and discoidal debitage, smaller industry	Gaudzinski-Windheuser et al., 2014
	Lehringen	MIS 5e	Levallois and discoidal debitage, smaller industry	Richter 2016
	Taubach	MIS 5e	Simple flake debitage, smaller industry	Weber et al., 1996

MIS 7

MIS 5e and MIS 6

N°	Sites	MIS	Artefacts	References
Rhine Valley	Achenheim, 14	MIS 5d-a	Levallois debitage, points, scrapers	Wernert, 1957, Junkmanns, 1989
	Mutzig, Rain, level 7D	MIS 5d-a	Levallois debitage, blade volumetric debitage, points, scrapers	Koehler et al., 2020
	Tönchesberg, 2B	MIS 5d	Blade and bladelet volumetric debitage,	Conard 1992
	Wallertheim D	MIS 5c	Blade volumetric debitage, points	Conard et al. 1995
North-West Europe	Bettencourt-Saint-Ouen, N3b, N3a, N2B & N1	MIS 5d, 5c & 5a	Levallois, point & volumetric blade debitage	Locht dir., 2002
	Fresnoy-au-Val SB & BSGF	MIS 5c & MIS 5a	Levallois, point & volumetric blade debitage	Locht, 2018
	Villiers-Adam	MIS 5c	Levallois, point & volumetric blade debitage	Locht et al., 2003, Koehler, 2012
	Saint-Hilaire-sur-Helpe	MIS 5c	Levallois & volumetric blade debitage	Locht, 2018
	Soindres, lev. F to A	MIS 5c & 5a	Levallois, point & volumetric blade debitage	Koehler, 2012 ; Lochet & Chaussé, 2021
	Mauquenchy, WA2	MIS 5a	Levallois & point debitage	Koehler, 2012 ; Lochet et al., 2013
	Riencourt-les-Bapaume CA	MIS 5a	Levallois & volumetric blade debitage	Tuffreau dir., 1993
	Angé	MIS 5a	Levallois, point & volumetric blade debitage and bifaces	Koehler, 2012 ; Lochet et al., 2015
	Auteuil upper level	MIS 5a	Levallois & point debitage	Swinnen et al., 1996 ; Koehler 2012
	Lailly Beaugard	MIS 5a	Levallois & volumetric blade debitage and bifaces	Depaepe, 2007
Central Germany	Molinos	MIS 5a	Levallois & volumetric blade debitage and bifaces	Depaepe, 2007
	Villeneuve l'Archevêque	MIS 5a	Levallois & volumetric blade debitage	Depaepe, 2007
	Neumark-Nord 2/0	MIS 5c	Simple flake debitage, discoidal and rarely Levallois debitage	Britton et al. 2019 ; Homelen 2011
	M1-Q of Sesselfelsgrötte	MIS 5c-a	Simple flake debitage, discoidal and rarely Levallois debitage	Weißmüller, 1995, Richter, 2016
	Achenheim, 13-9	MIS 4/3	Tall Levallois debitage, scrapers	Wernert, 1957, Junkmanns, 1989
	Beauvais 1 et 2	MIS 4	Discoidal debitage	Locht, 2004
	Havrincourt sect.1 et 2 niveau 2	MIS 4	Preferential tall Levallois debitage	Hérison & Goval, 2013
	Fitz-James	MIS 4	Preferential tall Levallois debitage	Locht, 2018
	Riencourt B1	MIS 4	Preferential and centripetal Levallois debitage bifaces	Tuffreau dir., 1993
	Savy N2	MIS4/MIS3	Few pieces, preferential tall Levallois debitage	Locht, 2018
Rhine Valley	Atilly 2 et 1	MIS4/MIS3	Few pieces, preferential tall Levallois debitage	Locht, 2018
	Gauville	MIS4/MIS3	Few pieces, preferential tall Levallois debitage	Locht, 2018
	Hénin-sur-Cojeul	MIS 3	Preferential and centripetal Levallois debitage	Marcy et al., 1993
	Salzgitter- Lebestedt	MIS 4/3	Keilmessergruppe	Bosinski, 2008
	Balver Höhle Iva et II	MIS 3	Keilmessergruppen et grands racloirs ?	Bosinski, 2008, Richter, 2016
	Sesselfelsgrötte, layers E3, G1-G4, G4a, G5	MIS 3	Keilmessergruppen	Richter, 2016
	Königsau A, B, C	MIS 3	Keilmessergruppen	Weißmüller, 1995 ; Richter, 2016
	Lichtenberg	MIS 3	Keilmessergruppen	Weber et al., 1996 ; Richter, 2016
	Klausennische	MIS 3	Keilmessergruppen	Bosinski, 1967, Richter, 2016
	Bockstein III	MIS 3	Keilmessergruppen	Bosinski 1967, Jöris, 2003
Central Germany	Rörshain	MIS 3	Keilmessergruppen	Jöris, 2003

Table 7 - List of sites from MIS 7 to 3 mentioned in figure 17

Tableau 7 – Liste des sites des SIM 7 à 3 mentionnés dans la figure 17