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MIDDLE AND UPPER PLEISTOCENE FLUVIAL EVOLUTION OF THE MEURTHE AND MOSELLE VALLEYS IN THE PARIS BASIN AND THE RHENISH MASSIF

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Stéphane CORDIER*, Manfred FRECHEN**,
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ABSTRACT

The terrace systems of the River Meurthe (Me), and the River Moselle (M) downstream from the present Moselle-Meurthe confluence are composed of eight stepped alluvial terraces (Me8-M8 to Me1-M1), situated at less than 90 m above the modern floodplain Me0-M0. Morphological, mineralogical and petrographical studies evidence that the oldest five terraces (Me8-M8 to Me4-M4) were formed by the “Palaeo-Meurthe”, while the Upper Moselle flowed towards the Meuse valley. Downstream from the confluence, the three youngest alluvial terraces (Me3-M3 to Me1-M1) contain crystalline sediments from the Upper Moselle basin; they have been formed since the Upper Moselle capture, dated about 250-270 ka before present. IRSL and radiocarbon datings provide independent absolute age control for these post-capture terraces, which respectively correlate with the end of the Saalian (Me3-M3) and the Weichselian (Me2-M2 and Me1-M1).

The constant relative height of the terraces between France, Luxemburg and Germany gives evidences that there was no differenciated tectonic movements along the valley since at least the capture.

A cyclic evolution scheme for the formation of the terraces is presented. The main gravel sedimentation occurred during cold periods (pleniglacial and late glacial phases), with a minor erosive period at the beginning of late glacial periods. Major incision occurs at the warm-to-cold transition.

Key-words: Meurthe and Moselle valleys, alluvial terraces, alluvial sequences, IRSL datings, heavy minerals, Upper and Middle Pleistocene.

RÉSUMÉ

L’ÉVOLUTION DES VALLÉES DE LA MEURTHE ET DE LA MOSELLE AU PLÉISTOCÈNE MOYEN ET SUPÉRIEUR DANS LE BASSIN PARISIEN ET LE MASSIF SCHISTEUX RHÉNAN

Les vallées de la Meurthe (Me), et de la Moselle en aval de la confluence avec la Meurthe (M), présentent, à travers le Bassin parisien et le Massif schisteux rhénan, huit terrasses alluviales (Me8-M8 à Me1-M1) étagées à moins de 90 m au-dessus du fond de vallée Me0-M0. Les analyses morphologiques et sédimentologiques (minéralogie et pétrographie) indiquent que les terrasses alluviales les plus anciennes (Me8-M8 à Me4-M4) ont été déposées par la Paléo-Meurthe alors que la Haute-Moselle s’écoulait vers la Meuse. En revanche, les terrasses alluviales plus récentes (Me3-M3 à Me0-M0) contiennent, en aval de la confluence Moselle-Meurthe, de nombreux éléments cristallins provenant du bassin supérieur de la Moselle ; elles ont été mises en place après la capture de la Haute-Moselle survenue vers 250-270 ka (OIS 8). Les datations IRSL et ^{14}C montrent que ces terrasses datent respectivement de la fin du Saalien (Me3-M3) et du Weichselien (Me2-M2 et Me1-M1).

Le parallélisme des terrasses (et en particulier des terrasses encadrant la capture Me4-M4 et Me3-M3) en France, au Luxembourg et en Allemagne montre qu’aucun soulèvement tectonique différenciel n’est survenu le long de la vallée depuis au moins la capture.

La genèse des terrasses alluviales semble s’effectuer de manière cyclique ; la sédimentation aurait lieu principalement lors des phases pléniglaciaires et tardiglaciaires du cycle climatique, avec une phase érosive mineure en début de phase tardiglaciaire ; l’incision majeure responsable de l’étagement des terrasses surviendrait durant la transition interglaciaire-pléniglaciaire.

Mots-clés : Vallées de la Meurthe et de la Moselle, terrasses alluviales, cycle climato-sédimentaire, datations IRSL, minéraux lourds, Pléistocène moyen et supérieur.

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INTRODUCTION

Today, the River Moselle and its major tributary the River Meurthe flow east of the Meuse, towards the Rhine (fig. 1). Prior to the Saalian glaciation, the Upper Moselle flowed towards the Meuse ("Upper-Moselle-Meuse"), while the "Palaeo-Meurthe" joined the Rhine (Harmand *et al.*, 1995). Detailed research was carried out in the Moselle and Meurthe valleys during the first part of the 20th century (de Lamothe, 1901; Dietrich, 1910; Borgstätte, 1914; Wandhoff, 1914; Ferrant, 1933a et b; Théobald et Gardet, 1935) and until the 1980's (Kremer, 1954; de Ridder, 1957; Liedtke, 1963; Müller, 1976; Osmani, 1976; Negendank, 1978, 1983). However, the presence of three main structural regions (the Vosges massif, the Paris basin and the Rhenish massif) and the partition of the area between three countries, France, Luxemburg and Germany, prevented general studies. Furthermore, research in the French valley mainly underlined the climate impact in the formation of alluvial terraces (Tricart, 1952), while authors from Luxemburg and Germany focused on the neotectonics influence (de Ridder, 1957; Fischer, 1962; Hoffmann, 1996).

The studied area is the so-called "Palaeo-Meurthe-Moselle". It corresponds with the Meurthe valley between Baccarat and the Moselle confluence near Pompey, and with the Moselle valley between Pompey and Bernkastel-Kues (fig. 1). The aim of this study is to propose an overview of the terrace system in the Paris basin and the Rhenish Massif, and to provide a more reliable chronostratigraphical frame for the post-capture alluvial terraces, enabling a first correlation between the terraces formation and the Pleistocene climate cycles.

As the terrace system in the Meurthe and in the Upper Moselle valleys has been recently described in detail (Cordier *et al.*, 2004), the morphological study (extension of the alluvial terraces, relative height of their bedrocks) focuses on the area located between Thionville and Bernkastel-Kues. The resulting geometrical correlations are confirmed by extended sedimentological analyses: heavy minerals counts (at least 200 grains for each sample) have been made by Monique Beiner on sands (40-315 µm fraction), isolated using bromoform (methodology in Parfenoff *et al.*, 1970). Petrographical counts have also been made on clasts (20-40 mm diameter).

The chronological study is based on infrared optically stimulated luminescence (IRSL) datings, carried out by Manfred Frechen at the GGA-Institut in Hannover. Luminescence dating is based on the assumption that the sediments were sufficiently long exposed to daylight during the fluvial transport and prior to deposition. Poorly bleached sediment would result in age overestimation. The theoretical upper age limit for potassium-rich monomineralic samples is about 1 Ma. This upper limit is controlled by the saturation of traps in the crytal lattice and by the stability of charge in those traps. The upper dating limit is a function of dose rate and the time elapsed since the last resetting of the radiometric clock by daylight.

Nine samples were taken from sediments of the middle and lower Meurthe terraces. The 100-200 µm grain-size fraction of potassium-rich feldspars was measured applying the single aliquot regenerative (SAR) dose protocol and the multiple aliquot additive dose (MAAD) protocol (Frechen *et al.*, 2004). The MAAD subsamples were stored after irradiation at room temperature for more than six weeks, reducing the likelihood of signal fading. Fading seems to be not significant for those samples, for which independent age control by radiocarbon is available. Reasons could be the extended storage of more than six weeks between irradiation and measurement of the samples, alternatively the potassium-rich feldspars might not exhibit anomalous fading for the fluvial sediments from the Meurthe and Moselle catchment area. In contrast to previous investigations of fluvial sediments from the Rhine-Meuse valley by Wallinga *et al.* (2001), the IRSL age estimates of feldspar-rich extracts did not indicate severe underestimation of deposition ages. Gamma spectrometry was applied in the laboratory to determine uranium, thorium and potassium content assuming radioactive equilibrium for the decay chains. Cosmic dose rate was corrected for the altitude and sediment thickness, as described by Aitken (1985) and Prescott and Hutton (1994). The water content of the sediments was estimated at 20±5%.

The IRSL datings are complemented by the radiocarbon age estimates already obtained, concerning both the present Meurthe and Moselle floodplains (Carcaud, 1992) and the lowest terrace in the Luxemburger valley (unpublished data provided by the National Museum for History and Art of Luxemburg).

I - THE MORPHOLOGY OF THE TERRACE SYSTEM

IN THE MEURTHE AND UPPER MOSELLE VALLEYS

The Meurthe valley between Baccarat and Pompey is mainly developed in the marly depressions (fig. 1). Three alluvial basins (Mondon, Vitrimont and Nancy, respectively n° I, II and III on fig. 1) have been studied. On the basis of morphological data, a terrace staircase including eight terraces, each situated at constant relative heights (ranging from 90 to 5 m above the present bedrock) has been distinguished, from Me8 the oldest to Me1 the youngest (fig. 2a; Cordier *et al.*, 2002). At higher relative height, only residual deposits were found.

Recent resarch in the Upper Moselle valley near Toul ("Moselle touloise", Mt; Harmand *et al.*, 1995; Harmand et Le Roux, 2000; Losson, 2003; Cordier *et al.*, 2004) allowed the definition of a similar terraces staircase, especially including five well-preserved alluvial terraces at less than 45 m above the present

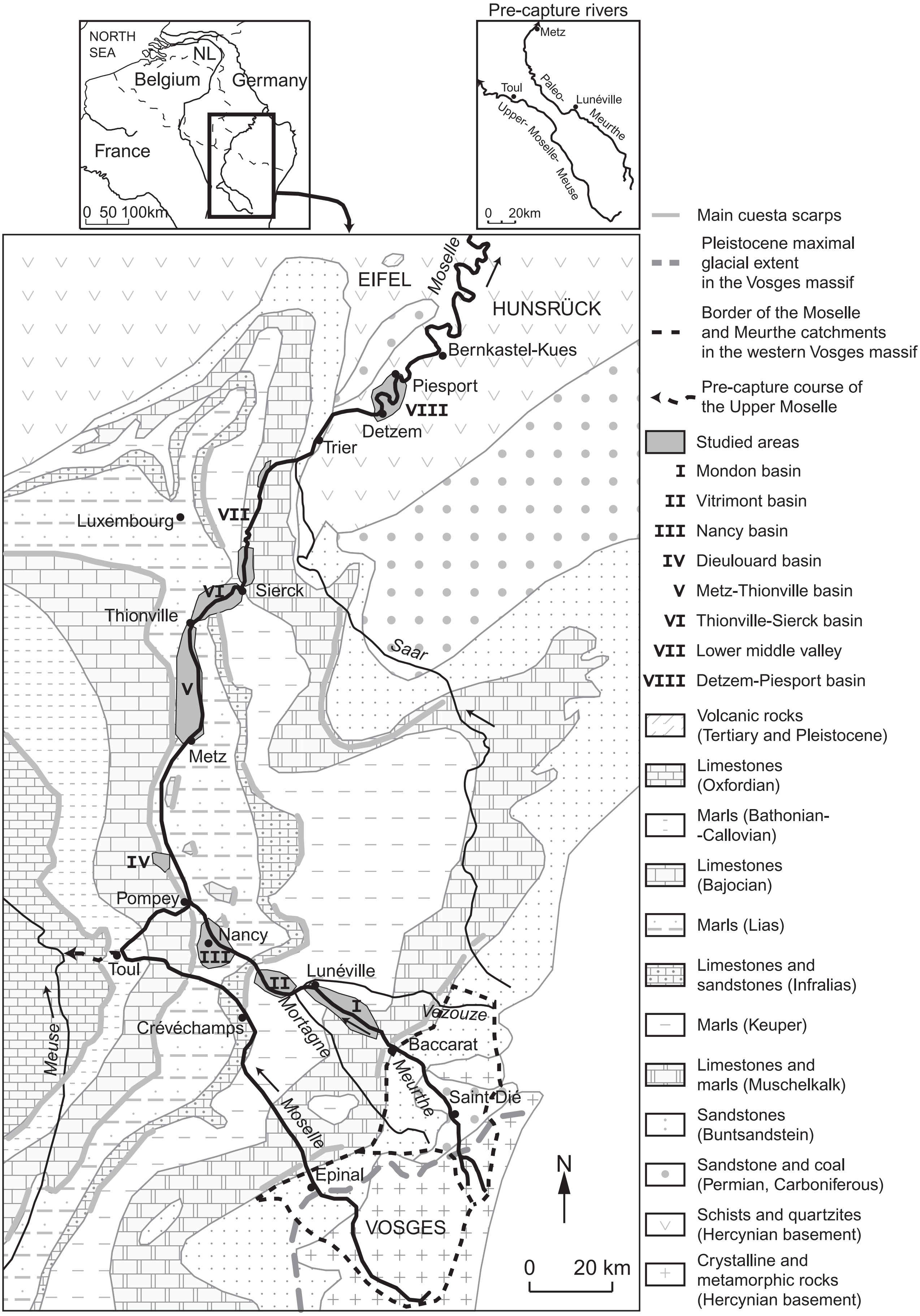


Fig. 1: **Location map of the Moselle-Meurthe catchment.**
Fig. 1 : Carte générale des bassins de la Moselle et de la Meurthe.

bedrock (from Mt5 to Mt1; fig. 2b). The capture of the Upper Moselle by the Palaeo-Meurthe occurred at the end of the deposition of the Mt4 sediments (33 m relative height; Harmand *et al*., 1995; Losson, 2003): the younger alluvial terraces follow the present course of the River Moselle, and must be connected with those located downstream from Pompey.

DOWNSTREAM FROM POMPEY

The valley can be divided into three sections between Pompey and Bernkastel-Kues (fig. 1):

- upstream from the Devonian threshold of Sierck, the valley crosses the cuestas of the Eastern Paris basin; three alluvial basins were formed in the marly stratas: Dieulouard, Metz-Thionville and Thionville-Sierck (n° IV, V and VI on fig. 1);
- between Sierck and Trier, the valley corresponds with the German-Luxemburger border (n° VII on fig. 1); as the bedrock mainly consists of Triassic limestones in this area, the alluvial basins are small, and only the youngest alluvial terraces are widely preserved;
- downstream from Trier, the valley cuts into the schists and quartzite of the Rhenish Massif; there, the Moselle river forms several meanders. Well-preserved alluvial terraces have been described for more than one century (Dietrich, 1910; Borgstätte, 1914; Wandhoff, 1914; Kremer, 1954; Müller, 1976; Negendank, 1983; Hoffmann, 1996). Detailed studies were carried out in the alluvial basin of Detzem-Piesport (n° VIII on fig. 1), owing to the presence of several sections.

The Pleistocene terrace system is divided into the “high terraces” (*sensu lato*) and the “middle and lower terraces” (fig. 2c and 2d). The “high terraces” (main terraces and high terraces *sensu stricto* of the German authors) are preserved upstream from Trier only as residual deposits situated between 100 and 200 m above the present River Moselle (fig. 2c). On the contrary, they correspond with thick alluvial formations (5 to 10 m, fig. 2d) in the Rhenish Massif, and follow a palaeo-valley (“Plateau valley”) whose course differs from the present meanders (Hoffmann, 1996). These terraces are allocated in previous studies to the Lower and Early Middle Pleistocene (Müller, 1976; Hoffmann, 1996). Owing to the contrast with the upper parts of the valley (upstream from Trier), where high terraces are not well-preserved, no reliable correlation can be proposed for these terraces through the Paris basin and the Rhenish Massif.

The “middle and lower terraces” are situated at less than 90 m above the present bedrock of the Moselle river. Eight alluvial terraces have been distinguished at a constant relative height between Pompey and Detzem-Piesport (fig. 2c and d). They may often be divided into three systems, especially in the Thionville-Sierck basin (fig. 2c): in this latter area, more than 120 drillings were carried out with the French Geological Survey (BRGM), enabling to distinguish three “upper middle terraces” at more than 50 m relative height (M8 to M6, fig. 2c), three “lower middle terraces” between 20 and 50 m relative height (M5 to M3), and two “lower terraces” (M2 and M1, at 10 and 5 m above the present bedrock, respectively).

II - THE STRATIGRAPHICAL SITUATION OF THE UPPER MOSELLE CAPTURE IN THE TERRACE SYSTEM

A MAJOR MINERALOGICAL AND PETROGRAPHICAL CONTRAST BETWEEN THE MEURTHE AND MOSELLE ALLUVIAL FORMATIONS

Mineralogical and petrographical analysis have been made both for the Meurthe and the Moselle touloise formations. The comparison reveals an important contrast in the composition of their sediments: the Meurthe sediments are mainly derived from Permo-Triassic stratas, and also contain sand-sized tourmaline and zircon, associated with quartz and quartzite clasts (Cordier *et al*., 2002; Cordier, 2004).

On the contrary, the Upper Moselle formations contain numerous granitic clasts and heavy minerals such as hornblende and garnet, coming from the crystalline basement (Harmand *et al*., 1995; Losson, 2003). This contrast can be explained by the lithology of the Vosgian catchments of both rivers (fig. 1): Permo-Triassic stratas represent more than 75% of the Meurthe catchment, while most of the Upper Moselle basin is developed in the crystalline basement.

THE PRE- AND POST-CAPTURE TERRACES BETWEEN POMPEY AND THIONVILLE

Sedimentological analyses of sands and clasts sampled in the Dieulouard and Metz-Thionville basins (Cordier *et al*., 2004) allowed the Upper Moselle capture to be positioned between the aggradation of terraces M4 (+ 30 m relative height) and M3 (+ 20 m) upstream from Thionville: the upper formations (M4 and older) are actually mainly composed of sediments that originated in the Permo-Triassic strata (fig. 3); on the contrary, the younger formations contain numerous crystalline sediments (hornblende, garnet, granite) originating in the Upper Moselle basin.

THE PRE- AND POST-CAPTURE TERRACES BETWEEN THIONVILLE AND BERNKASTEL-KUES

Several samples were taken from the alluvial formations, both in the Thionville-Sierck basin (owing to the realization of more than 120 drillings) and downstream from Trier, in the Detzem-Piesport basin (presence of several sections). Datas concerning the Luxemburger valley have been taken from N.A. de Ridder (1957).

The alluvial formations are mainly composed of sediments originating in the Vosges Massif (fig. 4 and 5),

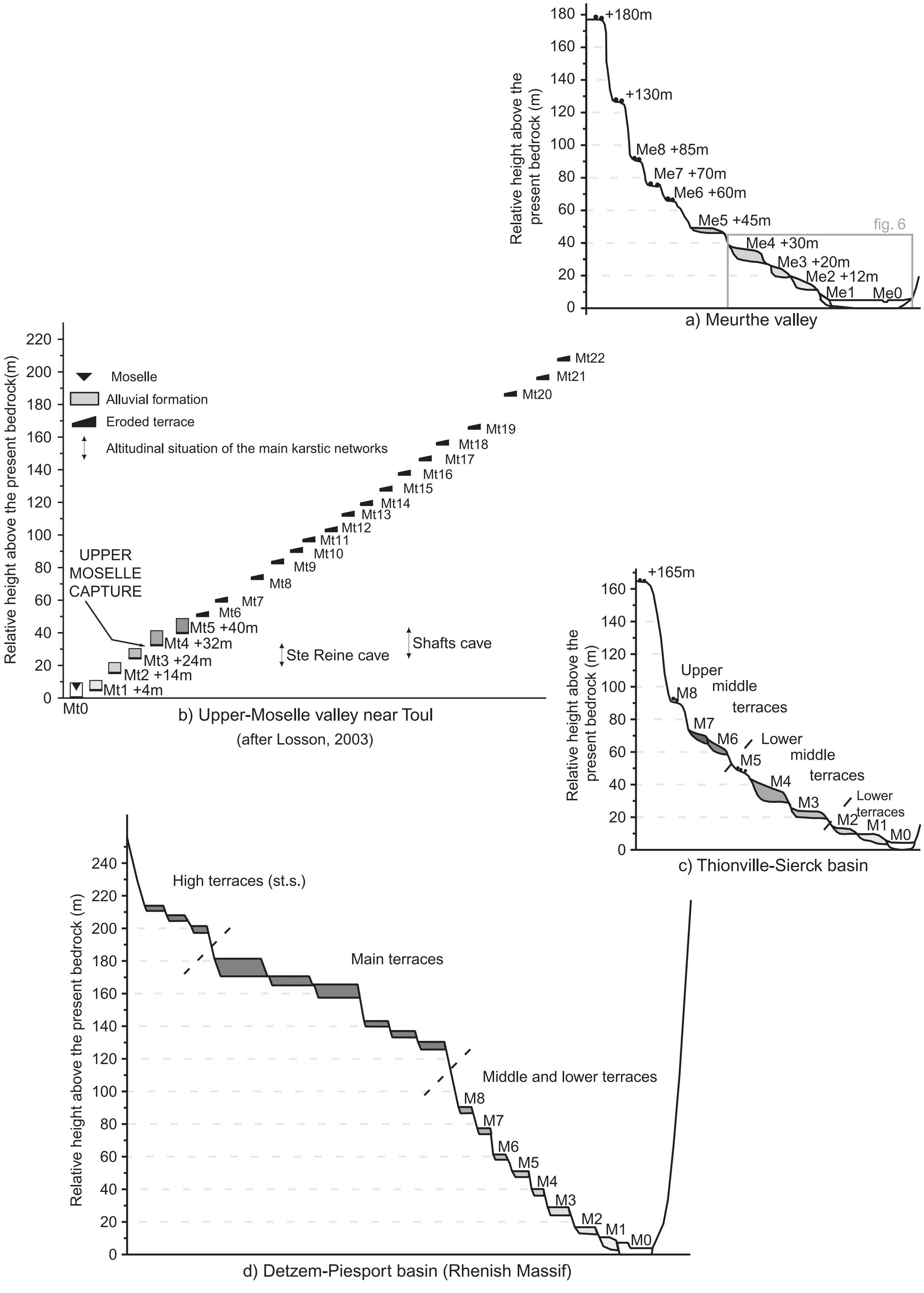


Fig. 2: **The terrace systems of the Meurthe and the Moselle valleys. a) terrace system of the Meurthe ; b) terrace system of the Upper Moselle near Toul; c) terrace system of the Palaeo-Meurthe-Moselle in the Thionville-Sierck basin; d) Pleistocene terrace system of the Palaeo-Meurthe-Moselle in the Rhenish Massif (after Hoffmann, 1996 and Cordier, 2004).**

Fig. 2 : Les systèmes de terrasses de la Meurthe et de la Moselle. a) le système de terrasses de la Meurthe ; b) le système de terrasses de la Moselle touloise ; c) le système de terrasses de la Paléo-Meurthe-Moselle dans le bassin de Thionville-Sierck ; d) le système des terrasses pléistocènes de la Paléo-Meurthe-Moselle dans le Massif schisteux rhénan (d'après Hoffmann, 1996 et Cordier, 2004).

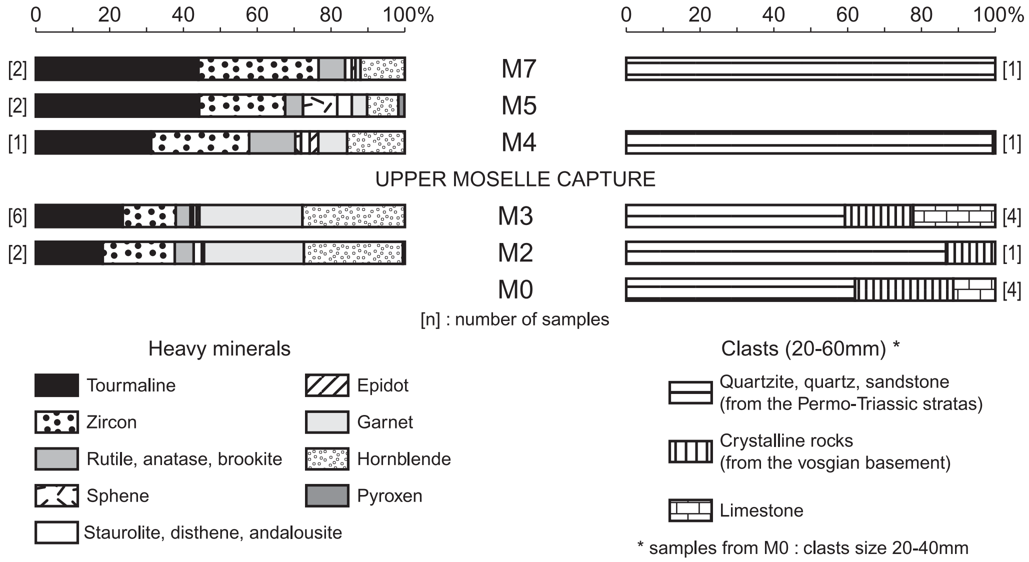


Fig. 3: **Mineralogical and petrographical composition of the alluvial formations between Pompey and Thionville.**
Fig. 3 : *Composition minéralogique et pétrographique des formations alluviales entre Pompey et Thionville.*

as evidenced by the predominance of its typical heavy minerals (tourmaline and zircon, hornblende and garnet) and clasts (quartz and quartzite, granites). The only exception concerns the terraces of the Detzem-Piesport basin, where sediments from the Rhenish Massif are predominant, both in the clasts and gravels fraction (high proportion of schists) and in the sandy fraction: the heavy minerals counts actually evidence a significant proportion of pyroxene (fig. 5), allocated to Pleistocene volcanic activity in the Eifel (Meyer, 1994). As the sphene can be associated with the Eifel volcanoes (Schmincke *et al.*, 1983), this could also explain the presence of sphene in the samples "Hoch", "Berg" and "Hettinger Weg" from the M4 and M3 alluvial formations in the Thionville-Sierck basin (fig. 4a).

The mineralogical and petrographical analyses give evidence for a major difference between the alluvial formations M8 to M4, situated at more than 30-35 m relative height, and the alluvial formations M3 to M0 (fig. 4 and 5):

- the older alluvial terraces (M8 to M4) are mainly composed of sediments that originated in the Permo-triassic stratas: tourmaline and zircon often represent more than 50% of the heavy mineral spectra, while in the coarse sediments crystalline clasts are very rare (less than 3% in the Thionville-Sierck basin).

The one exception, which will be discussed later, concerns the Thionville-Sierck basin, where two samples ("Hoch" and "Berg") located in the upper part of the M4 alluvial formation have a relative majority of hornblende and garnet;

- in contrast, the youngest three alluvial terraces (M3 to M1) and the present floodplain M0 contain more crystalline material: the percentage of hornblende and garnet ranges between 37% and 73% in the Thionville-Sierck basin, between 55 and 76% in the Luxemburger valley, and between 24 and 38% in the Detzem-Piesport basin. This result is confirmed by the petrographical investigations, which evidence a significant proportion of crystalline clasts in the alluvial formations of the Thionville-Sierck basin (about 5% in M3 and M2, 10% in M1 and 18% in M0). This percentage decreases downstream from Thionville, owing to increasing distance from the Vosges Massif; in the Detzem-Piesport basin, the clasts counts indicate that the granites never represent more than 1% of the total clasts percentage, even in the lower terraces (Kremer, 1954; Müller, 1976; Löhnertz, 1982); as a consequence, the petrographical study in the Detzem-Piesport basin was based on gravels (between 3,15 and 20 mm diameter; fig. 5), enabling to find a main difference between the sediments of the M4 and M3 terraces: the sediments of M3 actually contains more than 12 crystalline gravels/kg, but often less than 2 in M4 and M5.

This lithological contrast can not easily be explained only by the weathering of hornblende, garnet and granite in the older formations: mineralogical analysis in the Upper Moselle valley (Losson, 2003) and in the Meuse valley (Krook, 1993) actually evidenced the presence of high proportions of hornblende and granite in old terraces. As this contrast is constantly observed between the terraces M4 and M3 (respectively located around 30 and 20 m above the present river bedrock) from Pompey to Bernkastel-Kues, it must be correlated with the Upper Moselle capture, which also took place before the aggradation of the M3 terrace.

This result allows a correlation with the youngest terraces of the Upper Moselle:

- the post-capture alluvial terraces M3 to M1 are connected with the three post capture alluvial terraces of the Upper Moselle valley (Mt3 to Mt1), which are situated at similar relative height.

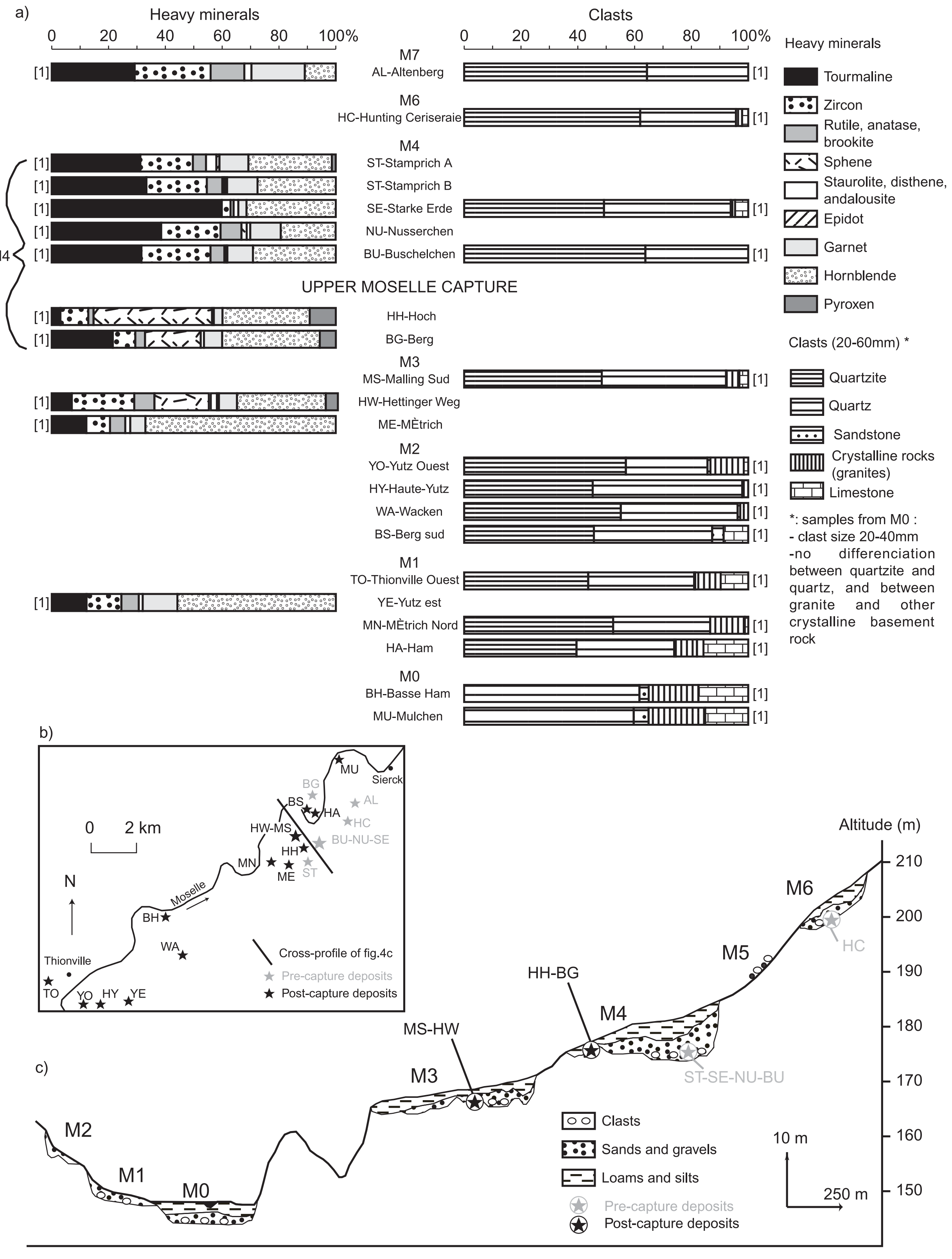
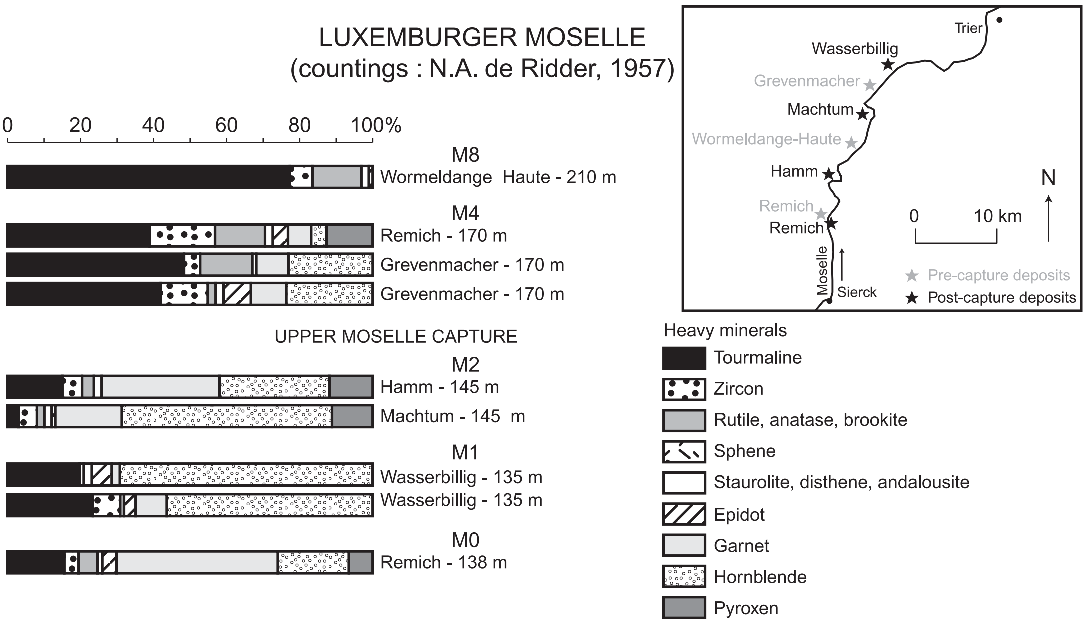
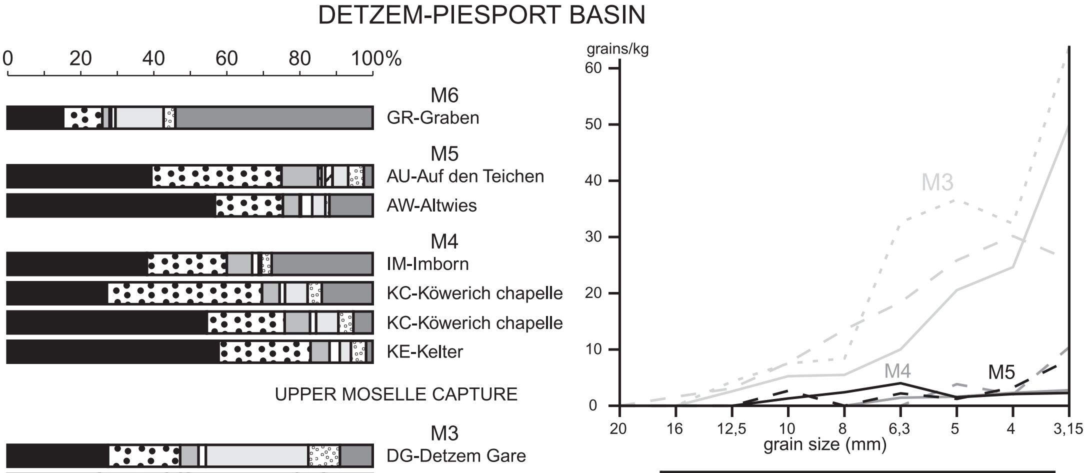
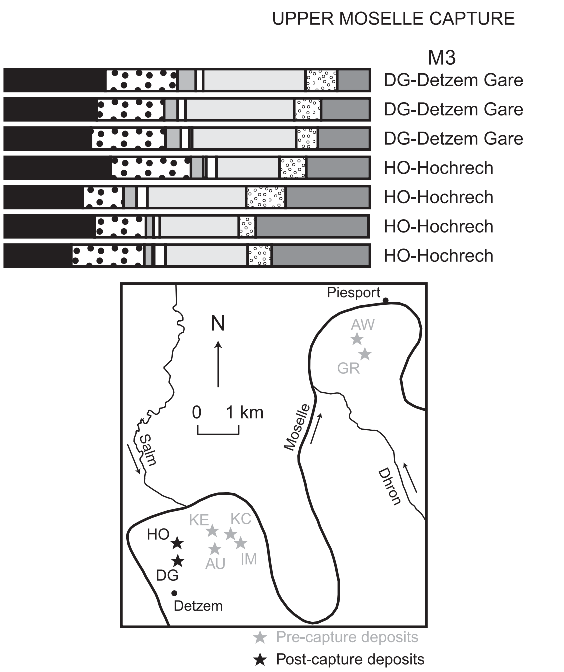


Fig. 4: **Sedimentological characteristics of the alluvial formations in the Thionville-Sierck basin. a) mineralogical and petrographical composition of the alluvial formations; b) location map of the samples; c) stratigraphical profile.**

Fig. 4 : Caractéristiques sédimentologiques des formations alluviales entre Pompey et Thionville. a) composition minéralogique et pétrographique des formations alluviales ; b) carte de localisation des sites de prélèvement ; c) profil stratigraphique.







	Whole sample (grains/kg)
DG-Detzem-Gare	12,19
HO-Hochrech	13,94
HO-Hochrech	14,69
M3 (mean value)	13,61
KE-Kelter	0,85
KC-Köwerich-Ch.	1,96
M4 (mean value)	1,40
AU-Auf-den-Teichen	1,70
AW-Altwies	1,34
M5 (mean value)	1,52

Fig. 5: **Mineralogical and petrographical composition of the alluvial formations between Sierck and Piesport.**
Fig. 5 : *Composition minéralogique et pétrographique des formations alluviales entre Sierck et Piesport.*

- the lack of crystalline sediments in the alluvial terrace M4 (fig. 4 and 5) shows that this terrace is mainly pre-capture. However, the mineralogical investigations in the Thionville-Sierck basin (samples “Hoch” and “Berg”, fig. 4) may indicate that the deposition of crystalline sediments occurred at the top of M4 immediately after the capture. This result is in excellent agreement with those from the Upper Moselle valley near Toul, which demonstrated that the capture occurred at the end of the deposition of Mt4 (Krook, 1993; Harmand et Le Roux, 2000). Terraces M4 and Mt4 can also be correlated, as they both correspond with the syn-capture terraces.

III - CHRONOSTRATIGRAPHY OF THE YOUNGER MEURTHE AND MOSELLE TERRACES

IN THE MEURTHE VALLEY

Owing to the deficiency of absolute datings, the chronology of the Meurthe terraces staircase has remained hypothetical. Only the sediments from the present floodplain Me0 (section of Art-sur-Meurthe, fig. 1) were dated using radiocarbon method on woods, sampled both in the lower coarse unit and in the upper silty unit of the formation (Carcaud, 1992). The radiocarbon age results range between 10.500 ± 150 yr B.P. and modern. The ages are in good agreement with those obtained by the same author in the Upper Moselle valley 40 km upstream from Toul (section of Crévéchamps, fig. 1), ranging from 12.640 ± 105 to 3.050 ± 150 yr B.P. They evidence that the present floodplain formed during the Late Glacial and Holocene.

To complete these first chronological results, the sediments from the terraces Me3 (20 m relative height) and Me2 (10 m relative height) in the Mondon and Vitrimont basins have been dated using IRSL method (fig. 6).

Except for the sample “Laronxe”, which provides a youngest age using the MAAD protocol, the age estimates for Me3 range between 163 ± 15 ky and 129 ± 13 ky: these datas make it possible to correlate Me3 with the last cold period of the Saalian (OIS 6). The IRSL age estimates for Me2 (and the corresponding terrace in the lower Mortagne valley, sample “Xermaménil”) range between 86.1 ± 6 and 40.6 ± 4.8 ky. It is very likely that fluvial aggradation of the Me2 sediments mainly occurred during the Early and Middle Pleniglacial (OIS 4 and 3).

The Meurthe terraces Me3 and Me2 were also formed during two successive climate cycles (fig. 6). Owing to the Late Glacial to Holocene age of the present floodplain, the youngest terrace Me1 may be correlated with the Upper Pleniglacial (OIS 2). As the luminescence age estimates are not available for the sediments of the oldest terraces, the age of Me4 remains unknown. According to its relative height (30 m) and three-dimensional extent (presence of broad surfaces associated with an alluvial formation whose thickness often exceed 6 m), as well as to the chronological framework of the younger terrace sediments, Me4 could however be assigned to OIS 8 (fig. 6).

IN THE UPPER MOSELLE VALLEY

The only independent absolute dating is available for the Upper Moselle capture. Speleothem, sampled from a gallery filled with siliceous deposits correlated with Mt4 (Shafts Cave, fig. 2b) in the surrounding of Toul, was investigated by uranium/thorium dating. These dating results yielded an age of about 250-270 ka (Losson and Quinif, 2001; Losson, 2003). In the lower Meuse valley, burned flints was sampled near Maastricht and investigated by thermoluminescence dating (Huxtable and Aitken, 1985) resulting in similar age estimates. The syn-capture alluvial terrace Mt4 also correlates to the Middle Saalian (OIS 8), as confirmed by uranium/thorium and thermoluminescence dating.

DOWNSTREAM FROM THE MEURTHE-MOSELLE CONFLUENCE

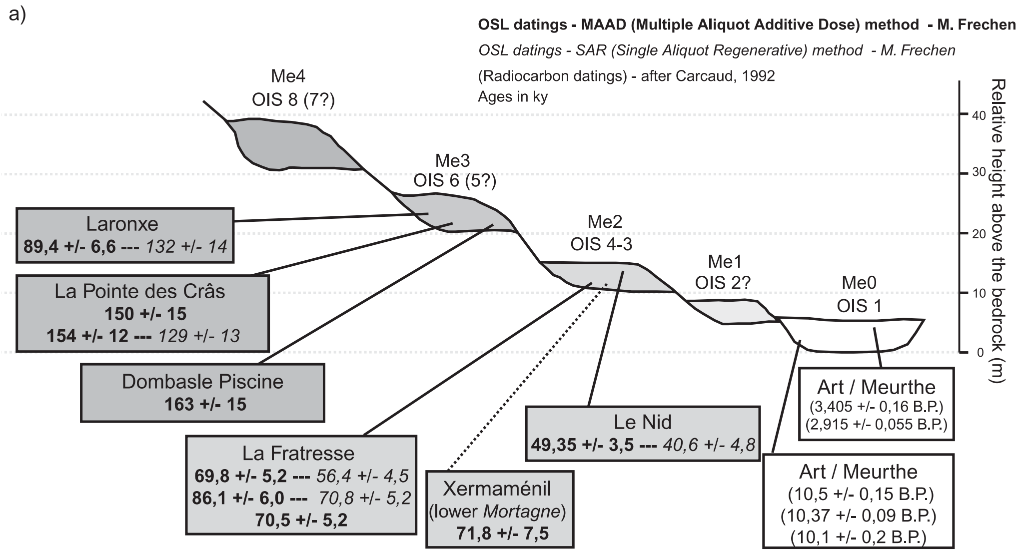
The only chronological data from this area concerned the present floodplain M0 and the lowest terrace M1:

- recent palynological studies from sediments of the present floodplain near Trier (Zolitschka and Löhr, 1999) enables a correlation with Late Glacial to Holocene age, confirming the radiocarbon ages obtained for Me0 and Mt0 by Carcaud (1992) in the French basin;
- the terrace M1 has been dated in the Luxemburger valley using radiocarbon method on a *Juniperus* charcoal sampled in the middle part of the formation. The age estimates is of 30 770 ± 300 yr B.P. (unpublished data, provided by the National Museum of History and Art of Luxemburg; laboratory number: β 182248). This result is confirmed by palaeoenvironmental evidences, as cryoturbation features (Coûteaux, 1970) and remains of *Mammuthus primigenius* and *Rhinoceros tichorhinus* in the Luxemburger valley (Ferrant, 1933b). It is in good agreement with the assumed Upper Pleniglacial age of the lowest Meurthe terrace Me1 (OIS 2).

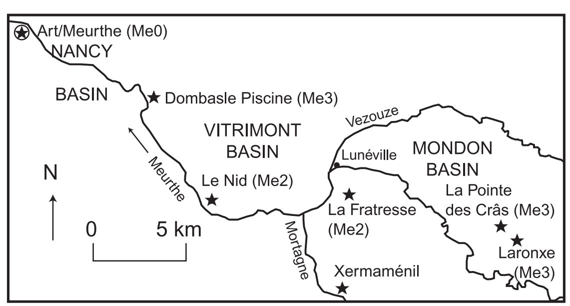
Complementary chronological data is provided by the stratigraphical position of the Upper Moselle capture in the terraces staircase. As the alluvial terrace M4 formed contemporaneously with the Upper Moselle terrace Mt4, its sediments most likely accumulated during the Middle Saalian (OIS 8).

These datas lead us to propose an extrapolation of the IRSL age estimates obtained in the Meurthe valley for the terraces Me3 and Me2 to the post-capture terraces M3 and M2; on the same way, the Me4 terrace is likely to correlate with Mt4 and M4.

a)



b)



c)

Section	Lab-ID. LUM	U [ppm]	Th [ppm]	K [%]	Cosmic [μGy/a]	Water [%]	Dose rate [Gy/ka]	Palaeodose [Gy]-MAAD	Palaeodose [Gy]-SAR	IRSL age [ka]-MAAD	IRSL age [ka]-SAR
La Fratresse	317	1.39 ± 0.06	4.94 ± 0.09	2.82 ± 0.04	140 ± 14	20 ± 5	3.58 ± 0.25	252.4 ± 4.8		70.5 ± 5.2	
La Fratresse	318	2.57 ± 0.05	9.97 ± 0.12	3.11 ± 0.06	140 ± 14	20 ± 5	4.49 ± 0.33	313.2 ± 2.8	261.8 ± 5.7	69.8 ± 5.2	56.4 ± 4.5
La Fratresse	319	1.44 ± 0.04	5.66 ± 0.08	3.64 ± 0.04	140 ± 14	20 ± 5	4.29 ± 0.30	369.0 ± 4.2	303.6 ± 8.0	86.1 ± 6.0	70.8 ± 5.2
Dombasle Piscine	320	0.76 ± 0.04	3.11 ± 1.32	1.72 ± 0.03	140 ± 14	20 ± 5	2.43 ± 0.22	395.4 ± 3.1		163 ± 15	
Xermaménil	321	1.25 ± 0.78	5.86 ± 0.09	1.68 ± 0.03	140 ± 14	20 ± 5	2.73 ± 0.28	196.3 ± 2.3		71.8 ± 7.5	
Le Nid	322	1.11 ± 0.03	5.79 ± 0.08	3.10 ± 0.03	140 ± 14	20 ± 5	3.80 ± 0.26	187.7 ± 2.5	154.2 ± 14.9	49.5 ± 3.5	40.6 ± 4.8
Laronxe	323	1.35 ± 0.07	6.26 ± 0.09	2.49 ± 0.06	140 ± 14	20 ± 5	3.42 ± 0.25	305.6 ± 3.8	449.8 ± 35.3	89.4 ± 6.6	132 ± 14
La Pointe des Crâs	324	1.06 ± 0.50	5.24 ± 0.09	2.64 ± 0.04	140 ± 14	20 ± 5	3.38 ± 0.27	520.6 ± 4.1	437.4 ± 29.4	154 ± 12	129 ± 13
La Pointe des Crâs	326	2.83 ± 0.05	12.13 ± 0.12	1.55 ± 0.04	140 ± 14	20 ± 5	3.51 ± 0.29	526.3 ± 29.2		150 ± 15	

Fig. 6: **Datings results of the youngest alluvial formations in the Meurthe valley. a) schematical cross-profile; b) location map of the IRSL and radiocarbon samples; c) synthetic table of IRSL datings.**
Fig. 6 : Résultats des datations concernant les formations alluviales les plus récentes de la vallée de la Meurthe. a) profil transversal schématique ; b) carte de localisation des sites de prélèvement ; c) tableau récapitulatif des datations IRSL.

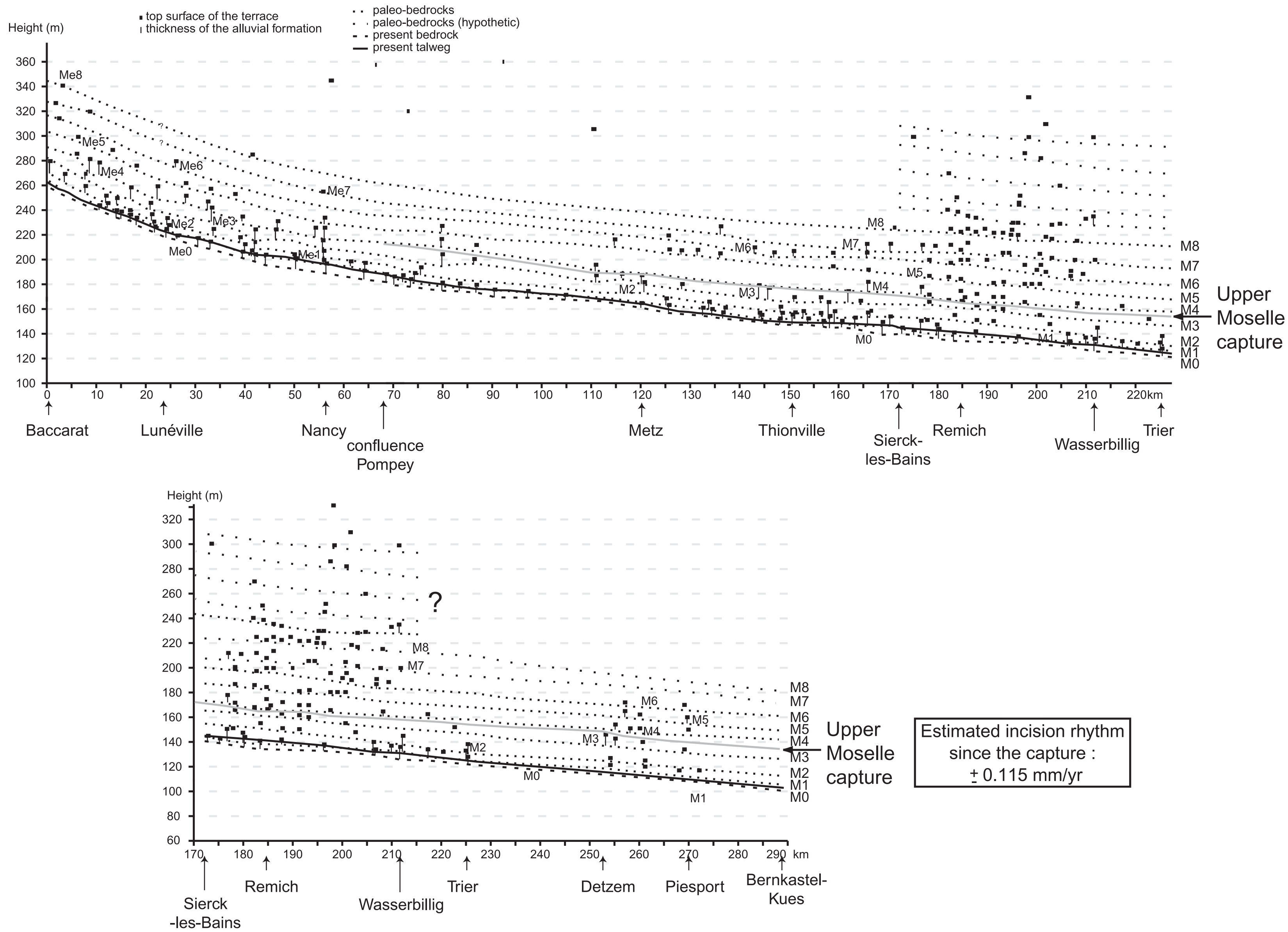


Fig. 7: **Longitudinal profile of the Palaeo-Meurthe-Moselle terraces between Baccarat and Bernkastel-Kues.**
Fig. 7 : Profil longitudinal des terrasses alluviales de la Paléo-Meurthe-Moselle entre Baccarat et Bernkastel-Kues.

THE LONGITUDINAL PROFILE

The chronological frame is in good agreement with the geometrical and sedimentological correlations. A general longitudinal profile of the Palaeo-Meurthe-Moselle middle and lower terraces between Baccarat and Bernkastel-Kues can be set up (fig. 7), based on a linear correlation ($Me_n = M_n$, with n the serial number of each terrace). It evidences the parallelism of the alluvial terraces, especially for the syn- and post-capture terraces (Me4-M4 to Me1-M1). This parallelism indicates no relative tectonic deformation along the valley between the Rhenish Massif and the Paris basin, since at least the Upper Moselle capture (Middle Saalian). The correlations with the Upper Moselle underline the weak incidence of the capture on the evolution of the Palaeo-Meurthe-Moselle valley: the altitudinal gradient between the equivalent terraces in Toul and Pompey remained constant since the diversion (about 15 m in height).

IV - THE ALLUVIAL SEQUENCES IN THE PALAEO-MEURTHE-MOSELLE VALLEY: FIRST RESULTS

The Upper Moselle basin was covered by Pleistocene glaciers (Seret, 1966; Seret *et al.*, 1990; Flageollet, 2002). Glacial forms and formations were also found on the crystalline basement of the Upper Meurthe basin (Nordon, 1928, 1931; Darmois-Théobald et Ménillet, 1973). According to the chronological results presented in this paper, the alluviation in the Palaeo-Meurthe-Moselle valley can be linked to Pleistocene climatic fluctuations. This cyclic evolution is confirmed by the study of numerous sections, which lead to define four alluvial sequences along the Palaeo-Meurthe-Moselle valley. These sequences respectively concern the formations Me4 to Me2 in the Mondon basin (downstream from the Vosges Massif); the formations Me5 to Me2 in the Vitrimont and Nancy basins of the Meurthe valley, and the pre-capture formations downstream from Pompey (M8 to M4); the post-capture formations (M3 and M2) downstream from Pompey; and the youngest formations (Me1-M1 and Me0-M0) in the whole Palaeo-Meurthe-Moselle valley.

THE FORMATIONS ME4 TO ME2 IN THE MONDON BASIN

The sequence of the Mondon basin, defined by the study of seven main sections in the alluvial formations Me4, Me3 and Me2, was described in detail by Cordier *et al.* (2004). These alluvial formations are composed of three units (fig. 8): the lower unit (whose thickness often exceeds 3-4 m) is sandy and mainly contains sediments from the Permo-Triassic sandstones and conglomerates; cryoturbation features were described in several sections (e.g. Hériménil; Cordier *et al.*, 2004, p. 74). The middle unit (1-3 m in thickness) is coarse and contains many clasts and sands that originated in the vosgian basement; it often channels the lower one (incision ranging from 1 to 3 m). The upper unit consists of silty to silty-sandy sediment, and its thickness ranges between 1 and 3 m.

Taking into account these characteristics, the lower unit is allocated to pleniglacial periods, while glaciers developed in the upper crystalline basin of the Meurthe. The presence of glaciers also appears as an important limiting factor for the supply of crystalline sediment. The middle coarse unit, with numerous crystalline elements, may be correlated with late glacial periods: a high capacity of the river, generated by the melting of the ice, can actually generate both the channelling of the lower sediments and the carriage of crystalline sediments. This interpretation is not contradicted by the radiocarbon age estimates obtained for the coarse unit of Me0, allocated to the Late Glacial or Early Holocene period (fig. 6; Carcaud, 1992). It however remains hypothetical, as the aggradation of middle unit might also occur under periglacial conditions (high seasonal contrasts in the flow regime, while the upper Meurthe basin is not covered by ice). The sedimentation of the upper unit and the main incision phasis may finally be correlated with interglacial conditions and with the warm-to-cold transition, respectively, despite neither pedological nor palaeontological evidence confirms it. This reconstruction (aggradation under periglacial context, main incision at the end of interglacial periods) is however in good agreement with those recently described in the Somme and Meuse valleys (Antoine, 1994; Vandenberghe *et al.*, 1994).

THE VITRIMONT AND NANCY BASIN AND THE PRE-CAPTURE TERRACES DOWNSTREAM FROM POMPEY

The definition of this second sequence is mainly based on the study of several hundreds drillings, especially in the Nancy and Thionville-Sierck basins (fig. 4b). Although their thickness is highly variable, owing to the weathering of the sediments, the formation are often composed of three units (fig. 4b): a lower coarse unit, where cold fauna remains (as *Mammuthus primigenius*) have been found (e.g. in Me3 in Nancy; Corroy and Minoux, 1931); a middle sandy unit, and an upper silty unit. The difference with the latter sequence is attributed to the influence of the periglacial tributaries which join the River Meurthe in Lunéville (the Mortagne and Vezouze rivers, fig. 1). As evidenced by an IRSL dating of sediments from the Lower Mortagne valley (sample "Xermaménil", fig. 6), these rivers carry their coarser sediments during cold periods as elsewhere (Mol *et al.*, 2000). This observation and the IRSL age estimates obtained in the Vitrimont basin, enable to propose a correlation of the coarse unit with both pleniglacial periods (owing to the influence of the tributaries) and with the beginning of late glacial periods (owing to the melting of the ice in the Upper Meurthe basin). The correlation of the sandy and silty

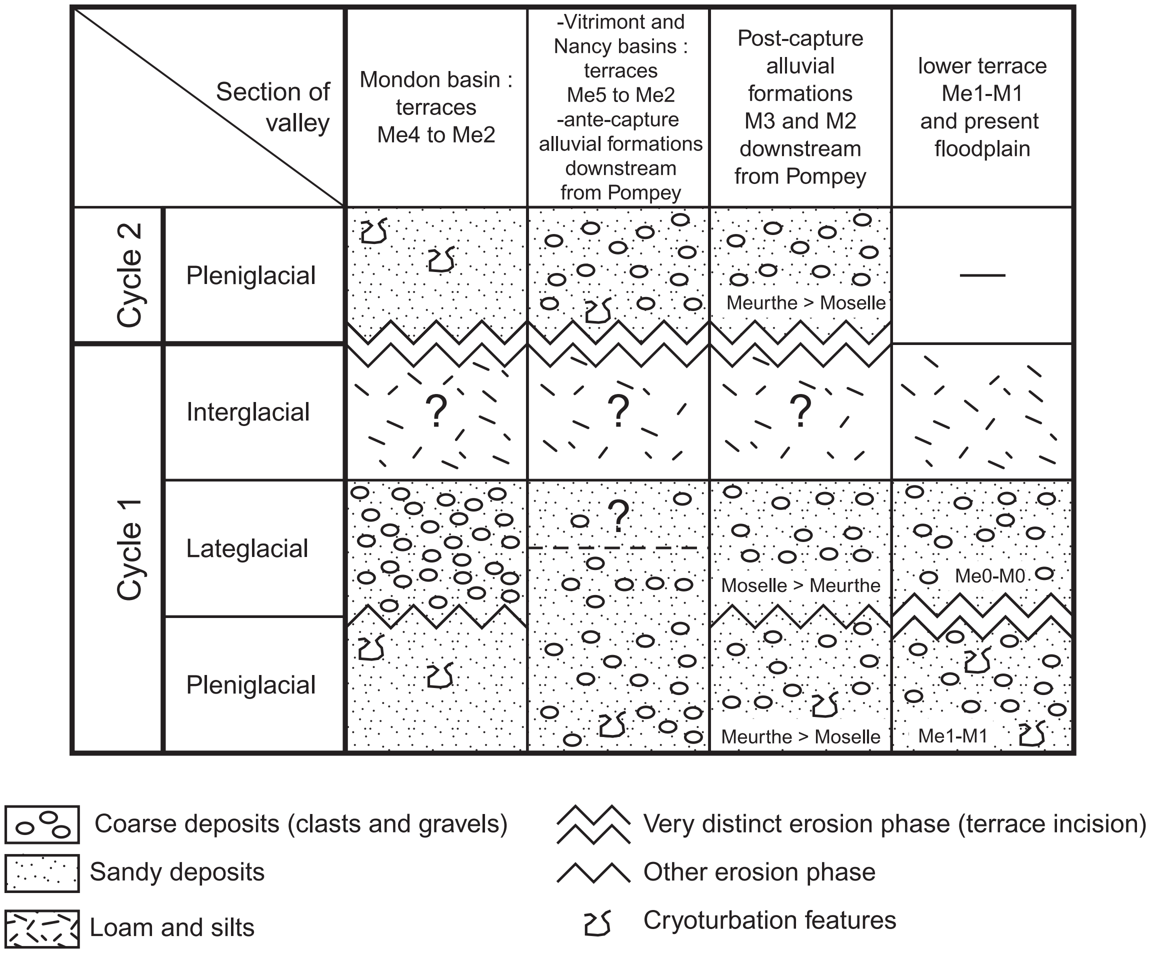


Fig. 8: **Synthetic presentation of the climato-sedimentary cycle proposed for the Palaeo-Meurthe-Moselle valley.**
Fig. 8: *Présentation synthétique du cycle climato-sédimentaire proposé pour les formations alluviales de la Paléo-Meurthe-Moselle.*

unit with warmer periods of the climate cycle is however only hypothetical, owing to the lack of palaeoenvironmental evidence.

THE POST-CAPTURE FORMATIONS M3 AND M2

Downstream from Pompey, the post-capture fluvial dynamics is influenced by the Meurthe, the Meurthe and Moselle periglacial tributaries, and the Upper Moselle. The latter basin was more covered by the Vosgian glaciers during Pleistocene cold periods than the Meurthe basin. The study of several sections and numerous drillings in the formations M3 and M2 and the sedimentological analysis in the Thionville-Sierck basin (fig. 4) allow to distinguish three main stages in the terrace formation:

- a first sedimentation period with sediments (up to 5 m thick) predominantly originating in the Permo-Triassic sandstones and conglomerates (e.g. samples “Haute-Yutz”, “Wacken” and “Berg sud”, fig. 4a),
- the second aggradation period characterizes by a similar thickness and a more pronounced influence of the Upper Moselle, as evidenced by the presence of sands and clasts coming from the Vosgian basement (e.g. sample “Yutz ouest”, fig. 4a). As these sediments are sometimes located close to the bedrock (e.g. samples “Métrich” and “Yutz est”, fig. 4a), a minor incision (about 3-5 m) probably occurred before this aggradation period. Taking into account these characteristics, the deposition phases can be allocated to pleniglacial and late glacial periods, respectively. This reconstruction is confirmed by the presence of cold faunal remains (as *Mammuthus primigenius* in the M3 formation near Metz; Delafosse, 1935 and 1965) The erosive phase may also correlate with early late glacial periods.
- the coarse and sandy deposits are covered by silts, whose aggradation may have occurred during interglacial periods. The main incision phasis for M3 and M2 (incision of up to 15 m in the sediments and the bedrock) can also be linked to early pleniglacial periods.

THE YOUNGEST FORMATIONS ME1-M1 AND ME0-M0

The genesis of the youngest formations (Me1-M1 and Me0-M0) differs slightly from the previous sequences: the morphological distinction between the Weichselian Upper Pleniglacial sediments (corresponding with the lower terrace M1) and the Late

Glacial sediments (corresponding with the present floodplain M0) actually evidences a more important erosive activity at the Early Late Glacial period than during the previous early late glacial episods. This first reconstruction will be improved by ongoing study of new sections.

These four alluvial sequences must still be improved, by the evidencing of palaeoenvironmental indications in new sections. Nevertheless, their comparison shows a relatively constant evolution between Baccarat and Bernkastel-Kues, characterized by two main periods of sedimentation (allocated to pleniglacial and late glacial periods), separated by a minor erosive phase. Except for the youngest formations, the major period of incision occurred at the cold-to-warm transitions; these results are similar to those recently described for the Lower Meuse valley (Vandenberghe *et al.*, 1994), and in others main valleys of the Paris basin, as the Somme (Antoine, 1994) or the Yonne (Chaussé, 2003; Chaussé *et al.*, 2004).

CONCLUSION

Along the Palaeo-Meurthe-Moselle valley, the middle and lower terrace system (less than 90 m relative height) was defined through the Paris basin and the Rhenish Massif; it corresponds with eight alluvial terraces, the three younger being deposited after the Upper-Moselle capture. A the longitudinal profile was realized, based on morphological studies (relative height of the terraces), sedimentological analyses (evidencing a main contrast between the pre- and post-capture formations downstream from the Meurthe-Moselle confluence), and absolute datings. This longitudinal profile provided evidence that there was no relative deformation along the valley since at least the Upper Moselle capture (250-270 ka). These first results must however be completed, mainly in the lower valley (between Bernkastel-Kues and Koblenz); furthermore, the longitudinal profile and the age of the higher terraces (especially the main terraces in the Rhenish Massif) remains unknown, owing to the lack of reliable dating results.

On the other hand, the study of numerous sections in France, Germany and Luxemburg allowed to propose an evolution pattern for the valley (“alluvial sequence”); this first pattern will however be improved by new sedimentological and chronological research, especially for the interglacial periods and for the post-Saalian deposits.

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