FLAG Biennial Meeting 2012

Remich, Luxembourg
September 2-7, 2012

New insight on the Quaternary evolution of the Moselle River and its tributaries (Luxembourg, France, Germany)

FIELD EXCURSION GUIDE

FLAG Biennial Meeting 2012

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Quaternary fluvial evolution in the Moselle catchment

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General presentation of the Moselle catchment

The Moselle River (in German Mosel) is the main tributary of the Rhine, with a length of ca 550 km (figure 0.1). Its catchment is developed on three major structural regions: two ancient mountains of Hercynian orogeny (the Vosges and the Rhenish massifs, culminating at 1424 and 816 m a.s.l., respectively) and a sedimentary basin, the Paris basin (figure 0.2). The Moselle and its main tributaries the Meurthe and the Sarre (Saar) rise within the Vosges Massif (NE France). Due to its southern location, the upper catchment of the Moselle is mainly developed on the crystalline basement (granite, gneiss). In contrast, the Sarre catchment is almost entirely developed in the Permo-Triassic cover of sandstones and conglomerates. Located between the Upper Moselle and the Sarre, the Meurthe catchment is predominantly composed of Permo-Triassic rocks (75% of the Vosgian catchment), the basement representing 25% of the catchment area. Another main difference between the three rivers relates to the extension of Pleistocene glaciers : the Vosges massif shows traces of several Pleistocene glaciations, especially in the Upper Moselle Basin where evidences for well developed ice-caps and glaciated valleys have been recognized (Seret, 1966; Flageollet, 2002). In contrast, only cirque glaciers seem to have been formed in the upper Sarre catchment, at least for the last glaciations (Saalian and Weichselian). In the Meurthe Basin, glaciers mainly covered the crystalline basement outcrops in the upper valley (Nordon, 1928, 1931; Darmois-Theobald and Menillet, 1973; Flageollet, 2002).

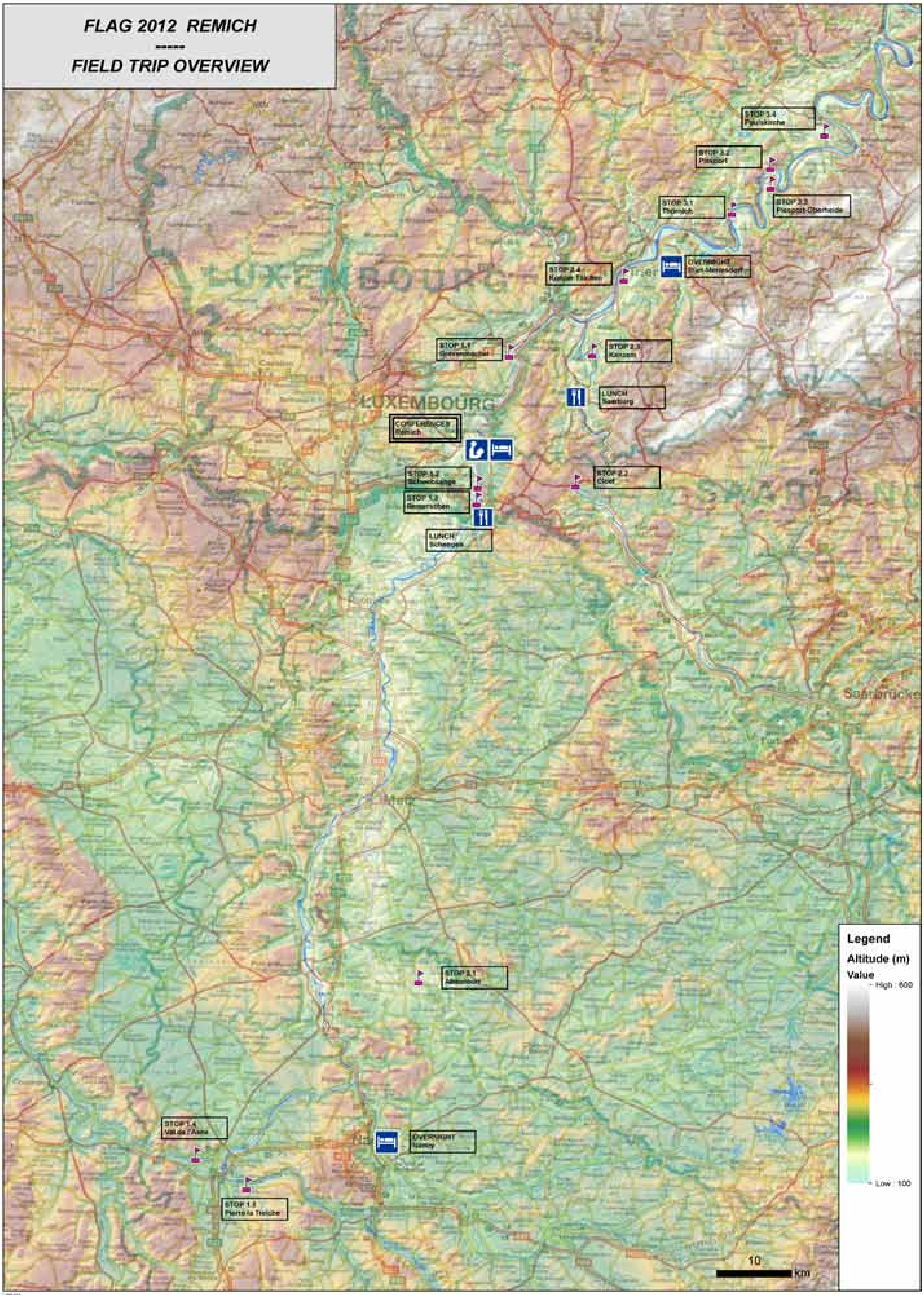
Downstream from the Vosges Massif, the Moselle and its main tributaries flow subsequently through the cuesta ridges of the Eastern Paris Basin. The Meurthe and Sarre join the Moselle North of Nancy and a few kilometres upstream from Trier, respectively. Other minor tributaries such as the Orne, the Seille (see day 2, stop 1) and the Sûre (Sauer) join the Moselle in the same area. Until the Middle Pleistocene, the Upper Moselle flowed west of Toul towards the Meuse ("Upper-Moselle-Meuse"), while the "Palaeo-Meurthe" flowed North of Nancy towards the Rhine (following the present Moselle course). Despite the mechanisms of the Upper-Moselle capture are well known (Harmand and Cordier, 2012; see also day 1, stops 4 and 5), the age remains unsure. It is however likely that the capture event took place between 250 and 450 ka ago.

The lower course of the Moselle (as well as that of the Sarre) is developed into the Rhenish Massif, a high schist plateau. The Moselle valley separates the Eifel and the Hunsrück until its confluence with the Rhine at Koblenz. The Moselle and Sarre valleys are characterized by the presence of well developed meanders.

The three morphostructural areas are characterized by uplift during the Pleistocene. Due to the lack of chronological constraints, the variation in uplift rates

through the Cenozoic (and especially during the Plio-Pleistocene) remains a matter of debate (Cordier et al., 2006b; Gibbard and Lewin, 2009). However, there is no doubt that this uplift allowed the formation of terraces staircases that are particularly well preserved in the Paris basin and in the Rhenish Massif. The terraces have been extensively studied for more than one century, especially along the Moselle valley (Davis, 1895; de Lamothe, 1901; Dietrich,1910; Borgstätte, 1914; Wandhoff, 1914; Ferrant,1933a et b; Théobald et Gardet, 1935; Kremer,1954; de Ridder,1957; Liedtke,1963; Müller,1976; Osmani,1976; Negendank,1978,1983). However, the presence of three main structural regions and the partition of the area between France, Luxembourg and Germany, prevented general studies. Furthermore, research in the French valley mainly underline the climate impact in the formation of fluvial terraces (Tricart, 1952), while authors from Luxemburg and Germany focused on the neotectonics influence (de Ridder, 1957; Hoffmann, 1996).
During the last decade, multi-proxy research has been carried out, including extensive mapping of the terrace, sedimentological analyses, and numerical dating using Optically Stimulated Luminescence (OSL) and Electron Spin Resonance (ESR). This has enabled a more complex terrace staircase to be identified through the Paris basin and the Rhenish Massif both in the Meurthe-Moselle valleys (Cordier et al., 2005) and in the Sarre valley (Harmand, 2007; Cordier et al., 2012). Collectively, this research has made it possible to highlight the influence of Pleistocene climate change on terrace formation (Cordier et al., 2006a), by allocating the terraces to distinct climate cycles. The climate was superimposed onto a general trend to tectonic uplift during the Pleistocene, leading to the formation of the terrace staircase (Cordier et al., 2006b).
The FLAG 2012 field excursion will allow us to travel through the Moselle catchment, and especially in the Middle and Upper Moselle valley (Day 1), the Seille and Sarre valleys (day 2), and the Lower Moselle valley in the Rhenish Massif (Day 3). The stops will provide insights into the Pleistocene evolution of the valley, especially focusing on the fluvial response to climate and tectonic forcing. Some stops will be devoted to the Upper Moselle capture and its relation with the development of karstic caves, to the slope evolution, and to the geoarchaeological research that are being conducted in the area for about two decades.

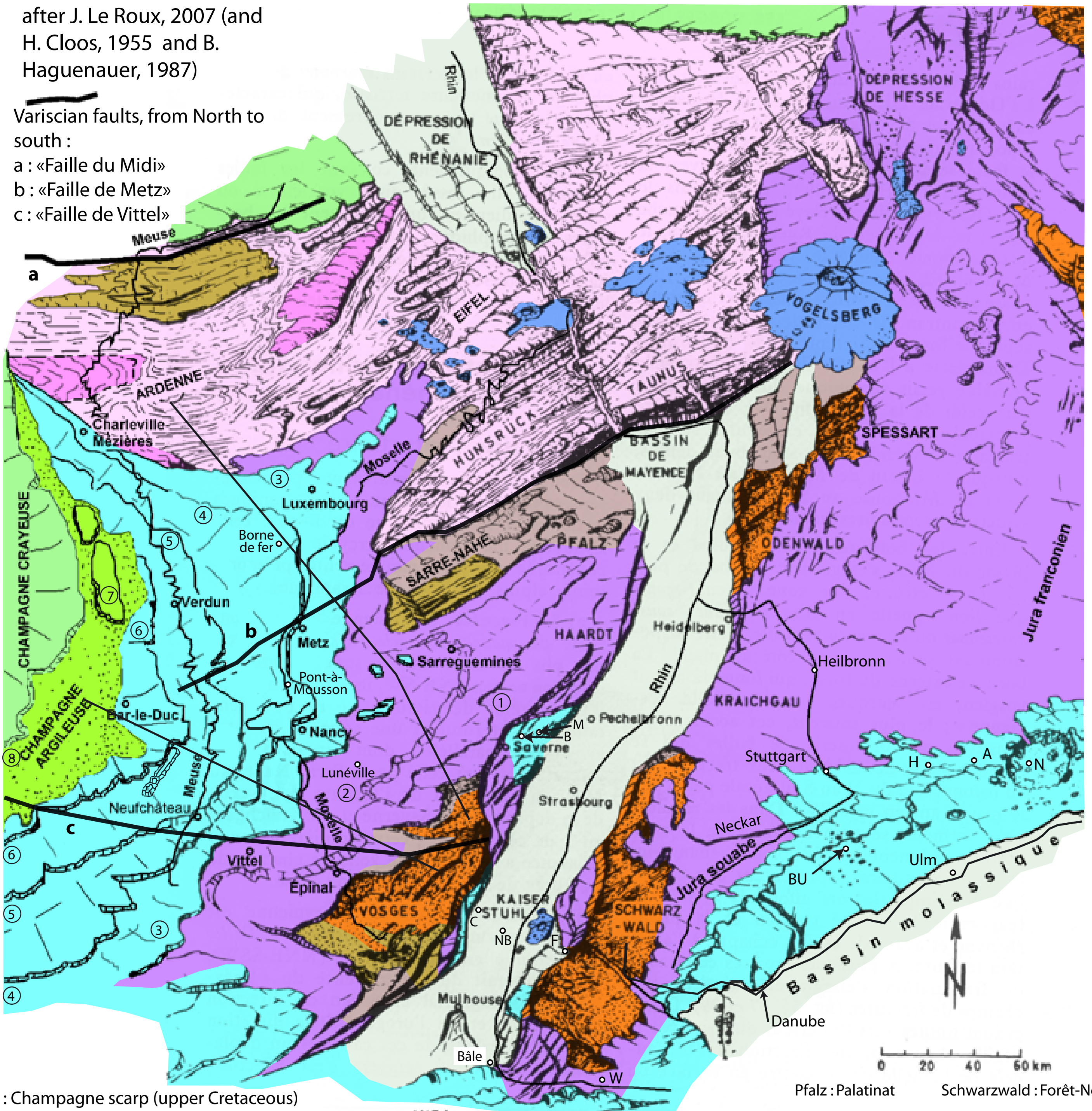
General map of the Moselle catchment with location of the excursion stops



Geological map of the area

after J. Le Roux, 2007 (and H. Cloos, 1955 and B. Haguenauer, 1987)

Variscian faults, from North to south :
a : «Faille du Midi»
b : «Faille de Metz»
c : «Faille de Vittel»



8 : Champagne scarp (upper Cretaceous)
7 : Argonne scarp (lower Cretaceous)
6 : Barrois scarp (Tithonian, upper Jurassic)
5 : Meuse scarp (Oxfordian)
4 : Moselle scarp (Dogger)

JURA

3 : Hettangian-Sinemurian scarp
2 : Muschelkalk scarp (middle to upper Triassic)
1 : Buntsandstein scarp (lower to middle Triassic)

Pfalz : Palatinat
Schwarzwald : Forêt-Noire

A : Aalen
B : Bouxwiller
BU : Bad Urach
C : Colmar
F : Freiburg
H : Holzmaden
M : Morsbronn-l-B.
N : Nördlingen
NB : Neuf-Brisach
W : Waldshut

Tertiary and Quaternary
Lower Cretaceous
Permian
Cenozoic volcanism
Jurassic
Carboniferous
Lower Paleozoic
upper Cretaceous
Triassic
Devonian
Variscian basement (granitic and metamorphic rocks)

Geomorphological map of the Eastern Paris Basin and its borders

Introducing paper : "The Pleistocene terrace staircases of the present and past rivers downstream from the Vosges Massif (Meuse and Moselle catchments)" by Dominique Harmand and Stéphane Cordier.

The following paper is a part of the recent special issue published in the Netherlands Journal of Geosciences (91-1, 2012) dedicated to Jef Vandenberghe. It provides a detailed and updated overview about the Pleistocene fluvial evolution in the Moselle and French Meuse catchments. In particular, it underlines the important work that has been performed especially during the last decade (mapping of the terraces, reconstruction of the capture events that took place in the area, first geochronological framework).

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The Pleistocene terrace staircases of the present and past rivers downstream from the Vosges Massif (Meuse and Moselle catchments)

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Abstract

This paper aims to provide a synthesis and update concerning the fluvial terraces of the rivers flowing from the Vosges Massif (Moselle and palaeo Upper-Moselle-Meuse, Meurthe, Sarre). The terraces of these rivers are especially well-developed in the marly depressions of the Eastern Paris Basin, justifying an extensive field mapping expedition. The main rivers exhibit terrace staircases with 8 to 13 stepped terrace steps within 100m of the present valley floor. The fluvial sediments mainly originate from the Vosges Massif (crystalline basement and Permo-Triassic sandstones and conglomerates). Another peculiarity of the study area is the presence of several palaeovalleys, typically related to fluvial capture events which occurred to the detriment of the River Meuse. Many palaeomeanders have also been recognised in the Paris Basin (Meuse catchment), and the Rhenish Massif (Moselle and Sarre valleys). Despite some similarities, palaeoenvironmental reconstructions provide evidence for the terrace staircases being distinct from one valley / section of valley to another. These differences are related to the morphostructural framework and to the climate forcing (presence/absence of glaciers in the upper catchment of the rivers). The chronological framework suggests that the terrace sequences and the main capture events may be older than previously thought.

Keywords: fluvial captures, fluvial terraces, Moselle, Meuse, palaeovalleys, Pleistocene

Introduction

The study of fluvial archives (sediments and landforms) was one of Jef Vandenberghe's main research topic, as shown by his involvement in the Fluvial Archives Group (FLAG) activities. Fluvial systems are largely dependent on internal (tectonic) and external (climatic and anthropogenic) driving mechanisms and are thus excellent indicators of palaeoenvironmental changes (Bridgland, 2000). The fluvial response to tectonic is shown by the location of the sediments, forming thick accumulations in subsiding areas (e.g. the Upper Rhine Graben and Lower Rhine; Busschers et al., 2007; Lauer et al., 2010) and terrace staircases in uplifted areas. The climatic control is both direct (variations in precipitations and evaporation) or indirect (influence on the sea-level, the glaciers or the vegetation). Furthermore, the fluvial response to such environmental changes depends on geomorphic thresholds (Schumm, 1979) which can vary from one river/section of river to another one.

The question of forcing has remained a main point of debate over the past decades in the Meuse and Moselle systems: as their catchment is developed through five countries (France, Luxembourg, Belgium, Germany, the Netherlands), the first reconstructions focused either on one part or the other of a valley. Furthermore, French research mainly focus on the correlation between the fluvial terraces and the glaciers in the Vosges Massif (Flageollet, 1988, 2002; Harmand and Durand, 2010), while Germans and Belgians focus on the influence of uplift in the Rhenish Massif (Negendank, 1983; Van Balen et al., 2000). To allow a better understanding of the driving mechanisms and reconstruct their Pleistocene evolution, the main valleys draining the northwestern part of the Vosges Massif (Moselle and Meuse catchments, Fig. 1) have been extensively studied during the last decade, as part of the IGCP 449 programme (Bridgland et al., 2009).

Complex terrace staircases have been recognised in the valleys of the Upper-Moselle (Losson, 2003; this study), the Meurthe, the Middle and Lower Moselle (Cordier, 2004, Cordier et al., 2005, 2006a, b, 2009), and the Sarre (Harmand, 2007). River terraces are well preserved in the Eastern Paris Basin, especially in the marly depressions developed in Triassic rocks and located in the vicinity of the Vosges Massif. Fluvial archives have also been widely recognised in the Rhenish Massif (Ardenne, Eifel, Hunsrück). Well preserved palaeovalleys and palaeomeanders occur in the Paris Basin (palaeovalley of the Upper Moselle in the Toul area), in the southern margins of the Rhenish Massif in the Meuse and Sarre valleys (Charleville and Saarburg-Konz areas, respectively), and in the Rhenish Massif (Moselle valley between Trier and Bernkastel). Research provided the first correlations with the fluvial systems located further downstream (Lower Meuse and Rhine; Pissart et al., 1997, Cordier et al., 2009). It also allowed a better understanding of the fluvial response to autogenic and allogenic forcings. Terrace formation is actually assumed to be the result of climate change superimposed onto a general trend to tectonic uplift. Research

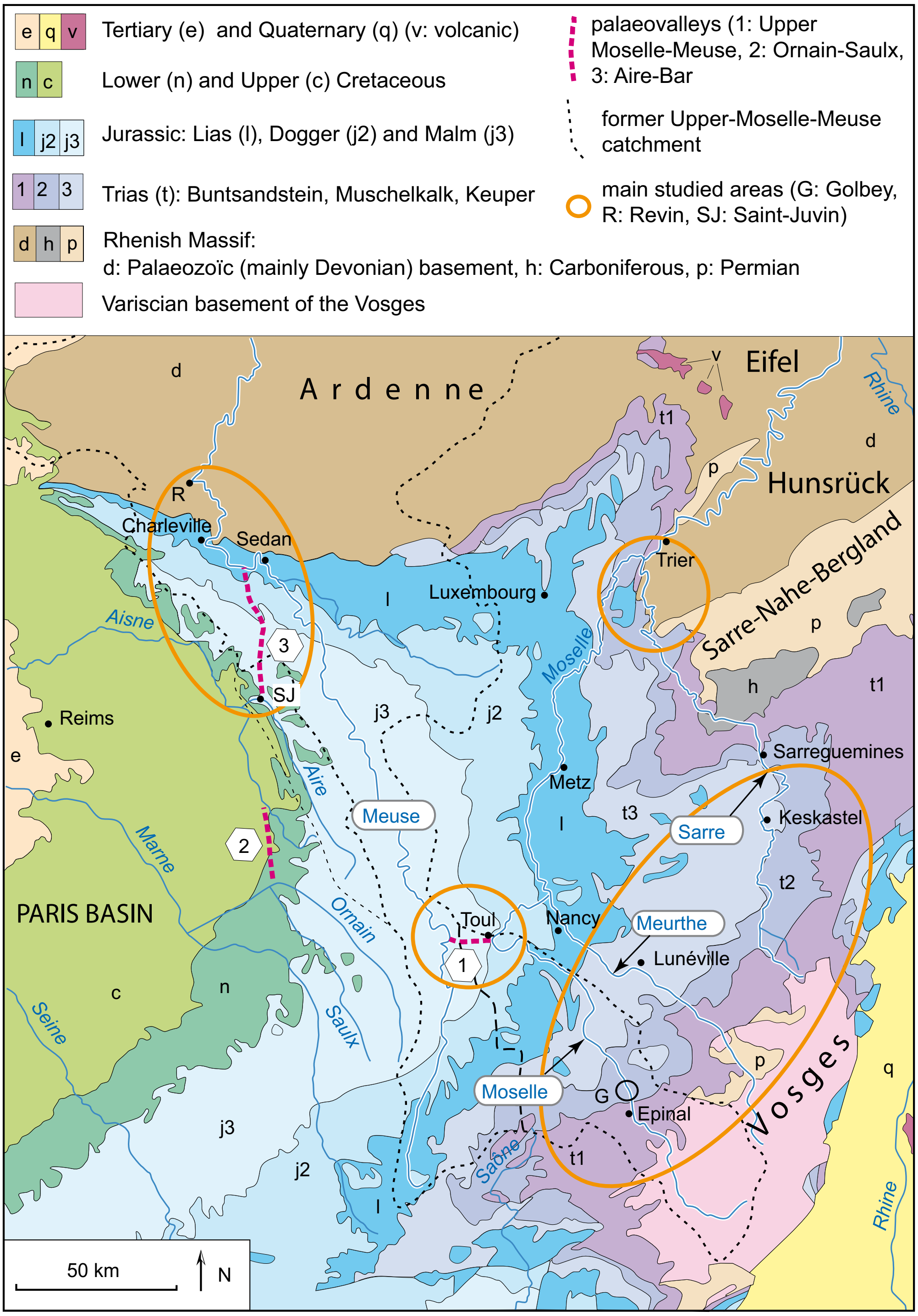

Fig. 1. General map of the study area, highlighting the geological context and the location of the main valleys and capture events.

also focused on several capture events that took place during the Middle Pleistocene in the study area. The main one concerned the Upper-Moselle, which before its capture by a tributary of the Rhine was an upstream continuation of the Meuse (Harmand et al., 1995; Harmand and Le Roux, 2000). The study of captures is of great importance not only in terms of chronostratigraphy (recognition and correlation of the pre- and post-capture terraces) but also because changes in the catchment area have had significant influence on fluvial evolution (increase or decrease of water input).

The present paper provides a synthesis of this research. It includes results of recent field work and numerical dating in the Upper Moselle valley and in the Meuse catchment. Two main topics will be discussed: 1) the recognition of a regional terrace system (e.g. from the Meuse to the Sarre, Fig. 1), and 2) the question of the linearity of fluvial response to climate change through space and time. These topics will be discussed by providing correlation between the fluvial terraces of the valleys under study, using numerical dating but also lithological changes in sediment composition related to the main captures, and by the analysis of some key-sections. After a presentation of the study area and methods, the terrace staircases and sediment characteristics will be described. Hereafter the main results concerning the fluvial captures and changes in drainage courses will be presented. Finally, the correlations between fluvial terraces and the role and inprint of climate change will be discussed.

The authors are indebted to the research conducted by Jef Vandenberghe during recent decades. Research focusing on the Maas terraces (e.g. the Maastricht-Belvédère terrace; Vandenberghe et al., 1985,1995) contributed to provide the first absolute chronology for the fluvial evolution in the study area (Moselle and Meuse catchments). Research dealing with the periglacial features (e.g. Vandenberghe, 1983, 1992) provided a robust background for the palaeoenvironmental reconstructions in the study area. Finally the contribution of Jef Vandenberghe to improve understanding of the fluvial response to climate forcing (Vandenberghe, 2003, 2008; Vandenberghe et al., 2010) provided valuable guidance in the unraveling of the fluvial evolution in the Moselle and Meuse catchments.

Study area and methods

The Meuse, Moselle, Meurthe and Sarre rivers flow in south-north to SSE-NNW direction (Fig. 1). They drain, successively, the Vosges Massif (excluding the Meuse since the Upper Moselle capture), the Eastern Paris Basin and the Rhenish Massif (excepting the Meurthe which joins the Moselle to the north of Nancy). The Vosges and Rhenish massifs are blocks of Variscan basement that have been uplifted since the Tertiary. This slow but general uplift explains the presence of terraces staircase in the whole study area. The massifs are major sources for fluvial sediments, which are mainly siliceous. In the Vosges Massif, sediment supply was enhanced during the Pleistocene by the presence of glaciers during the cold periods. The glaciers covered large parts of the upper catchment of the Moselle, and, to a lesser extent, that of the Meurthe River. Sediments have been deposited in fluvial basins downstream from the Vosges Massif (Figs 2, 3 and 4). Even if they may relate to structural conditions, these basins are typically allocated to the presence of less resistant rocks. The widest basins (25 to 30 km long in the Upper Moselle and Meurthe valleys, Fig. 2) are preserved in the vicinity of the Vosges massif, and correspond with outcrops of Muschelkalk (Upper Anisian) and Keuper (Upper Ladinian, Carnian and Norian) marls (Durand, 2010). Further downstream, the fluvial basins are smaller due to the predominance of Jurassic limestones. The main ones can be found in the Moselle valley in the vicinity of Toul or downstream from Metz, and in the middle Sarre valley (Sarre-Nahe basin in the Permian and Triassic soft sandstones and clays; Harmand, 2007). The alternation of resistant and less-resistant rocks is also very important to explain the location and preservation of the fluvial terraces in the Paris Basin. It is less significant in the Rhenish Massif due to the homogeneity of the rocks (predominance of schists and quartzites in the Eifel and Hunsrück, associated with limestones in the Ardenne) and to the importance of the local sediment supply.

Research on the fluvial terraces first includes a high resolution morphological mapping of the terraces (scale 1 : 25 000), on the basis of intensive field work coupled with the analysis of previous boreholes. The boreholes provided useful information on the thickness of the fluvial terraces and the height of the bedrock. Due to the predominance of erosion against aggradation in the study area, such a detailed work was fundamental to enable longitudinal correlations (Meikle et al., 2010). This work was complemented by sedimentological, stratigraphical, grain-size, mineralogical and petrographical analyses of sediments exposed in sand- and gravel pits. The sedimentological analysis was important to identify major changes in sediment composition and therefore possible fluvial capture events. Special attention was also given to the construction of a numerical chronological framework using Optically Stimulated Luminescence (OSL) method on quartz and feldspars (IRSL), and the Electron Spin Resonance (ESR) method.

The fluvial valleys of the Meuse, Moselle, Meurthe and Sarre rivers

Terrace staircases

Mapping of the terraces focused primarily on the main fluvial basins preserved downstream from the Vosges Massif. It was conducted in several phases and included the Upper Moselle (Fig. 2, this study), the Sarre (Fig. 3, Harmand, 2007), and the Meurthe with its main tributaries the Mortagne and the

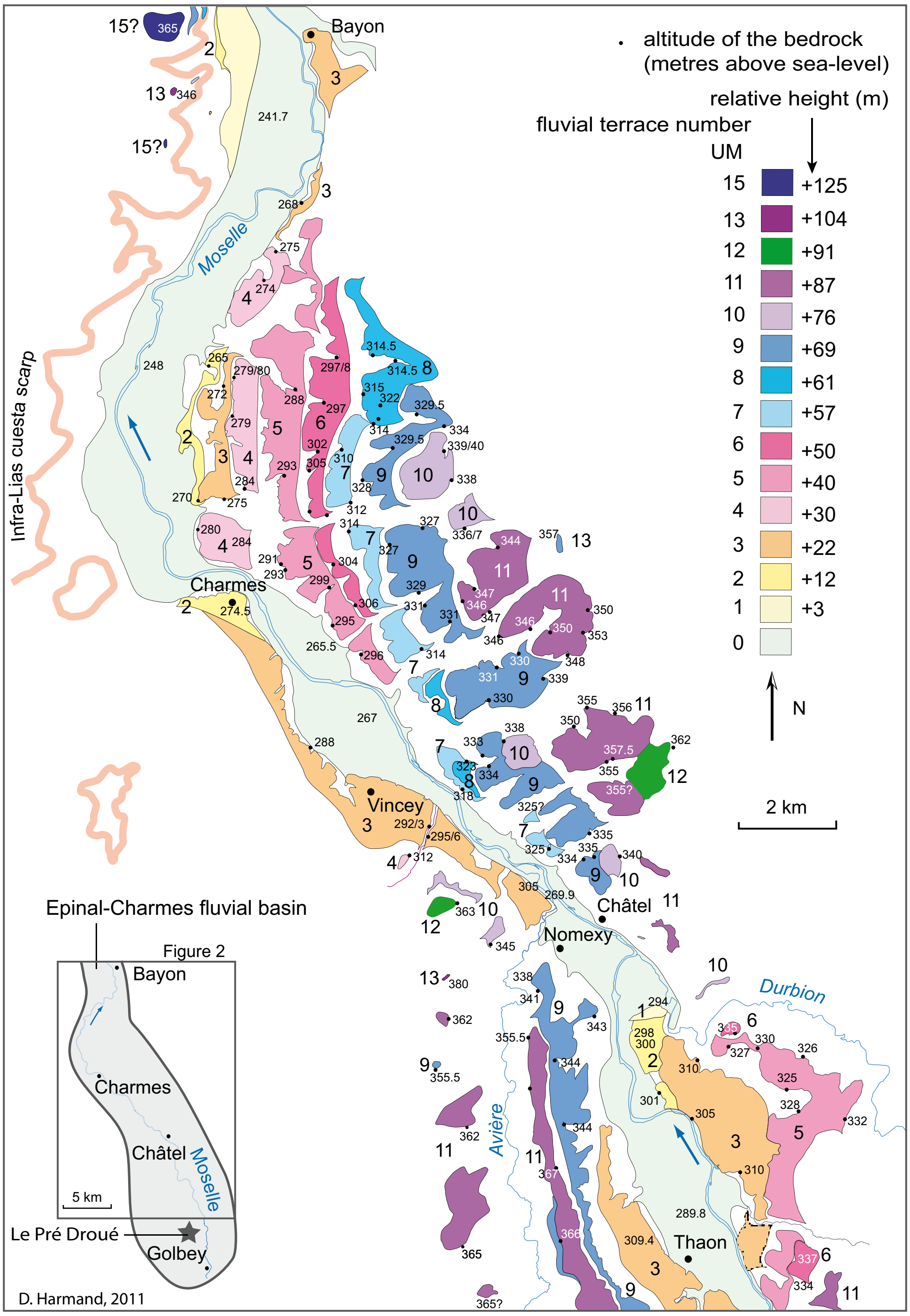

Fig. 2. The fluvial terraces of the Upper Moselle between Epinal and Bayon.

Vezouze (Fig. 4; Cordier, 2004; Ménillet et al., 2005). The number of well-preserved terraces in the whole study area strongly depends on the lithology of the bedrock, as the most preserved landscape associated with thick fluvial sediments are to be found on less resistant rocks such as clays or marls. However, the terrace staircase may vary from one valley to another, in relation with the morphostructural framework.

The most preserved terrace staircase has been recognised in the Upper Moselle valley downstream from the Vosges Massif: Between Epinal and Charmes, the terraces are preserved on a 30 km long and up to 7 km wide area. South of the Châtel dome, the fluvial terrace are developed on the faulted Muschelkalk and Lettenkohle limestones and dolomites. The oldest terraces (UM 9 and UM 11) are assumed to be proglacial fans (Minoux, 1978; Flageollet, 1998; Vincent et al., 1989). The well-preserved terrace UM 3 (10 km long) also corresponds to a younger proglacial fan (Taous 1994). Field work conducted in 2011 north of Châtel showed thirteen terraces, mainly preserved on the eastern part of the present Moselle (Fig. 2). The morphology of the terrace is well preserved and the thickness of the sediments commonly reaches several metres. This terrace staircase clearly suggests that the Moselle moved westwards as the river was

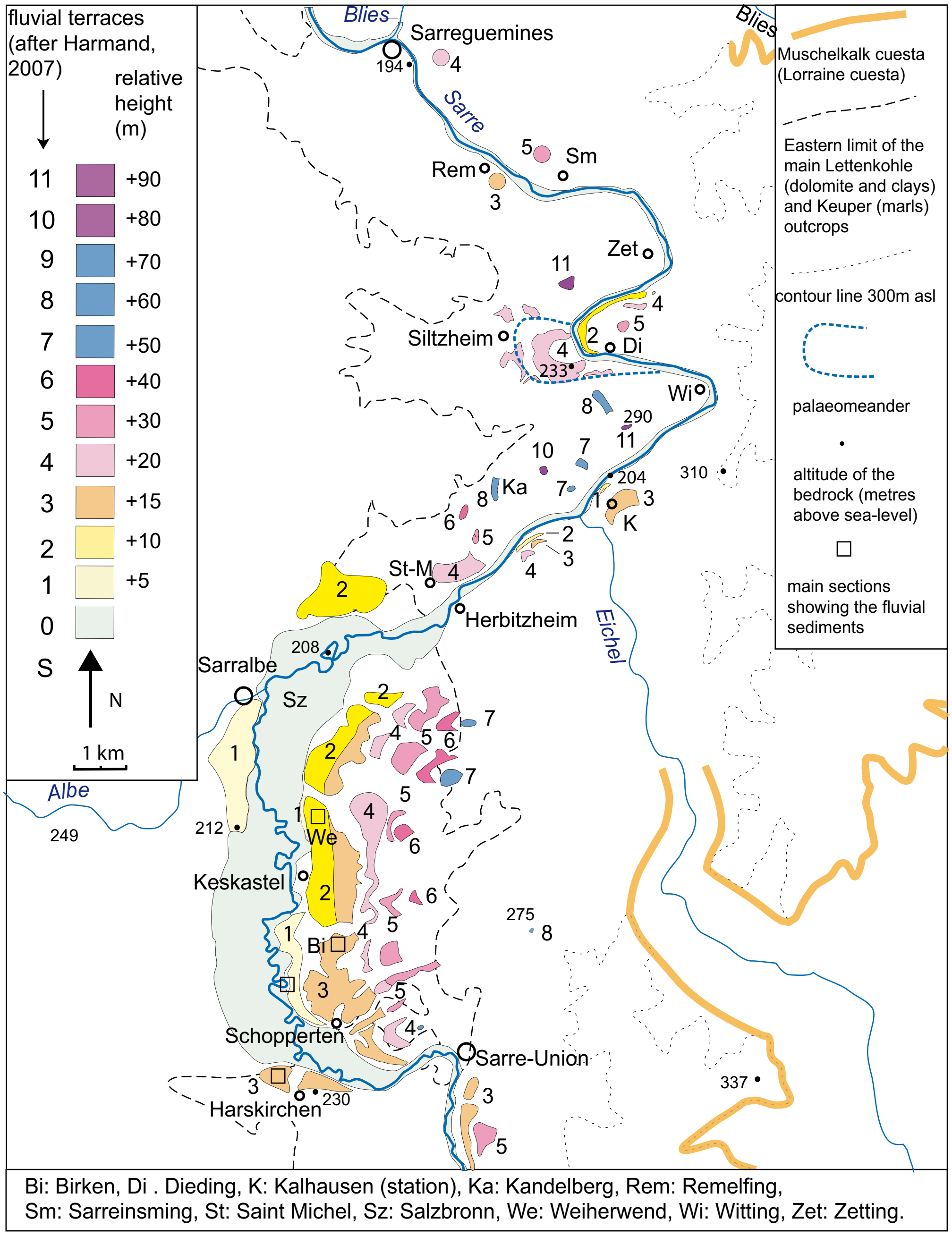

Fig. 3. The fluvial terraces of the Upper Sarre.

forming its valley. Downstream from Charmes, the fluvial sediments are less well-preserved on the Jurassic limestones. Some relict terraces have been found in the Moselle valley up to +120 to +140 m near Bayon, on the lower Liassic limestones, and even at +200 m on the top of the Dogger cuesta (Allouc, 1977; Harmand, 2004; Figs 1, 2). Similarly, in the Meuse valley, relict fluvial deposits of the Upper-Moselle-Meuse have been observed at +180 m above the present valley floor on the Oxfordian limestones (Harmand, 1989).

In the Palaeo-Meurthe valley (Moselle valley north of the present Moselle-Meurthe confluence), as in the Meurthe and Sarre valleys, only the lowest terraces are more or less preserved in the depressions formed in the Liassic marls (Cordier, 2004; Le Roux, 1999, 2000; Fig. 4). Older and higher terraces have been weathered and only show relict deposits, for example on top of the Dogger cuesta (Cordier, 2004). The Meurthe valley and its two main tributaries the Vezouze and the Mortagne flow through the Triassic and Liassic marls and clays between the Vosges Massif and from Lunéville. This led to the recognition of eight terraces in the Meurthe valley (Cordier 2004), 4 in the Vezouze and 5 in the Mortagne. Well preserved terraces have been recognised up to +35m in the Meurthe valley, due to this predominance of marls (Fig. 4) that are more sensitive for lateral erosion. Finally the South-North Sarre valley exposes various terrace staircases due to the morphostructural context: in the Sarrebourg and Sarreguemines areas, the valley is narrow due to the presence of Muschelkalk (Middle Trias) limestones (Harmand, 2007; Fig. 3). Up to 11 terraces have been recognised,

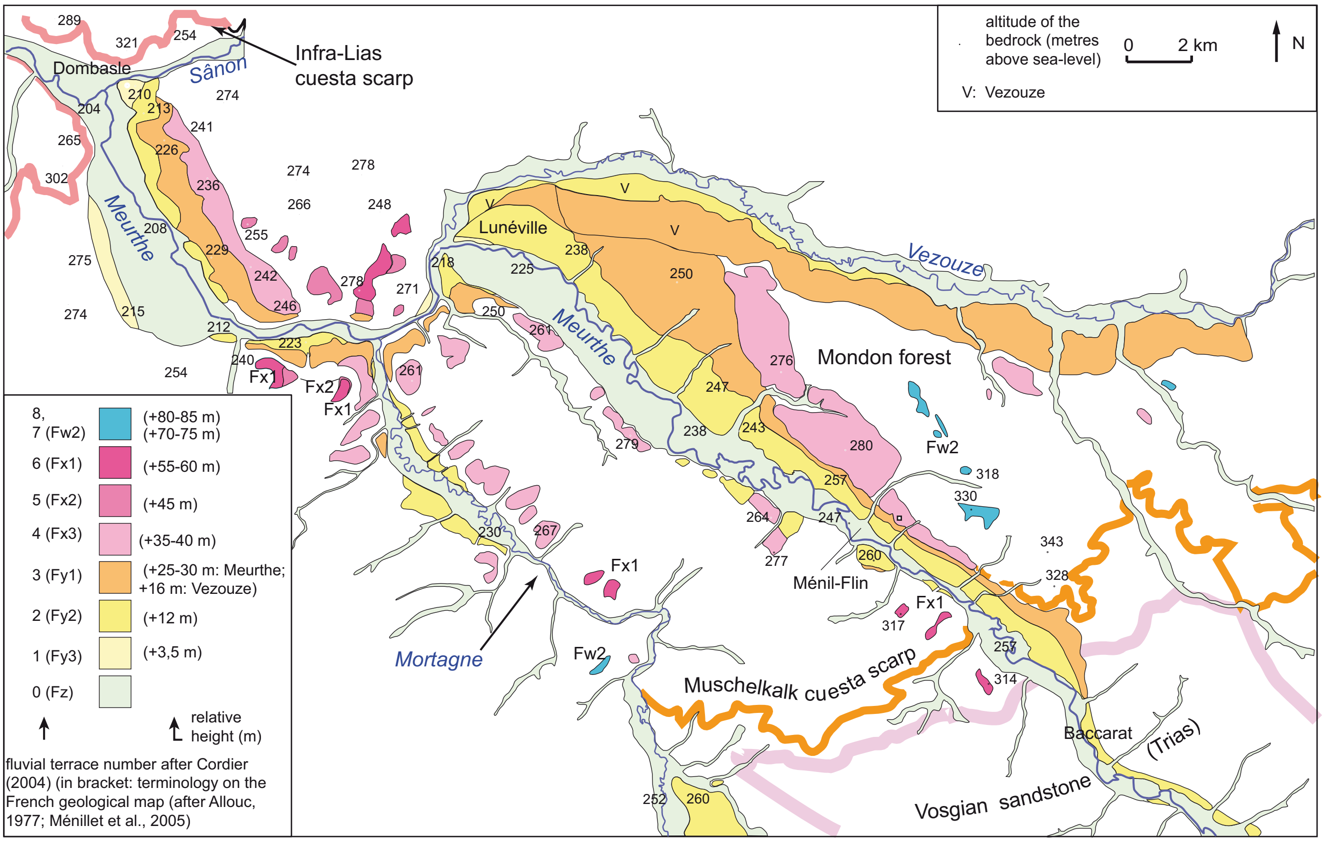

Fig. 4. The fluvial terraces of the Meurthe and its main tributaries the Mortagne and the Vezouze downstream from the Vosges Massif.

but most of them are residual. In contrast, a well preserved staircase is exposed in the Triassic marls and clays south of the Sarreguemines syncline, with 7 terraces up to +50 m. The terrace system is similar in the Middle Sarre valley (Sarre-Nahe fluvial basin), developed on sandstones, clays and limestones of Carboniferous to Triassic age (Harmand, 2007).

Sedimentary characteristics and climatic significance of the fluvial deposits

The study of several sections allowed the identification of depositional facies as well as petrographical and mineralogical analyses. Several lines of evidences from the fluvial terraces of the Upper Moselle (showing an alternation of coarse and sandy layers, each of one being several dm thick; Taous, 1994; Harmand, this study; Fig. 6), the Meurthe (showing channel fill cross bedding; Cordier, 2004) and the Sarre valleys (showing cross bedded structures and erosional features; Harmand, 2007) suggest that the deposition of the coarse and sandy sediments occurred in braided systems.

Special attention was given to the fluvial sediments preserved in the depressions of Triassic rocks of the Eastern Paris Basin. This made it possible to confirm the role of the Vosges Massif as main source for sediment supply but also to recognise distinct lithofacies on the basis of the lithology, mineralogy and grain-size of the sediments. The Meurthe and Sarre terraces are characterised by a predominance of sediments originating from the Permo-Triassic rocks of the Vosges Massif: in the Sarre valley (which only drains the Permo-Triassic strata), the sediments are typically sandy and originate from the Buntsandstein (Lower and middle Triassic) sandstones (Beiner et al., 2009), as indicated by the homogeneous heavy mineral composition (predominance of tourmaline, associated with zircon; Wolf, 1982, in Konzan, 1992). The coarser sediments (quartz and quartzites pebbles) originate from the conglomerates (Senones layers, Upper Permian; basal conglomerates of the Vosgian Sandstone; main Conglomerate of the Olenekian (Lower Trias); Durand, 2010). In the Meurthe valley (Cordier et al., 2005), the sediments are also mainly sandy. The sands originate from the Buntsandstein (presence of tourmaline and zircon as for the Sarre valley), but also from the crystalline basement, as indicated by the presence of hornblende. In the Mondon basin located between the Vosges Massif and Lunéville (Figs 1 and 4), the top of the sands is (as observed in terraces Me2, Me3 and Me4) eroded and overlain by a coarse unit which also includes a significant component of crystalline sediments. The presence of such deposits (granites, gneiss, etc, and associated minerals such as hornblende) is explained by the fact that about 25% of the Vosgian drainage area of the Meurthe (especially in the upper Meurthe) is developed in the crystalline basement. Their increasing presence in the top of the fluvial sequence is related to the melting of the glacier in

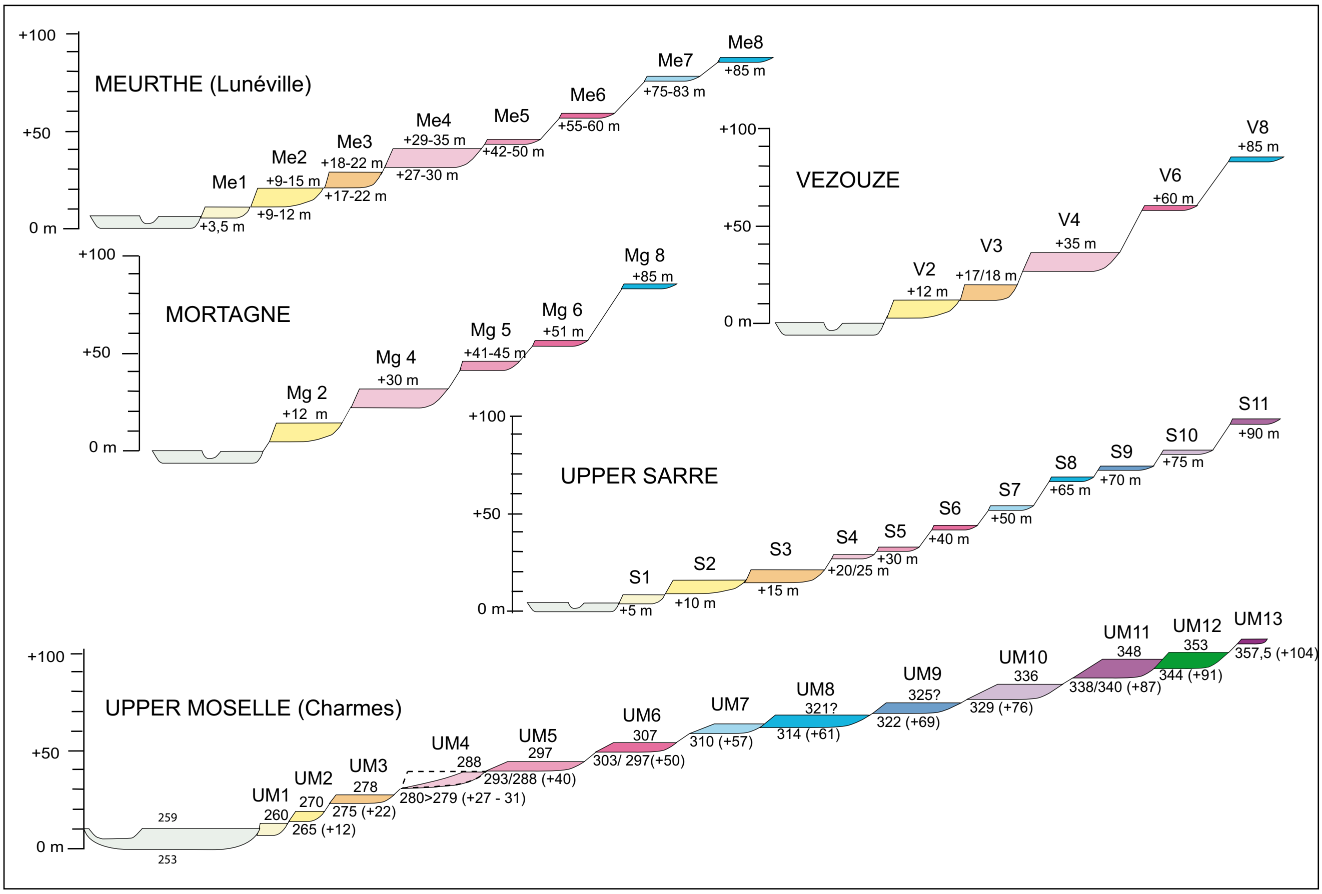

Fig. 5. Idealised sketch of the terrace staircases for the main rivers under study. Mapping performed during the past decade has made it possible to provide evidence for a significantly higher number of terraces than previously recognised.

the upper Meurthe valley. In the Upper Moselle valley, several sections have been studied, especially in the Golbey-Chavelot alluvial fan (Pré Droué and Cobrelle gravel-pits; Taous, 1994) and in the vicinity of Toul (Beiner in Losson, 2003; Cordier et al., 2004). The Moselle sediments include both sandy and coarse units. Mineralogical and petrographical investigations showed that most of the sediment have a crystalline origin (predominance of granite and gneiss pebbles associated with hornblende and garnet typical from the Vosges basement). This result is consistent with the lithology of the Upper Moselle

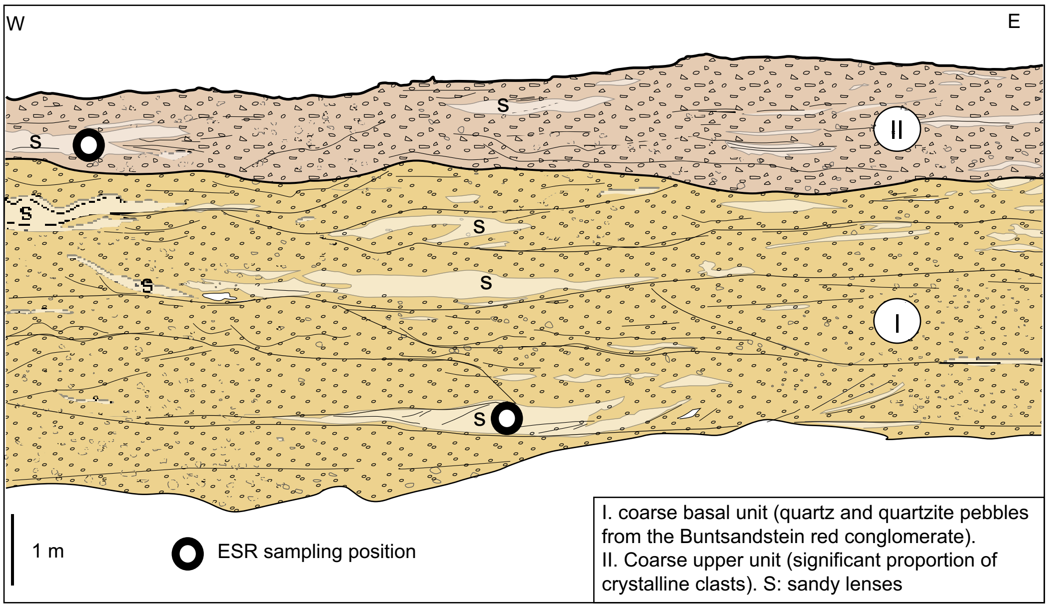

Fig. 6. General description of the Pre-Droué section (Golbey-Chavelot alluvial fan, terrace UM3) with location of the ESR sampling positions.

catchment (75% of the surface being composed of crystalline rocks). Following this, the Moselle and Meurthe sediments are characterised by clearly distinct sediment compositions. The lithology of the sediments should hence be considered as a reliable tool to recognise the pre- and post-capture terraces downstream from the present Moselle-Meurthe confluence (Cordier et al., 2004).

Captures and changes in river course

The study area is characterised by several capture events, with the main one being that of the Upper Moselle. In addition, local captures as well as changes in fluvial courses (e.g. meander downcutting) have been recognised at the border between the Paris Basin and the Rhenish Massif, in the Meuse valley (vicinity of Charleville-Mézières) and near the Moselle-Sarre confluence.

Impact of the Upper Moselle capture

Recognised more than one century ago and made famous by Davis (1895), the Upper-Moselle capture has been extensively studied (Harmand et al., 1995; Le Roux and Harmand, 1998; Losson, 2003). Recent research has shed new light on this event (Pissart et al., 1997; Losson, 2003; Harmand, 2004; Cordier et al., 2005). It led to the recognition of six well-preserved stepped terraces in the vicinity of Toul (Figs 7, 8). The older terraces (UM 6 to 4) correlate with terraces in the Meuse valley (pre-capture terraces. Upstream from Toul, in the Bajocian limestones, these terraces are residual. However, fluvial sediments associated to these terraces have been found in karstic caves, which provide evidence for partial defluviation of the Moselle towards the North (Losson 2003). In contrast, pre-capture terraces cover large areas in the Callovian clays near Toul, and the associated sediments are up to 10 m thick (Justice terrace, UM 5). Further West, the Val de l'Asne palaeovalley (connecting the Moselle and Meuse valleys) is also well preserved and exhibits beautiful palaeomeanders entrenched in the Oxfordian limestones. The relative height of the terraces is significantly different between Toul and the Meuse valley: the UM4 terrace, which is preserved a +30m near Toul, corresponds with the valley floor in the Val de l'Âne and in the Meuse valley. In the latter area, however, a significant reworking of the sediment took place: the valley floor sediments are actually mainly calcareous (in keeping with the lithology of the post-capture Lorraine Meuse catchment, which only drains the Jurassic limestones and marls of the Eastern Paris Basin). Their age ranges from the Weichselian Pleniglacial and Late Glacial (Lefèvre et al., 1993, 1995) to the Holocene for the top of the deposits (Harmand, 2004). This result clearly demonstrates that the Meuse and Moselle (Rhine) catchments have evolved very differently since the capture event: while an incision of ca 30m took place in the Moselle valley and its tributaries, no vertical incision occurred in the Meuse valley. This is explained by the strong decrease of water input and by the predominance of hard rocks (Mesozoic limestones in the Eastern Paris basin, sandstones and quartzites in the Ardenne Massif).

In contrast with the pre-capture terraces, the three lowest terraces (UM3 to UM1) follow the present Moselle valley (post-capture terraces) from Toul to the Meurthe confluence. Recent field work (Harmand, this study) demonstrates that these terraces (and especially the first post-capture terrace UM3, located at +20 m relative height) are also well preserved between Epinal and Charmes. The post-capture terraces have also been correlated firmly with the terraces preserved downstream from the Moselle-Meurthe confluence, both in the Paris Basin and in the Rhenish Massif downstream from Trier. An important change in sediment composition (petrography of pebbles and gravels, heavy-mineral spectra) has been recognised between terraces M4 and M3: the fluvial deposits of terrace M4 (and older terraces) are very similar to those of the Meurthe, with a predominance of sediments originating from the Permo-Triassic cover of the Vosges Massif (quartz and quartzite pebbles, tourmaline and zircon). In contrast, the sediments of terraces M3 and youngest (M2 to M0) include a significant proportion of crystalline sediments (granite pebbles, hornblende and garnet). A comparison with the lithology of the upper catchments of the Moselle and Meurthe (see above) allow this major change to be related to the Upper-Moselle capture (Cordier et al., 2005, 2006b).

Changes of river course in the Southern Rhenish Massif

Charleville-Mézières area (Southern Ardenne)

Three significant drainage changes have been recognised in the vicinity of Charleville-Mézières (Fig. 1; Harmand, 2004, this study). The drainage change are associated to the Aire-Bar-Meuse palaeovalley (Fig. 9), the Meuse of Gespunsart palaeo-valley, and the Sormonne valley (Figs 10 and 11).

Aire-Bar-Meuse palaeovalley

The River Aire is a tributary of the Seine, that previously flowed through the Bar valley to join the Meuse north of Charleville (Aire-Bar-Meuse, Harmand, 2004). A first capture event occurred when the Meuse of Gespunsart (corresponding to the Upper Moselle-Meuse) was captured by the Aire-Bar-Meuse between Sedan and Charleville (see below). The upper part of the Aire-Bar (the Aire) was subsequently captured by the Aisne. Mapping of the terraces in the area of the Aire capture allowed the recognition of one pre-capture (Aire-Bar terrace AB 5) and four post-capture terraces (Aire terraces from Ai4, the oldest, to Ai1, the youngest; Fig. 8; Harmand and Le Roux, 2009). In contrast to the post-capture sediments which occur in the modern valley towards the Aisne, the pre-capture sediments are preserved along a large meandering valley (present valleys of the Agron, Briquenay and Bar), which

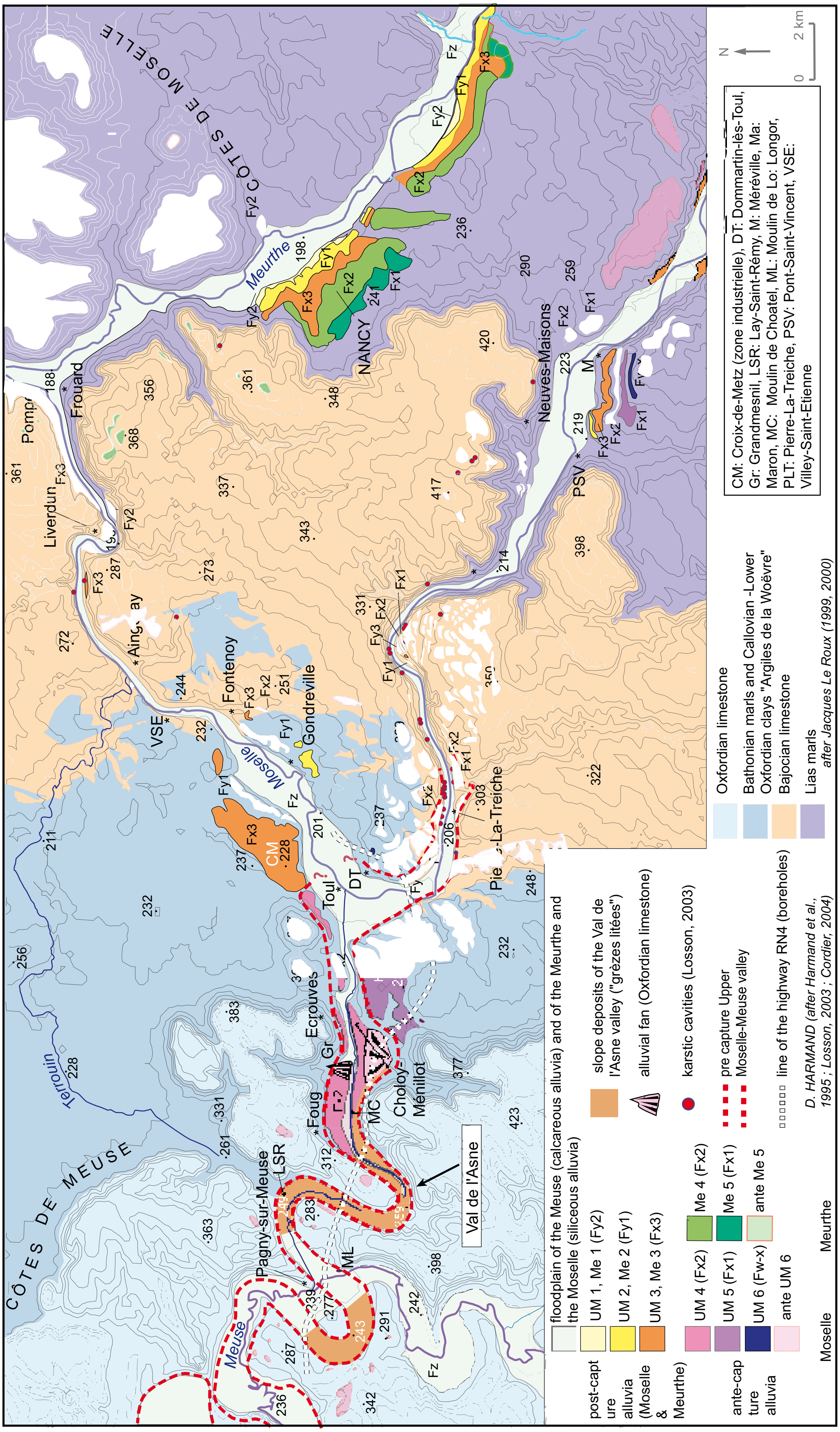

Fig. 7. The Upper Moselle capture area.

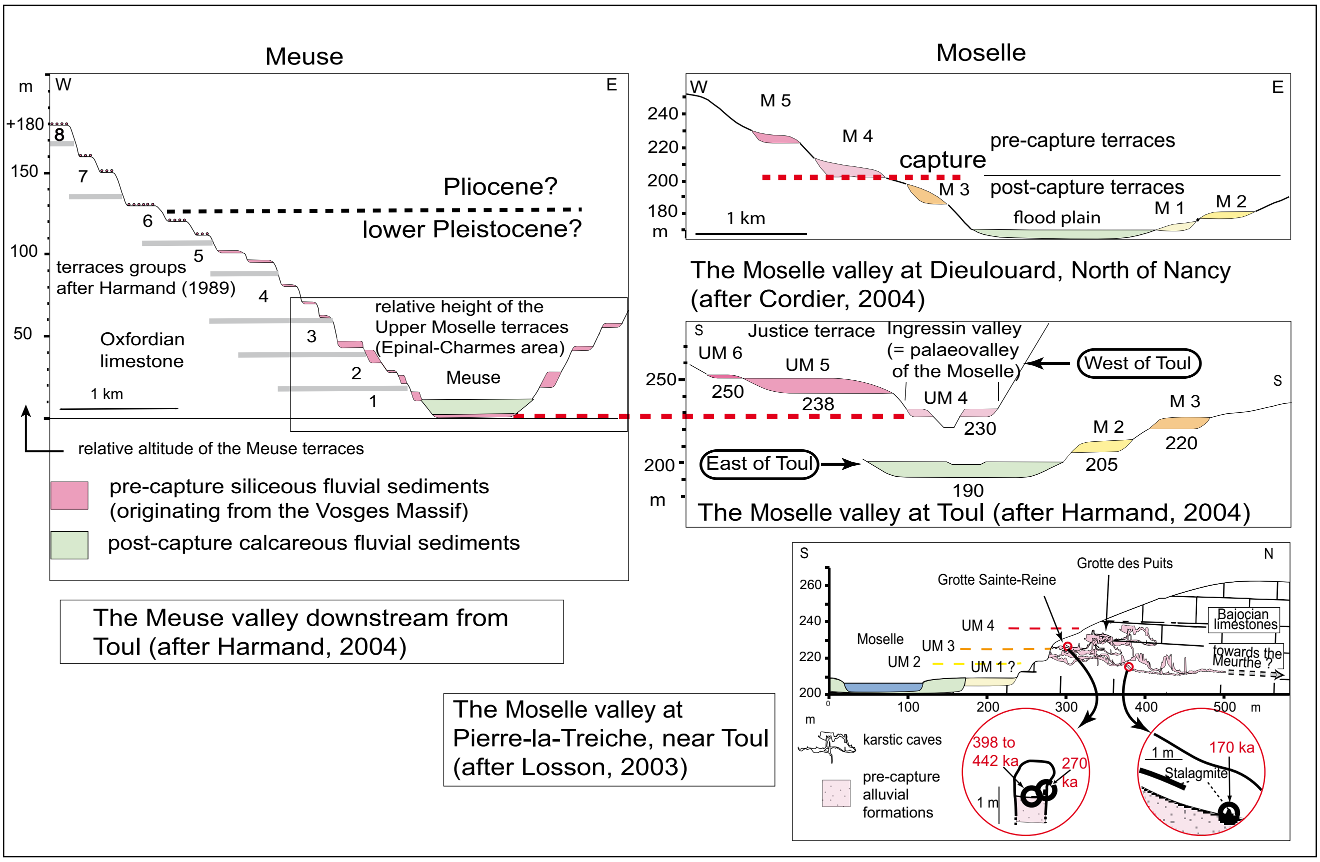

Fig. 8. The Upper Moselle capture and its record in the Meuse and Moselle valleys and in the karstic systems in the vicinity of Toul.

cannot have been formed by the present small rivers. Due to subsequent incision, the bedrock surface of terrace AB5 is ca 45 m above the present Aire valley. The incision was less pronounced in the palaeovalley due to the lower water input: the relative height of the basis of AB5 is only 2-3 m above the Agron floodplain at Verpel. Further North, at the border between the present Aire and Meuse catchments (Buzancy area), a borehole recorded by the French Geological Survey (BRGM; borehole 110.4.7) suggests that the sediments of terrace AB5 (8 m thick) are even covered by 14 m of slope deposits. Modern wetland covers the sediments of AB5 as well as the present floodplain. As the Aire and Aisne Rivers flows through the same Mesozoic strata (Jurassic limestones and Cretaceous siliceous sands), there is no lithological signature in the fluvial deposits that records the capture (Harmand, 2004). However, a minimum age estimate for the Aire capture event is provided by ESR dating of Aisne terrace As3 (correlated with Ai3), which yielded an age of ca 220±15 ka (Cojan et al., 2007). The AB 5 terrace formation and the Aire capture are thus significantly older than MIS 7.

Meuse of Gespunsart palaeovalley

The Gespunsart Valley is situated east of Charleville-Mezières and joins the present Meuse valley at Nouzonville (fig 9). The size of the palaeomeanders along the Gespunsart valley is comparable with that of the Meuse meanders. Previous study allowed the recognition of eight fluvial terraces, the highest being located at 315 m a.s.l. (+180 m above the present Meuse river; Fig. 10). Furthermore, a significant proportion of the relict sediments preserved in this valley originated from the Vosges Massif (crystalline basement and Permo-Triassic cover; Pissart, 1960; Voisin, 1980). Paleoenvironmental reconstructions derived from this evidence indicate the presence of two parallel palaeo-rivers joining to the North of Charleville (Fig. 9): the Aire-Bar-Meuse and the Upper-Moselle-Gespunsart Meuse. The capture of the Upper-Moselle-Meuse by the Aire-Bar-Meuse is well recorded in the Meuse sediments at Charleville (Pissart et al, 1997): the sediments from below the Mont-Olympe terrace (+15 m above the present Meuse) mainly contain tourmaline and zircon originating from the Ardenne and Cretaceous rocks, while hornblende typical of the Vosges crystalline basement is lacking (Fig. 10c; Voisin, 1980). In contrast, the sediments from below the +10 m terrace preserved at Warcq and Montcy-Notre-Dame (upstream and downstream from Charleville, respectively) contain a significant proportion of hornblende. The six terraces located between +80 m and +15 m must therefore have been formed by the Aire-Bar-Meuse, in contrast to the lowest terrace, which has been formed by the Upper-Moselle-Meuse (Harmand, 2004).

Sormonne valley

West of Charleville, a third change of river course was recognised (Voisin, 1972). The Ruisseau de Faux is a 10 km long tributary of the Meuse which flows through the Liassic strata of the Pre-Ardenne depression and the Ardenne basement (Fig. 9). A terrace is preserved at 60m above the present river (220 m a.s.l, Fig. 10). The section exposes a coarse basal unit (1.20 m thick) with quartzite pebbles, overlain by yellow sands (2 m thick) and slope deposits. The presence of glauconite and sponge spicules in the sands indicates that they originate from Cretaceous outcrops, which occur a few kilometres further to the south, in the present Sormonne catchment (Fig. 9). Taking into consideration the great width of the present Ruisseau de Faux valley, we assume that the sediments from below the +60m terrace were deposited by a palaeo-Sormonne before the river eroded the Pre-Ardenne depression during the Pleistocene.

The palaeomeanders in the Lower Sarre valley

The Lower Sarre valley is developed through the Devonian schists of the Hunsrück Massif (Figs 1 and 12). The presence of hard rocks has allowed the preservation of the fluvial terrace sequence (as lateral erosion is restricted) and a staircase of ca 15 terraces (up to +200 m relative height) has been recognised. The fluvial sediments are thick, especially for the older terraces: terraces S9 (+85 m) and S12 (+125 m) expose up to 14 and 9m of sediments, respectively (Fischer, 1957; Müller, 1976; Zöller, 1985; Harmand, 2007, Fig. 13). Fluvial deposits are also preserved in several palaeomeanders such as the Ayl-Wawern palaeomeander (relative height +7 m), the Irsch-Ockfen palaeomeander (+85 m) and the Konzer Tälchen palaeomeander (+100 m). The last (which may be older than 1 Ma as suggested by the ESR datings, see above) has been formed not only by the Sarre but also by the Palaeo-Meurthe, as indicated by the presence of iron ooliths originating from the Toarcian layer of the Dogger cuesta (Müller, 1976). The presence of several generations of palaeomeanders (Figs 12, 13), allocated to the Early to Middle Pleistocene (Irsch-Ockfen, Konzer Tälchen) or to the Upper Pleistocene (Ayl-Wavern), provides evidence for a complex evolution of the river's course, which may have been controlled not only by the tectonic activity (uplift of the Rhenish Massif) but also by climatically driven fluvial erosion.

The preservation of the terrace staircase allows correlation with the Moselle valley in the Rhenish Massif. In particular terraces S5 to S1 (+50 to +5 m relative height) are located at relative height similar to the Moselle terraces M5 to M1. At higher relative heights, the number of terraces is higher in the

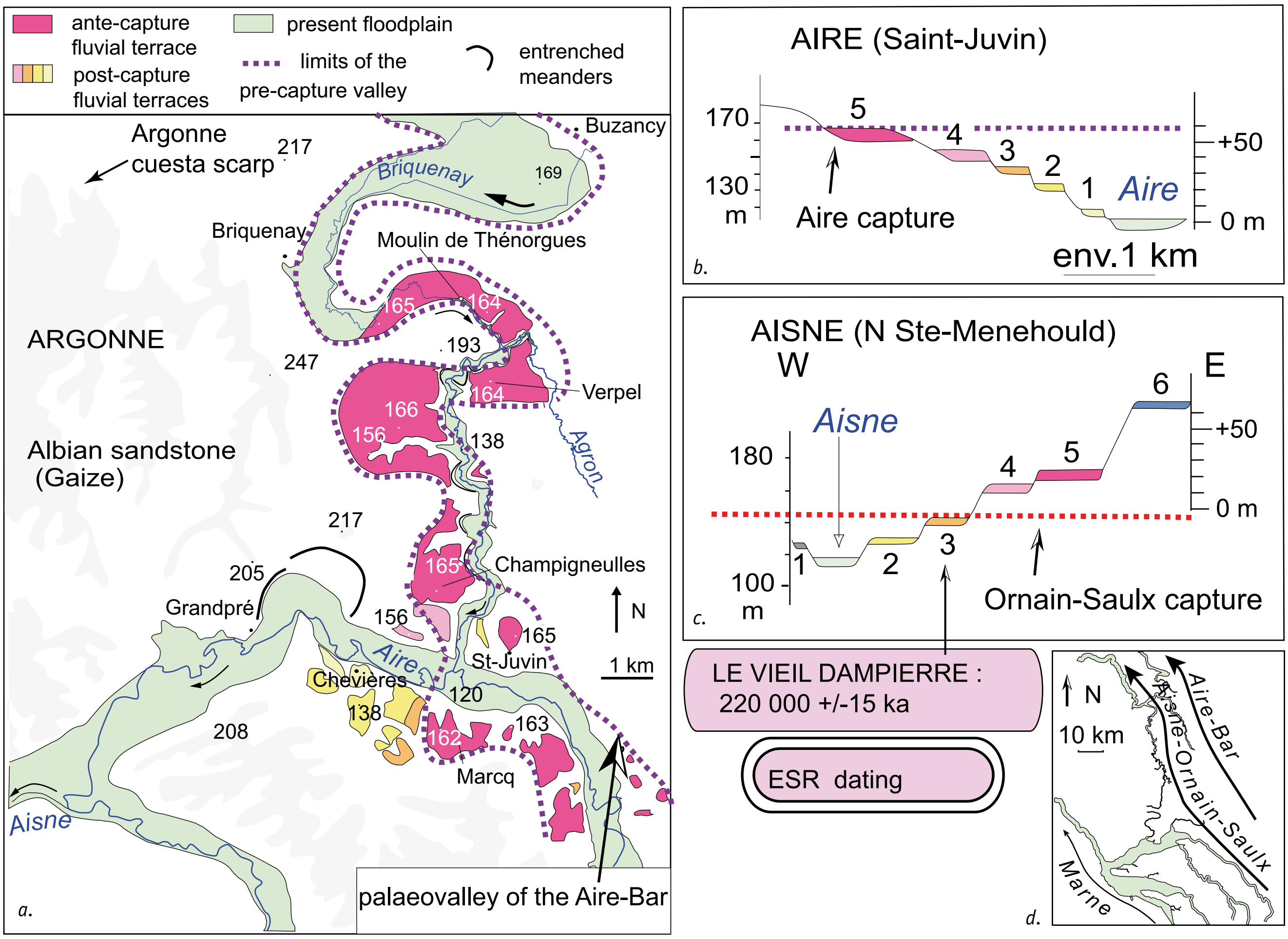

Fig. 9. The Aire-Bar capture and its chronostratigraphical framework. a. Morphological map; b. Terrace staircase of the Aire valley; c. Terrace staircase of the Aisne valley; d. Location map with indication of the palaeorivers.

Sarre valley. In contrast, the Moselle valley is characterised by a hiatus between what is called the 'lower and middle terraces' (less than 100 m relative height) and the 'main terrace' complex (above 100 m).

Discussion

The timing of terrace formation and river capture events

Ages of the lower terraces

The chronological framework of the fluvial sediments in the study area has been significantly enhanced during the last decade, using OSL, ESR and radiocarbon dating methods, especially for the youngest terraces. This makes it possible to correlate the youngest terraces (terraces 2 and 1, Fig. 5) and the present valley floor within the last glacial cycle (Weichselian to Holocene). The present floodplain of is allocated to the Late Glacial to Holocene period, on the basis of radiocarbon dates performed in the Meurthe and Moselle (Carcaud, 1992) valleys. In the Meuse valley, radiocarbon dating underlined the Holocene filling of channels cut into the older coarse gravel (Harmand, 2004). The incision from terrace M1 to M0 is likely to have occurred at the beginning of the Late Glacial. OSL dates from Moselle terrace M1 in Luxembourg and Sarre terrace S1 actually suggest that the main aggradation period occurred during MIS 3 (and possibly MIS 2; Cordier et al., 2010). Similarly OSL dating of terrace 2 in the Meurthe valley indicates that it was deposited during MIS 4. The MIS 3 age proposed for this terrace (Cordier et al., 2006) should, in contrast, be considered with caution, due to methodological problems. Furthermore, comparison with the other major rivers of the Eastern Paris Basin (especially the

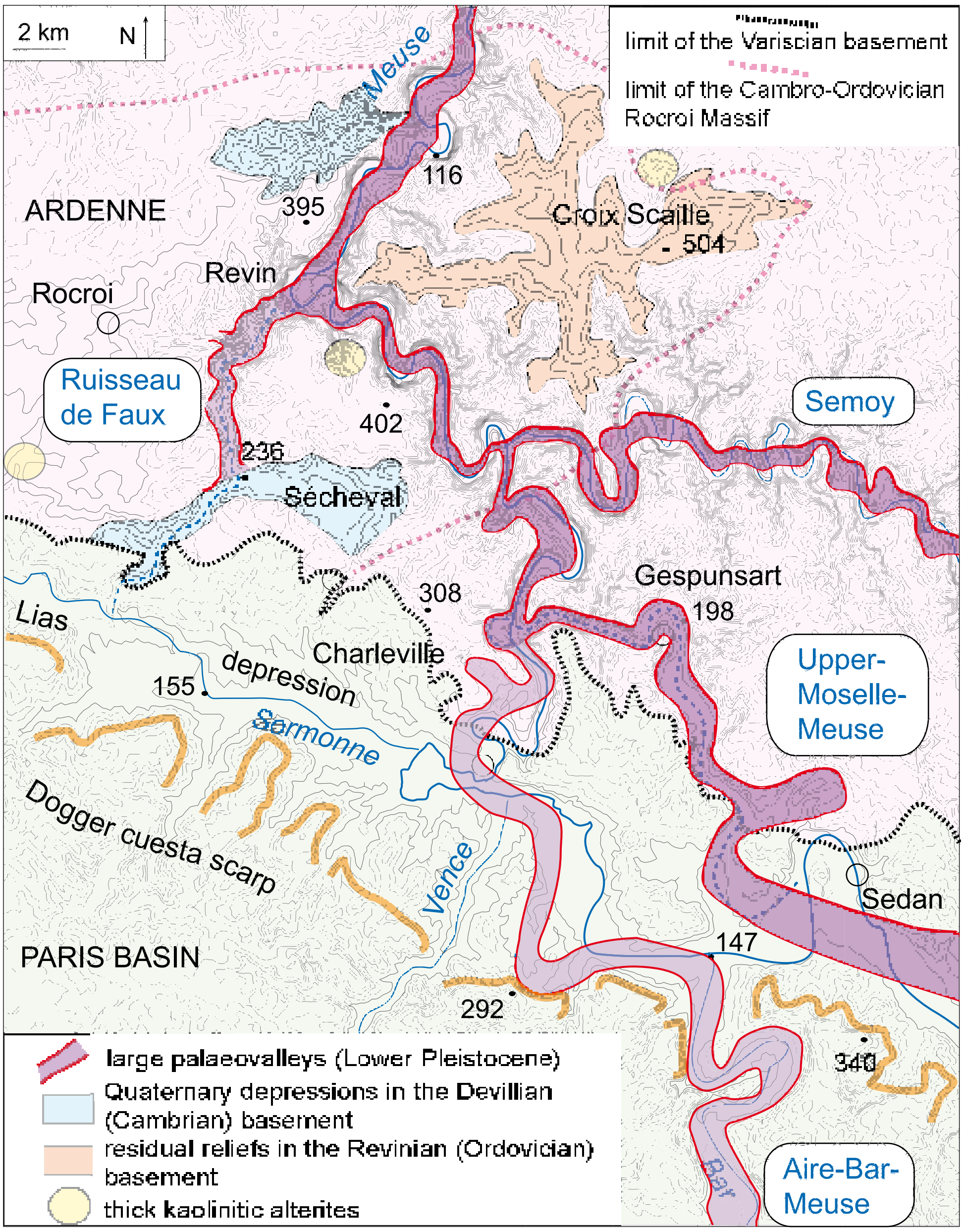

Fig. 10. Valleys and palaeovalleys in the Southern Ardenne.

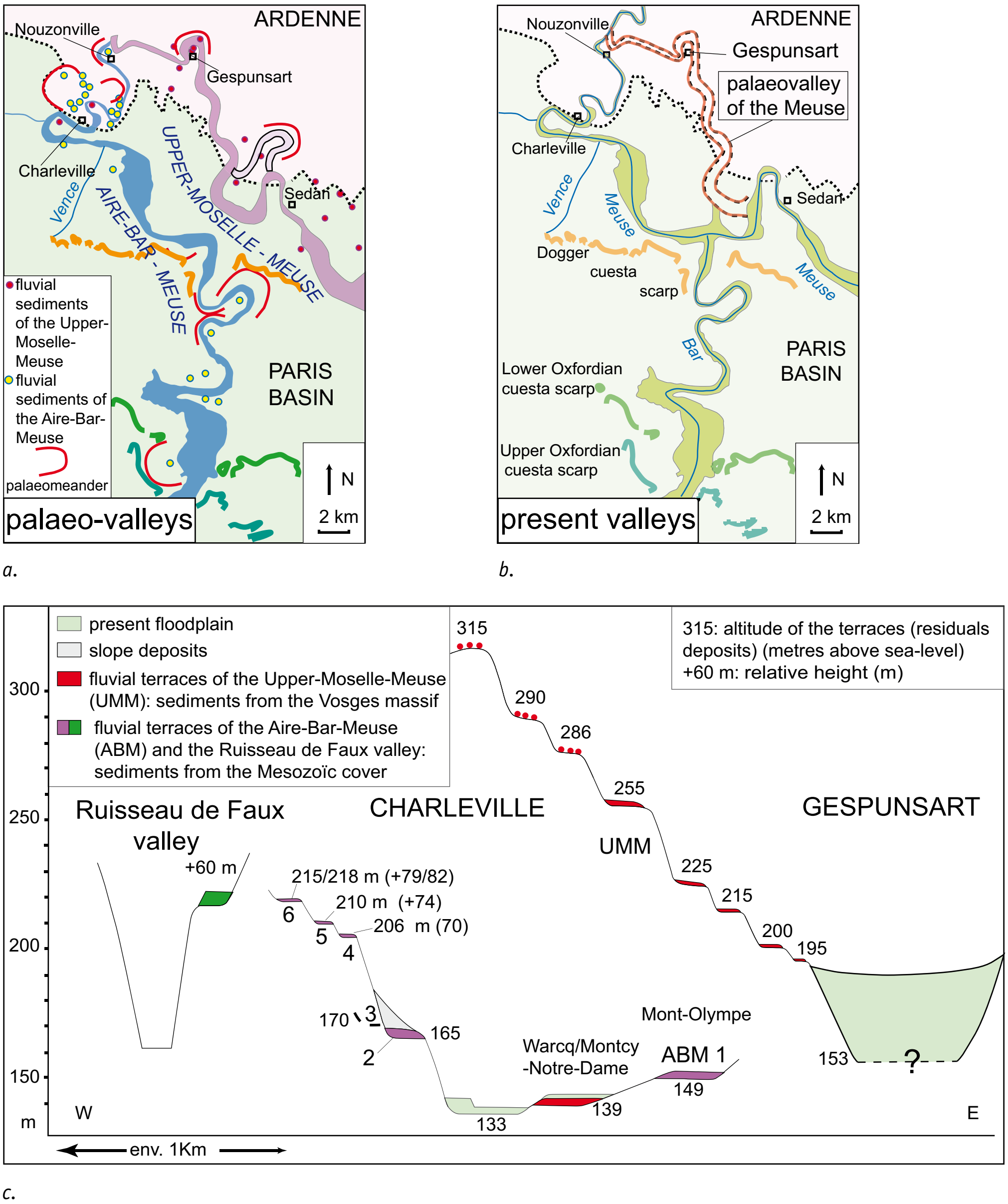

Fig. 11. The palaeovalleys and valleys in the vicinity of Charleville: location and stratigraphical location of the Gespunsart Meuse capture. a. the palaeorivers in the Charleville area; b. the present valleys; c. cross profile of the terraces in the Meuse and palaeo-Meuse valleys (after Pissart, 1961; Voisin, 1980; Pissart et al., 1997; Harmand, 2004).

Marne, tributary of the Seine, in which ESR dating yielded an age estimate of 93±9 ka; Cojan et al. 2007) suggests that MIS 5 sediments could also occur in terrace 2. This reconstruction for the terraces 2 to 0 is in excellent agreement with the reconstruction for the Lower Moselle valley at Trier (Zolitschka and Löhr, 1999). The proposed chronology is also consistent with the numerical datings from terrace 3. In the Meurthe valley, Infra-Red Stimulated Luminescence (IRSL) dates have indicated ages in MIS 6 (between 170 and 130 ka; Cordier et al., 2005). These should however be only considered as minimum ages, due to the lack of a fading correction. However, they are in good agreement with the recently obtained ESR dates from Upper Moselle terrace 3 at Golbey (Pré Droué section), which yielded ages of 191±30 and 218±30ka. This result makes it possible to overturn the reconstruction of Taous (1994), who recognised three main Saalian periods of aggradation within the Golbey alluvial fan deposits. Although further dating is required to improve knowledge about the formation of terrace 3, these results are comparable with two dates from sediments undertaken for sediments from terrace 3 in the Aisne and Marne catchments, which yielded age estimates of 220±21 and 150±18 ka (Cojan et al., 2007). Taking into consideration the results obtained from the youngest terraces, a relation can be identified between the Pleistocene cold periods and terrace formation. This fact is consistent with the recognition of periglacial features in the fluvial sediments of the main studied rivers (see below).

Ages of the Upper Moselle capture (M4, UM4 and Sa4 terraces)

The age of the Upper Moselle capture event remains a matter of debate. A first chronological control on the event was obtained in the Maastricht-Belvédère terrace of the Meuse (the Netherlands).

In this terrace the pre-capture sediments (including sediments from the Vosges Massif) are overlain by post-capture sediments and by a palaeosoil. Thermoluminescence dating of burnt flints preserved in this palaeosoil yielded an age of ca 250-270 ka for the capture event (Huxtable and Aitken, 1985; Krook, 1993). This age is in good agreement with the relative chronologies proposed for the Moselle terrace and the end of the 20th century (Harmand et al., 1995), as well as with the numerical dating of the youngest terraces. However, it should, for methodological reasons, be considered cautiously. More recently, two speleothems found near Toul, in a cave containing fluvial sediments related to the UM4 terrace have been dated using U/Th (Losson & Quinif, 2001; Losson, 2003). A first dating yielded an age of 270 ka for a speleothem preserved in a cave

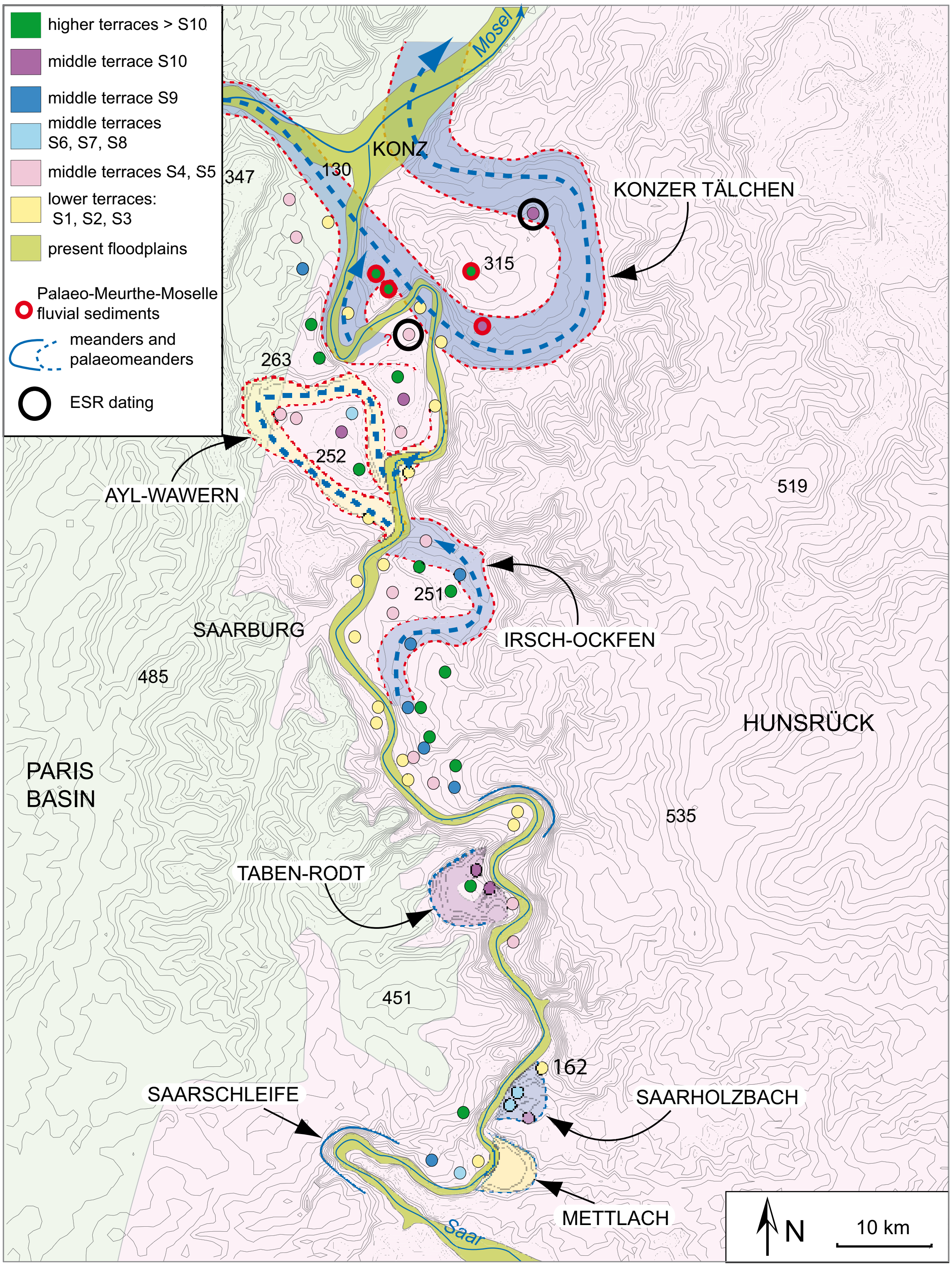

Fig. 12. The meanders and palaeomeanders of the Lower Sarre (after Müller, 1976; Zöller, 1985; Harmand, 2007).

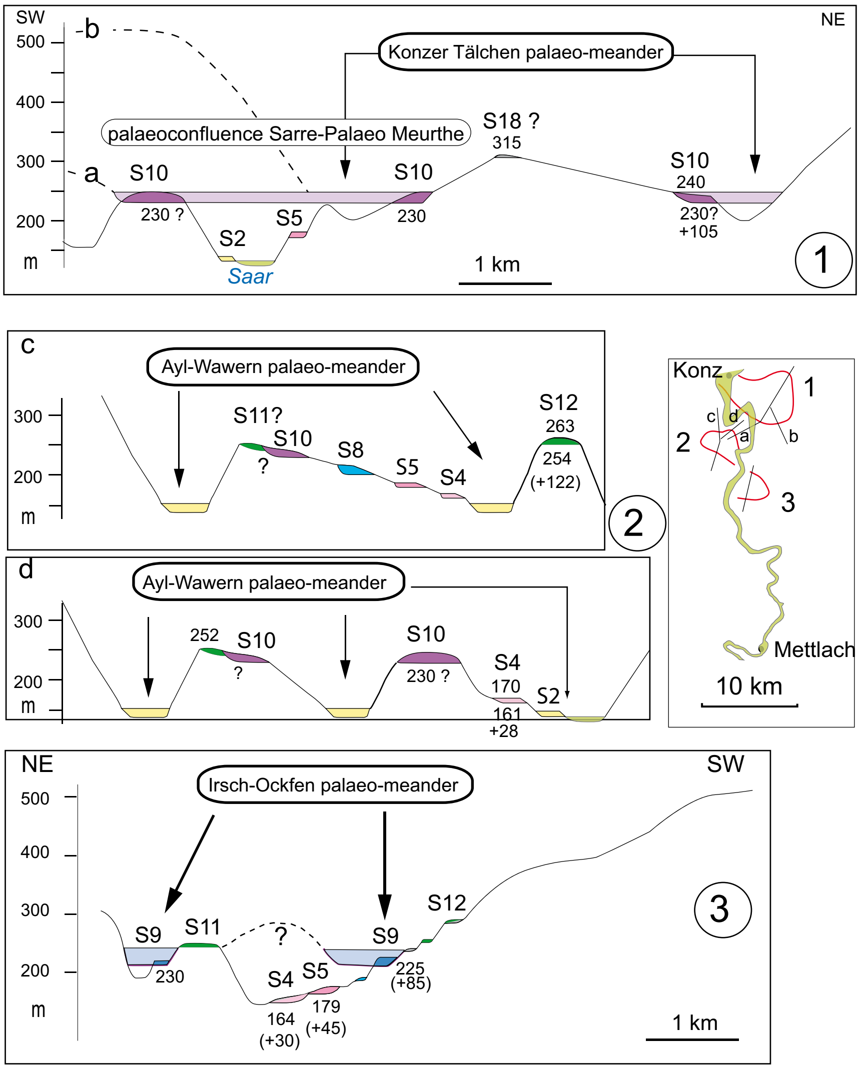

Fig. 13. Palaeomeander and terraces staircase in the Lower Sarre.

formed by the Moselle water contemporaneously with the UM4 terrace. The presence of this speleothem demonstrates that the cave was dewatered 270 ka ago, and therefore that the capture is older than 270 ka. However, the dating of a second speleothem sampled in the same cave yielded an age of 398-442 ka which should similarly be considered as a minimum age for the capture. Following from this, the capture event may be significantly older than previously expected. This observation is consistent with other U/Th dating of speleothem performed in the Meuse catchment in the Ardenne (Quinif, 2002), which demonstrated that the Meuse and its tributaries had not carved their valley significantly since 400 ka. It is also consistent with the ESR dating of the Sarre terrace Sa4 at Kanzem, which yielded an age of 340 to 410 ka, suggesting a correlation with MIS 11-10 (Cordier et al., 2012). On the base of morphological correlations, this age could be extrapolated to the last pre-capture terrace of the Moselle (M4) and to the UM4 terrace. However, both the ESR age and this correlation needs to be confirmed : further datings are obviously necessary to obtain a reliable age estimate for this major capture event and the associated terraces.

Age of the older terraces

If we follow the assumption (derived from the chronology for the youngest terraces, see above) that each cold period corresponds with a terrace formation, the presence of about ten pre-capture terraces in the Upper Moselle valley (Harmand, this study) suggests that the formation of the oldest terraces could be significantly older than 1 Ma. This reconstruction is consistent with the ESR dating on samples from the Sarre terrace Sa10 at Kommlingen (palaeo Moselle-Sarre confluence), which yielded ages of ca 1100-1250 ka, suggesting an Early Pleistocene age for Sa10 (Cordier et al., 2012). It is also consistent with previous research in the German Moselle valley (Cordier et al., 2006b), and in the Upper-Mselle-Meuse where Pissart et al. (1997) proposed age ranges from 2.2 Ma to 260 ka for the terraces between Toul and Maastricht. In contrast, it is in contradiction with the modelling of Westaway et al. (2009), who proposed that the middle and lower terrace formation (terraces located at less than 100 m relative height) took place after the Mid-Pleistocene revolution: following this reconstruction, the incision in the Moselle valley in the Rhenish Massif during the last 900 ka would have largely exceeded 100m, against less than 15m for the Meuse in the Southern Ardenne. Further dating of the older terraces is consequently required to provide a reliable reconstruction of long-term valley evolution in the Moselle and Meuse basin, taking account of regional uplift, morphostructural local conditions, and the incidence of the capture events.

Mechanisms for the fluvial captures

The occurrence of fluvial captures in the Eastern Paris basin results from a combination of lithological, palaeoclimatic and (at a larger scale) structural factors (Harmand et al., 1995; Harmand et Le Roux, 2009). The lithological factor is fundamental: all the capture events actually took place in marly or clayey depressions (Liassic clays and marls for the Gespunsart Meuse and the Palaeo-Sormonne; Callovian clays for the Upper Moselle; Lower Cretaceous clays for the Aire). These depressions are systematically located (following the pre-capture rivers) upstream from gorges sections: Ardenne basement for the Charleville area, Jurassic limestones for the Aire-Bar and Upper-Moselle. The presence of limestones in the latter areas has enabled seepage processes that have been recognised in the Upper Moselle, and are possible in the Aire-Bar area. However, infiltrations are not expected to have had a major influence on capture events, as demonstrated by the research of Losson (2003) in the Toul area and by the fact that capture events also occurred in non-karstic area (e.g. Charleville area). In contrast, the downstream sections following post-capture rivers are typically developed in soft rocks: easily eroded Chalk of Champagne for the Aisne river, Liassic marls for the Palaeo-Meurthe. The captures were finally realised by tributaries of these rivers, such as the Palaeo-Terrouin (tributary of the Palaeo-Meurthe; Figure 7) for the Upper Moselle (Le Roux and Harmand, 1998).

The second main factor relates to the climatic conditions: palaeoenvironmental reconstructions suggest that most of the capture took place at the end of cold periods. Recent research (Cordier et al., 2006a, b) demonstrated that most of the sedimentation took place during pleniglacial conditions (deposition of coarse deposits originating from the Vosges massif for the Upper-Moselle-Meuse valley, from the Barrois frost-shattered limestones for the Aire). Following from this, it is likely that the pleniglacial sedimentation led the river (and their tributaries) to raise the level of water, allowing diversion into another catchment. This process requires sufficient erosion of the marly interfluves, hence determining the timing of the capture event.

At a larger scale, the influence of the structural Barrois threshold was fundamental. The Barrois threshold corresponds to the border between the Paris basin (*stricto sensu*) and the Lorraine Triassic basin. It was active during the Jurassic and the Early Cretaceous, but corresponded to a depressed area during the formation of the hydrographic network at the end of the Cretaceous (Le Roux and Harmand, 2003). The Barrois threshold broadly corresponds to the present Meuse and Aire catchments in Lorraine (Fig. 1). These rivers also have a surelevated location in comparison with the Seine and Moselle catchments. The capture events that took place in the Eastern Paris basin should therefore be interpreted as readjustments of the hydrographic network to the Cenozoic structural conditions.

Climate forcing on fluvial evolution

The terrace staircases described above obviously reflect an internal forcing corresponding with a general tectonic uplift since the Tertiary. However, change in the fluvial system functioning (alternation of depositional and erosion periods) has to be interpreted in terms of climate change (Cordier et al., 2006a, b), as suggested by sedimentological and geochronological evidences. The study of several sections that expose the fluvial sediments shows that the main depositional phases correlate with the cold periods (e.g. pleniglacial and lateglacial periods of the glacial-interglacial or stadial-interstadial cycles). Periglacial features have actually been recognised in the fluvial sediments in the Meurthe valley (involutions in the fluvial sediments related to the presence of a continuous permafrost; J. Vandenberghe, pers.comm), in the Pré Droué section of the Upper Moselle valley (coarse deposits associated with longitudinal bars; Taous, 1994), and in the Sarre valley (basal pebbles of ice-raft origin; Zöller, 1985; Harmand, 2007; Harmand and Durand, 2010). This is consistent with the evidence for deposition in braided channels (see above), which are typically associated with cold conditions in Western Europe (e.g. Mol et al., 2000; Busschers et al., 2007). It is also likely that the capture events occured at the ends of cold periods. This is especially the case for the Upper-Moselle capture, which is recorded in the Maastricht-Belvédère section below a palaeosol assigned to a Saalian interstadial (Vandenberghe, 1995).

Detailed study in the Meurthe valley downstream from the Vosges Massif (and especially of terrace Me4 sediments) allowed a more precise correlation between sediment deposition and the climate cycle as defined by isotope analyses of deep-sea and ice cores (Lisiecki and Raymo, 2005). Two thick sandy units were recognised and related to braided channels active during a pleniglacial phase. The low proportion of crystalline sediments is explained by their trapping in the glaciated area, but also by the morphostructural framework: downstream from the glaciated area, the Meurthe actually flows first through the Saint-Dié basin, then through the sandstone gorges formed in the area of Raon-l'Etape, enabling high amount of crystalline sediments to be trapped in the Saint-Dié basin. The top of the upper sandy unit was eroded before the deposition of coarser deposits (see above 3.2). This erosional transition and the significant component of crystalline sediments originating from the upper Meurthe catchment made it possible to correlate this unit with the melting of the Meurthe glacier at the cold-to warm transition (Cordier et al., 2006a, b). It seems, however, difficult to propose a regional correlation between terrace formation and Pleistocene climate changes. In particular, the sedimentation at the Pré Droué section is influenced by its proglacial location: the two main stratigraphical units observed in this gravel-pit correspond with two distinct sedimentations periods. The lower unit including a significant crystalline component originating from the upper catchment, but also sediments produced by the erosion of the regoliths developed on Triassic sandstones. In contrast the upper unit is mainly composed of angular crystalline sediments. They are associated either with a progression of the glacier front, or with the erosion of a previously deposited moraine (Taous, 1994; Harmand and Durand, 2010). Due to the error range, the ESR age estimates obtained from this gravel-pit (see above) do not allow a more precise correlation with climate.

A correlation between the terraces and the four glaciations recognised in the Vosges Massif (Flageollet, 2002 ; Harmand and Durand, 2010) is, however, plausible. The last glaciation (Würm) is associated with the Noirgueux end moraine, located ca 20 km upstream from Epinal (Flageollet, 1988; Seret et al., 1990). Due to the lack of an absolute chronology, the correlation between the Noirgueux system and Upper Moselle terrace UM 1 or 2, recognised downstream from Epinal, remains uncertain. In contrast, ESR dating of the Pré Droué section is consistent with the correlation, proposed by Flageollet (1988), with the penultimate glaciation ('Riss'). Finally, the fluvial sediments associated with the two embedded fans of Epinal-Châtel (terraces UM 9 and 11) correlate older glaciations attributed to the Mindel by Flageollet (1988). Following this, a significant gap separates the two old glaciations (ice caps covering the Vosges Massif and associated with terraces UM9 and 11) and the last two glaciations (valley glaciers contemporaneous with the Pré-Droué and Noirgueux systems and younger than 250 ka). The lack of glacial landforms associated with terraces UM8 to UM4 suggests either that they have been eroded by the subsequent glaciations, or that the climatic conditions did not allow a real glacier to cover the Vosges Massif.

The formation of terrace (e.g. succession of periods of sedimentations with possible reworking/partial erosion of the sediments, and of incision periods leading the the formation of a new valley floor below the previous one) should hence be firmly allocated to climate forcing. Sedimentological and geochronological evidences indicate that most of the fluvial deposition took place during and at the end of the Pleistocene cold periods. The periods of erosion are allocated to the climate warm-to-cold or cold-to-warm transitions. As shown by Cordier et al. (2006a), this evolution is comparable with the recognised in many other fluvial systems, especially in Northwestern Europe. However, the reconstructions for the study area also suggest that the response of the different rivers to a given climate change may differ. Similarly the response in a given area may be different from one Pleistocene climate cycle to another. This is well illustrated by the comparison between the Meurthe fluvial terrace Me4 (which exposes sediments related to various environmental conditions) and the younger levels (Me1-M1 and Me0-M0) in which the Pleniglacial and Late-Glacial to interglacial sediments are separated. It should especially relate to the crossing (or absence of crossing) of geomorphic threshold (Schumm, 1979).

Conclusions

This paper provides a regional overview of the terrace systems of the main rivers originating from the NW part of the Vosges Massif (Moselle, Meuse, Meurthe and Sarre). Recent research allowed a extensive mapping of the terraces, and the development of a chronological framework based on the OSL and ESR dating methods. Numerical ages are actually fundamental to confirm the correlations between the valleys, as these were first based on morphological evidences and on the occurrence of several captures. They also confirm that major depositional events take place during the cold periods associated with the presence of glaciers in the Vosges Massif. The capture events are likely to occur at the end of cold periods. However, the comparison between the different valleys shows that their evolution may differ strongly, in particular in terms of incision rates. The occurrence of several capture events and palaeomeander downcutting phases should therefore be considered not only as the consequence of the distinct evolution of neighbouring valleys but also as a trigger for post-capture fluvial evolution (e.g. in the Meuse valley). Further dating is, however, required to improve knowledge of valley evolution and regional correlations.

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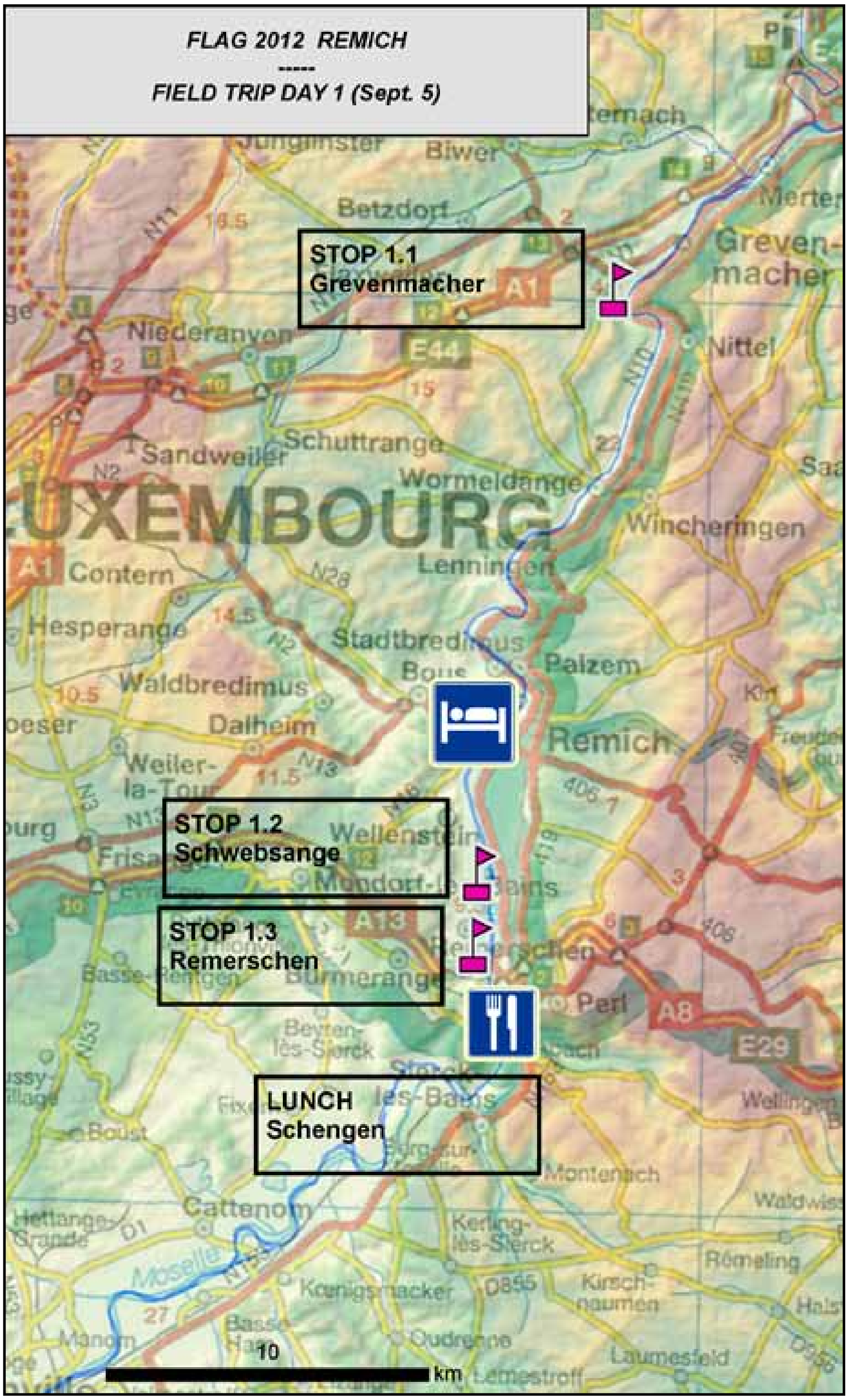
September 5, 2012

From Remich to Nancy : the Moselle valley in Luxembourg and France

The Moselle valley at Remerschen (picture : A. Humbert / CERPA)

Day 1


FLAG 2012 REMICH

FIELD TRIP DAY 1 (Sept. 5)
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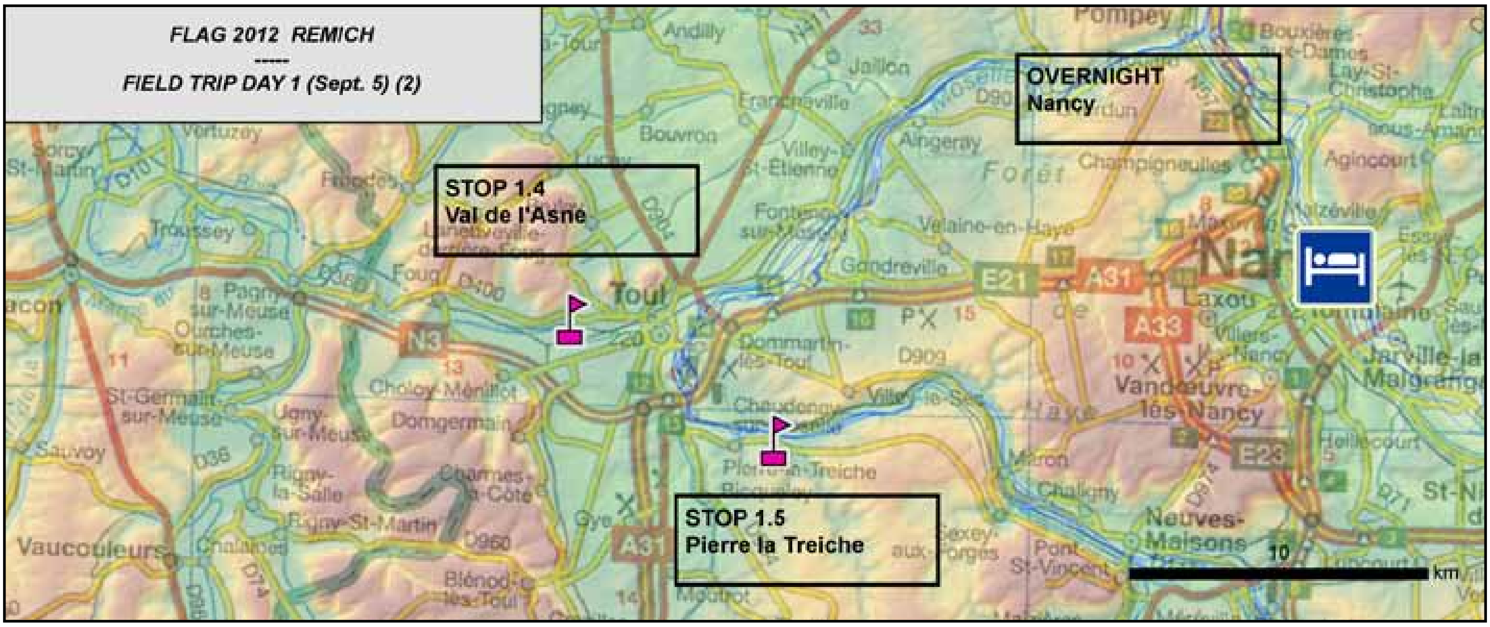
Grevenmacher
STOP 1.2
Schwebsange
STOP 1.3
Remerschen
LUNCH
Schengen
10
km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FIELD TRIP DAY 1 (Sept. 5) (2)
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September 5, 2012

Stop 1.1 : Grevenmacher

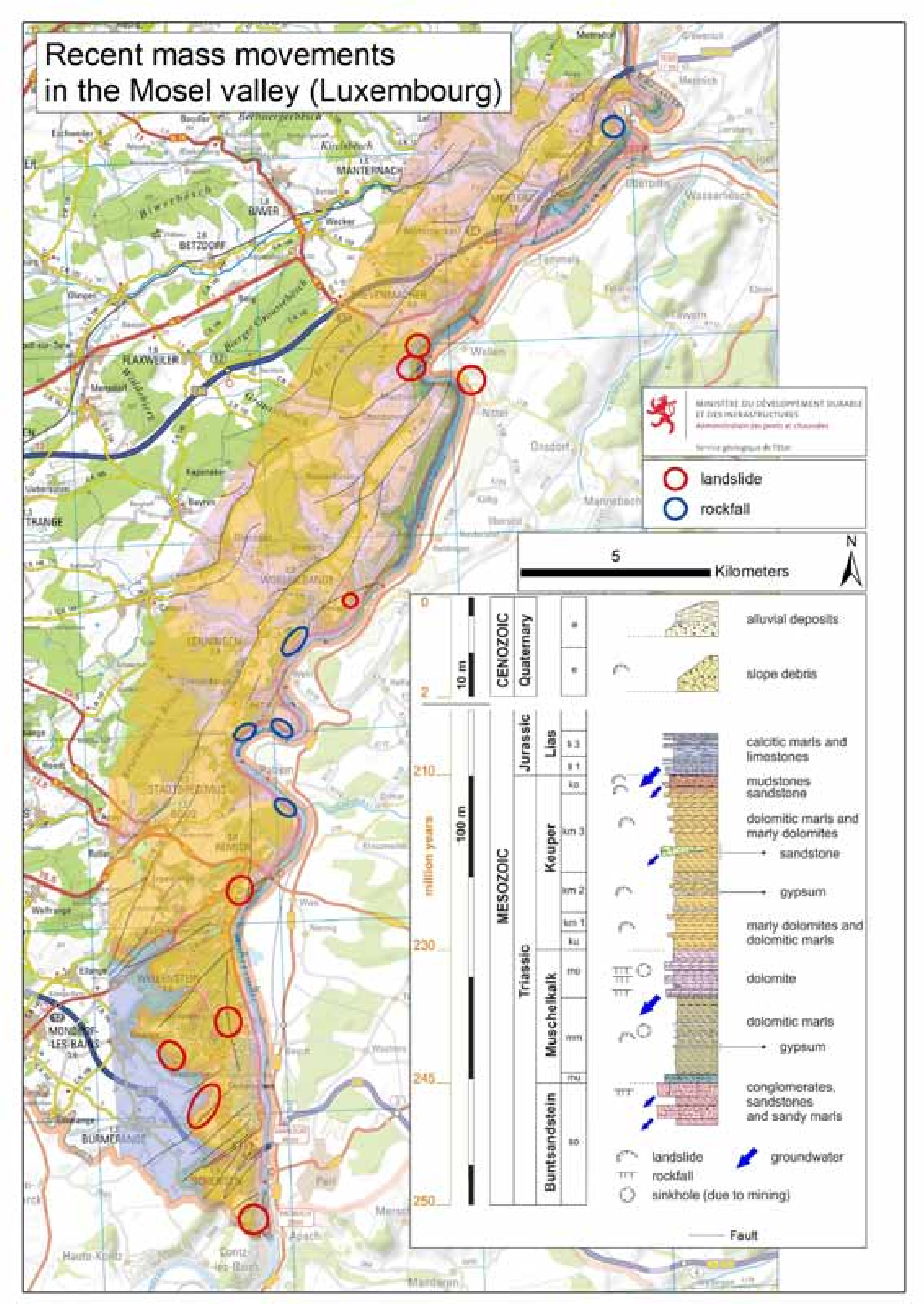


Figure 1.1.1 : Recent mass movements in the Mosel valley (Luxembourg)

Stop 1.1 : The morphological evolution of the hillslopes of the Mosel valley – examples of mass movements south of Grevenmacher

General presentation of the area

The southern part of Luxembourg is formed by Mesozoic rocks deposited in the Gulf of Luxembourg as a part of the NNE-SSW striking Eifel-Lorraine depression. The underlying substratum is formed by folded Palaeozoic rocks that outcrop in the Northern part of the country (local Eisleck and Belgian Ardennes, parts of the Rhenish Massif). The Gulf of Luxembourg area has been mildly folded in a large synclinal structure characterised by several secondary synclines and anticlines where older rocks may be exposed. The Palaeozoic basement points through the Mesozoic cover in the Moselle valley floor south of Schengen, near the French border. Similarly, in the Grevenmacher and Echternach areas, Buntsandstein rocks outcrop or are preserved at a shallow depth, as indicated by the presence of salty and mineralized waters typical of that formation.

The lithological column (figure 1.1.1) shows the succession of Triassic rocks. It is characterised by a succession of hard rocks (resistant to weathering, forming steep slopes, fractured and thus pervious to water) and soft marly and clayey rocks (not resistant to weathering, forming soft slopes, not much fractured and thus quite impervious to water). The hard rocks mainly correspond to sandstones and dolomites developed as thick packages and constituting the Buntsandstein (sandstone and conglomerate), Muschelkalk (dolomite) and Liassic (Luxembourg sandstone - Jurassic age) cuesta ridges. The soft rocks consist of marls and argillites. These Triassic formations have been largely faulted, forming horst and graben structures.

The Moselle River has cut deeply in its geological substratum since the middle Tertiary, following tectonic uplift. Due to the morphostructural conditions, the preservation of the fluvial sediments remains limited in the Luxembourgian valley. The fluvial deposits are typically residual, except in the Wintrange fluvial basin (stop 1.3) and in the Wasserbillig area North of Grevenmacher. In contrast, the combination of steep slopes and rocks subject to mass movement led to erosion processes and locally gravitational mass movement. Geomorphological evidences and scars of historical (and even older) mass movements are actually well visible on the vine growing slopes. The substratum is actually commonly overlain by slope debris of clayey nature mixed with dolomite and sandstone fragments.

In case of heavy rainfall, the water movement corresponds to overland flow while groundwater movement occurs essentially at the contact between the marls and the overlying slope deposits. In case of higher discharge, hydraulic pressure may increase, destabilize the slope debris cover and trigger off landsliding. Sliding surfaces of circular type affect the marly substratum which is

partly incorporated into the slope deposits. Following this process, landslides will move progressively up or down the slope, affecting also laterally larger areas.
The evolution of the Moselle slopes mainly depends on their geological and geomorphological characteristics. The triggering happens under natural conditions after extreme hydrogeological conditions. However, the valley is since the Middle Holocene a major settlement area (see stop 1.3): anthropogenic influence increased during the last millennia with the development of settlements and the building of transport ways, leading human societies to play an important role as “geofactor”. Some of the more recent mass movements observed in the Mosel valley and affecting generally roads (figure 1.1.1) are obviously of anthropogenic origin.

Landslides in the Grevenmacher area

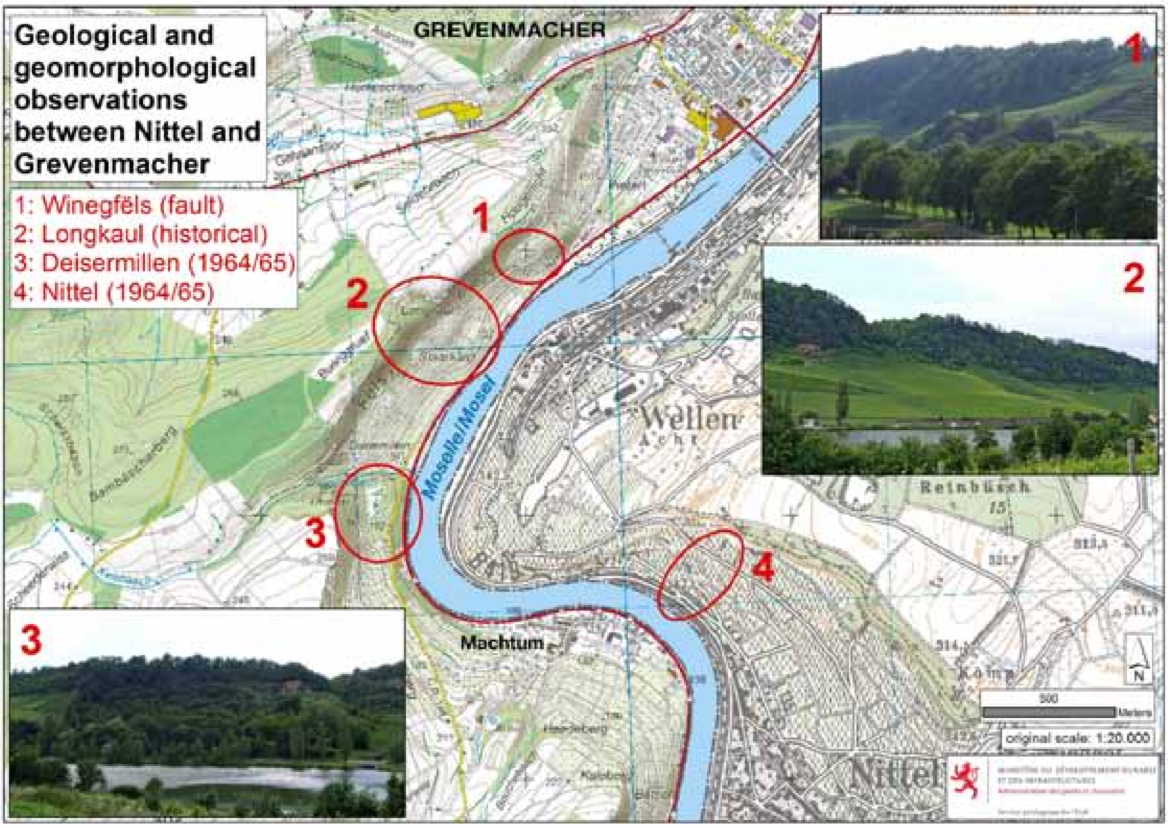


Figure 1.1.2 : Geological and geomorphological observations between Nittel and Grevenmacker

Another interesting part of the Mosel valley showing slope evolution by different geological and geomorphological processes can be observed about 1 kilometre south of Grevenmacher and west of the German village of Nittel. The map of figure 1.1.2 shows the localisation of the large landslides that occurred in the area, the slopes showing the typical landslide topography.
The geological substratum is formed by Keuper and Muschelkalk rocks. A c.50

meter thick dolomite package of the upper Muschelkalk forms an impressive scarp on both sides of the Moselle valley. It can be seen nicely on the map as topographic feature and it is largely affected by stone and rock fall. The dolomites and marly dolomites are disposed in layers of variable thickness and are intercalated with few and relatively thin marl layers. The presence of these marls induces differential alteration on the scarp surface. This influences largely the local stability to rockfall as well as does the well-developed conjugate joint system. Due to their fracturing, the dolomites are quite pervious and constitute an aquifer of regional importance. Drastic variations of the water tables characterised by rapid response to precipitations are quite common. The dolomite has been exploited in underground quarries; collapse structures are observed on the map above the abandoned underground works.
Gypsiferous marls of the middle Muschelkalk are underlying the dolomitic unit. This unit is, due to is clayey character very sensible to landsliding. Dissolution of gypsum develops locally a secondary permeability inducing new groundwater circulation paths in a normally quite impervious material. Marls with intercalations of lower Keuper dolomites are overlying the dolomitic unit. Their ability to earth sliding varies largely with water circulation which is influenced by the strata dipping and by the degree of faulting. A more or less thick mantle of weathered material (clays with dolomitic fragments) covers the substratum. A spring is observed on the top of the scarf, at the base of the Keuper marls. It corresponds with water that has been drained in order to attempt to slow down the slide movement in the upper part of the Longkaul and has been directed to a fountain placed at the bottom of the scarp.

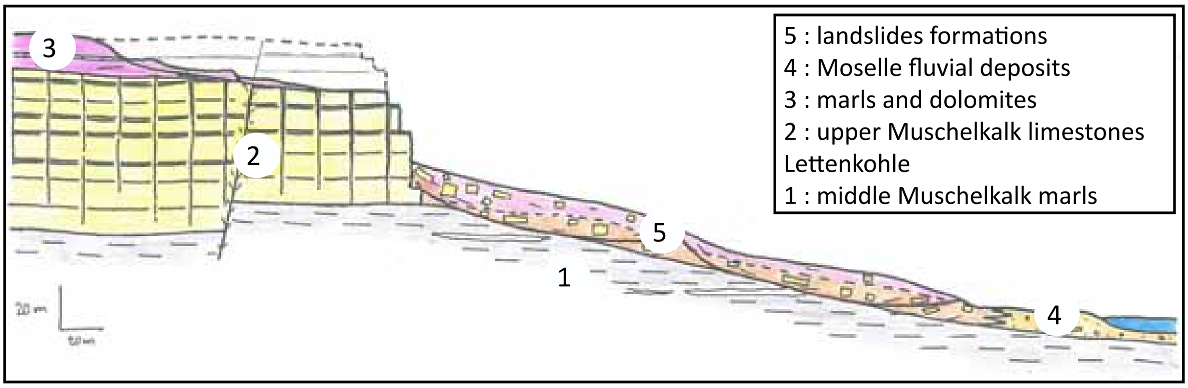


Figure 1.1.3 : the Longkaul main landslide

Figure 1.1.3 shows a profile in the complex Longkaul landslide. Since historical times, about 200 000 cubic meters were (and still are) in movement on the slope. The folk story of the Longkaul man, living in the Kelsbaach and throwing, during storms and rainy periods mud and stones into the valley is well known and is a nice description of mass movement (Gredt, 2005). The scar of the upper landslide is well seen on the 1:20 000 map. The movement has pushed

during successive periods the muddy material over the cliff. The latest movements in the 1980's and 1990's have been documented by newspapers and geologists. A quite large rockfall at the northern extent has probably also been triggered by the moving material.
The muddy material pushed over the cliff overloads the slope debris beneath the scarp. The overload affects stability and induces a first slide movement. Slope parts further down are progressively overloaded in the toe region and the process continues towards the bottom of the valley. A lateral extension is observed at the same time and the slide toe moves finally into the river. It is quite possible that the river erosion at the toe reduces the retaining forces and reactivates the movement again. The slide mechanism is in that case reversed

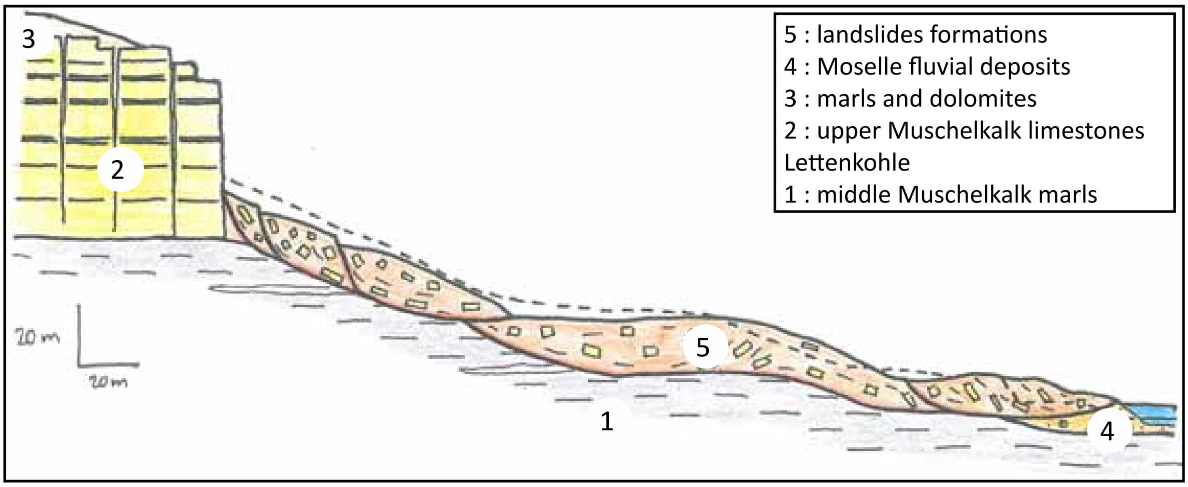


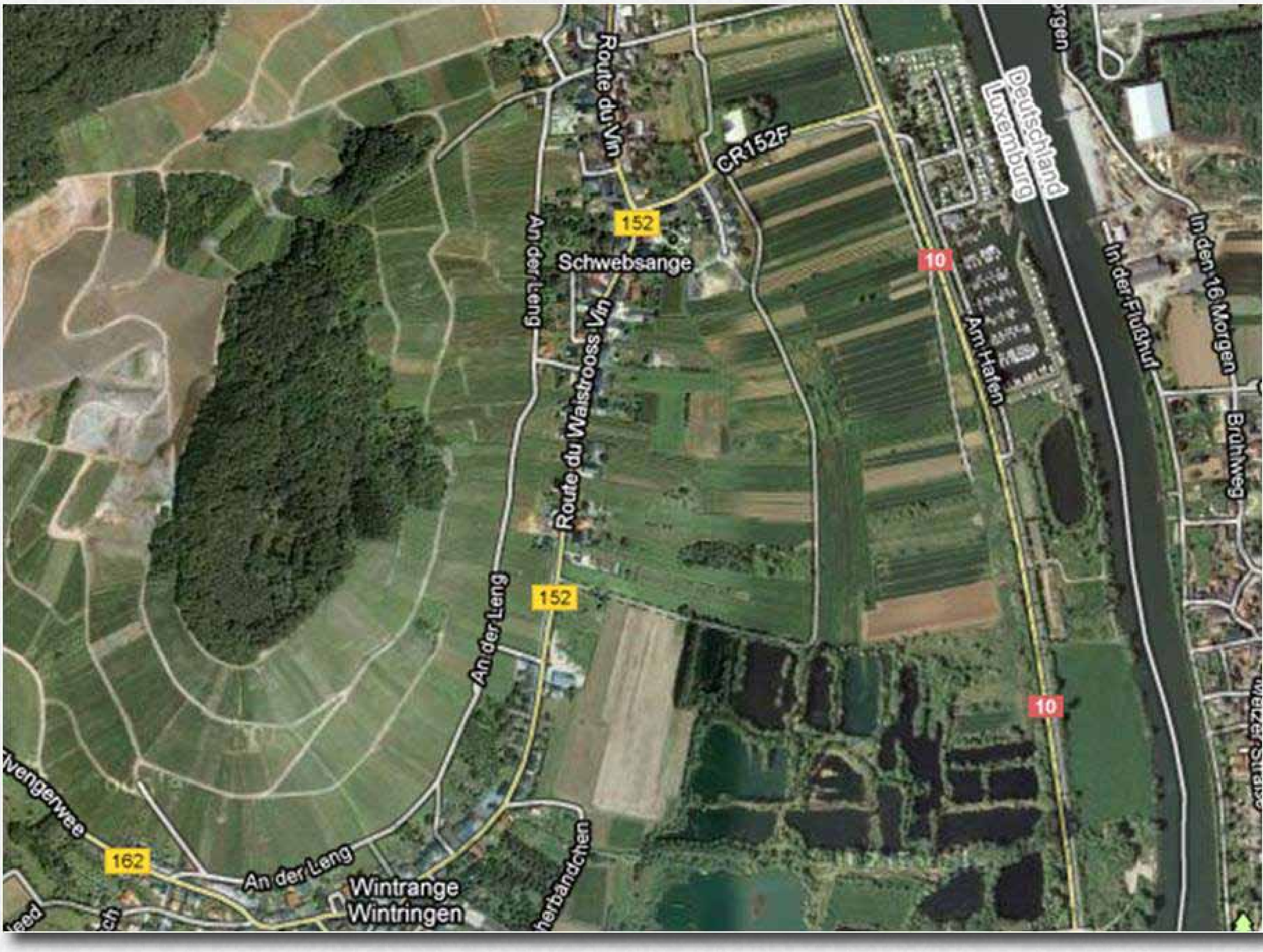
Figure 1.1.4 : the Deisermillen main landslide

and the slide develops a tendency to move uphill.
A few hundred meters south of the Longkaul, the scars of the quite large Deisermillen landslide can be observed (figure 1.1.4). The area, which was used for wineyard until the 1960's, is now covered by woods. Several springs whose catchment areas lie at the base of the dolomitic scarf are observed. The geological context is very similar to that of the Longkaul. The marls of the middle Muschelkalk are covered here also by thick slope debris, and a spring is observed. The water has been used until recent times to activate up to 4 mills. Topographic maps of 1958 show a undulated land surface, suggesting old slide movements due to erosion of the toe at the outer bank of the Mosel. In the winter 1964-1965 a very large movement has been triggered off affecting progressively the entire slope, destroying several buildings and pushing the valley road in the river. At the same period a similar slide happened on the German side of the river (Heyl, 1971). Works on the Mosel waterway had been done since the beginning of the 1960's. The water level of the Mosel had been raised by the Grevenmacher lock gate up to 4 metres. The higher water table reduced

the groundwater down flow rate and raised hydraulic pressure at the toe of the slope. At the same time earthworks at the new Mosel road reduced the load on the toe. A first destabilized lower slope slice of about 200 m length moved very rapidly to the river and affected by reducing the retaining forces the upper parts of the slope. The movement progressed uphill over a couple of months up to the dolomitic scarf dragging even some dolomite slabs.

September 5, 2012

Stop 1.2 : Schwebsange



The Luxembourgian Moselle valley between Wintrange and Schwebsange (source : Google Earth)

Stop 1.2 : Slope evolution west of Schwebsange

The Felsbesch is a hill situated on the western slope of the Moselle above the village of Schwebsange. The substratum is formed by red green and light gray dolomitic marls of Middle Keuper age, overlain by about 5 m of Rhaetic sandstone and red/black argillites. These rocks are very sensitive to changes in water content, which may strongly reduce their geomechanical properties. More than half of the landslides that occurred in Luxembourg are actually related to this unit. Dark gray marls (calcitic cement) of the lower Jurassic interbedded with limestones generally form the upper parts of the slopes. Due to their fracturation, the limestones and the Rhaetic sandstones are pervious and contain groundwater. Numerous springs with small but quite variable discharge rates are observed locally at almost every fractured layer.

Geomorphologic studies in the forefront of activities of land consolidation have shown that the northeastern part of the Felsbesch was affected by a large slump. Therefore, drillings and diggings have been undertaken in different slope positions on the eastern slope of Felsbesch to obtain further information on the subsoil and to assess the risk of new slumps due to the land consolidation. Further information on the subsoil could be obtained from a building pit. The outcropped sediments made it possible to reconstruct the evolution of this part of the Felsbesch (figure 1.2.1).

The present day morphology of the slope is dominated by the slump. The drilling cores made on the upper and middle slope indicate the presence of marl and slope debris. At the bottom of the slope, below the sliding masses, loamy sands (assumed to have been deposited by the Moselle) are interbedded with slope-deposits. Here, alternating effects of processes controlled by slope and fluvial dynamics appear. The contact between this unit and the marly bedrock is located at 143.5 m a.s.l. This value is comparable to that observed in various drillings for the bedrock of the terrace M1 defined by S.Cordier (2004) in the area (Naton et al., 2009). The sandy sediments can therefore be allocated to the terrace M1.

The marly deposits covering the terrace are divided into two parts by a fossil humus horizon, which has been radiocarbon dated at 383 cal BC (radiocarbon dating of a charcoal, KIA27891). Other radiocarbon datings of charcoals (yielding ages of 1893 to 1912 cal BC , KIA27892) and the presence of fragments of roman bricks within the sliding masses of the middle slope provide indication of persisting movements during the last thousands years.

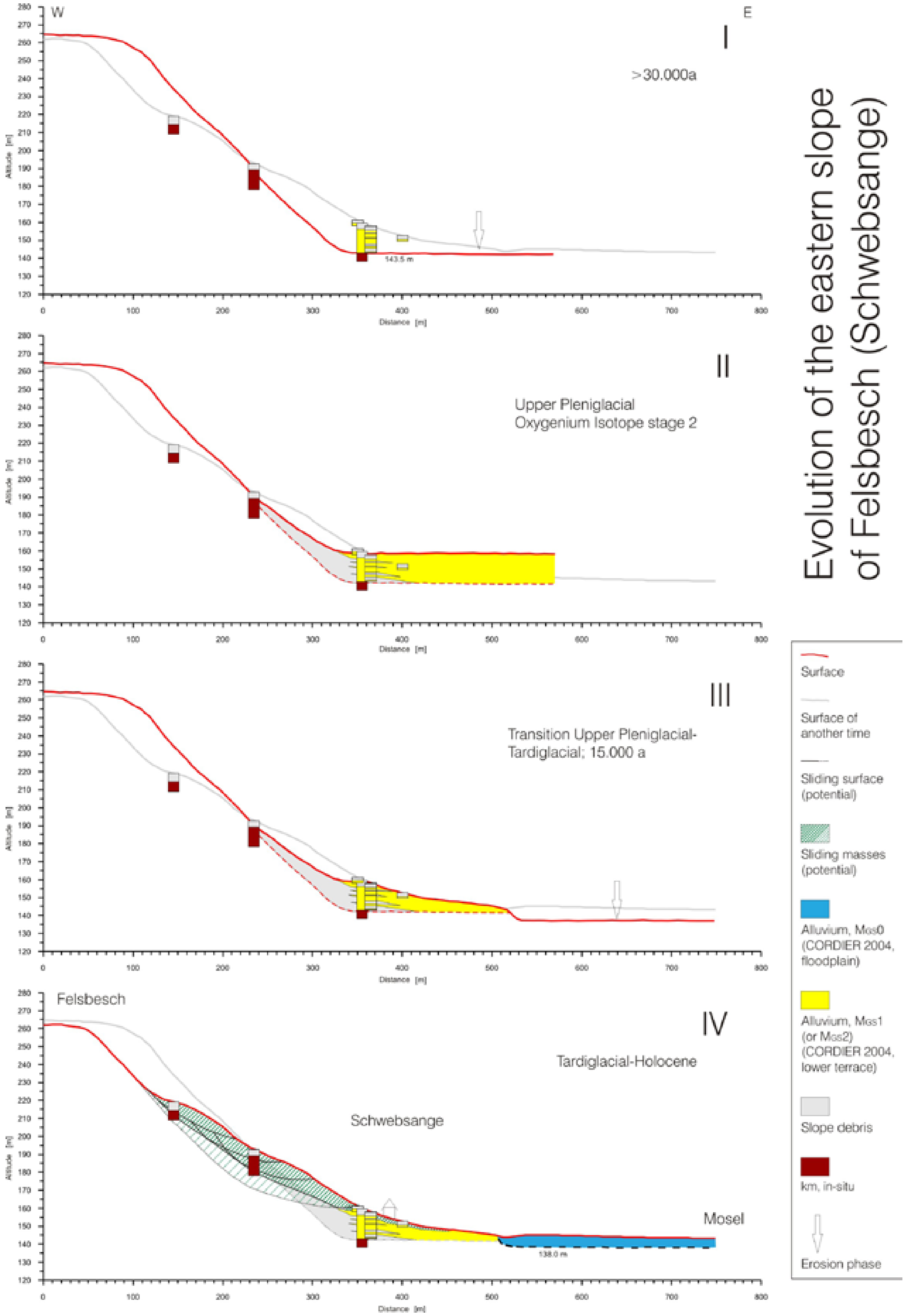


Figure 1.2.1: Late Pleistocene-Holocene evolution of the western slope of the Luxembourgian Moselle at Schwebsange

September 5, 2012

Stop 1.3 : Remerschen

Remerschen VI profile (picture : S. Cordier)

Stop 1.3 : Remerschen

Location

The area is located a few kilometres north of Schengen, between the villages of Remerschen and Wintrange, in the central part of the Wintrange alluvial basin. This basin is 10 km long (from Schengen to Remich) and up to 4 km wide. It is located between the Sierck gorge (where the Moselle flows through Buntsandstein sandstones and the Devonian Taunus Quartzites) and the Remich threshold exposing Muschekalk limestones (see cover picture). The Wintrange basin corresponds with a syncline depression developed in Keuper and Liassic marls. Fluvial terraces are more preserved on the right bank of the Moselle, where most of the terraces recognized in the French valley have been found (Cordier, 2004). In contrast, terraces remains are sparse on the Luxembourgian bank, except the lower terrace M1 (+3 m relative height) on which the villages of Remerschen and Wintrange have been built. The sediments of this terrace and the present floodplain M0 have been intensely quarried, leading to the presence of many ponds (figure 1.3.1).

The Pleniglacial complex of the Moselle valley at Remerschen

Georchaeological research related to rescue archaeology has been conducted over the past two decades by the Service d'Archéologie Préhistorique at the Musée National d'Histoire et d'Art (MNHA) of the Grand-Duchy of Luxembourg at several sites in the surroundings of Remerschen (Rem I to Rem VI, figure 1.3.1). This led to a palaeoenvironmental reconstruction of the valley evolution since the Pleniglacial (Naton *et al.*, 2009), made possible by the preservation (unusually for the Moselle catchment) of slope and aeolian deposits above the fluvial sediments of the lower terrace M1. Seven sedimentary units were identified (Fig. 1.3.2):

- Unit A: the bottom of the sequence consists of 6 m of coarse-grained alluvial deposits (gravels and boulders up to 0.5 m^3; Fechner and Langohr, 1994). The sediments are angular and included within a sandy matrix. The deposition of these boulders originating from Taunus quartzites outcropping a few kilometres upstream is attributed to ice-rafting, as recognized in other sections of the Moselle valley (Cordier *et al.*, 2006a). The other sedimentological characteristics suggest that the deposition of this coarse unit A is likely to have occurred in braided channels.
- Unit B: this unit (1 to 3 m in thickness) is made up of sandy sediments with trough cross- bedding, similarly attributed to a braided river.
- Unit C: this unit of varying thickness (between 50 cm and 2 m) is made up of a series of centimetre-scale beds of sands and silts. This facies is typical of natural levee deposits brought by a relatively unactive river.

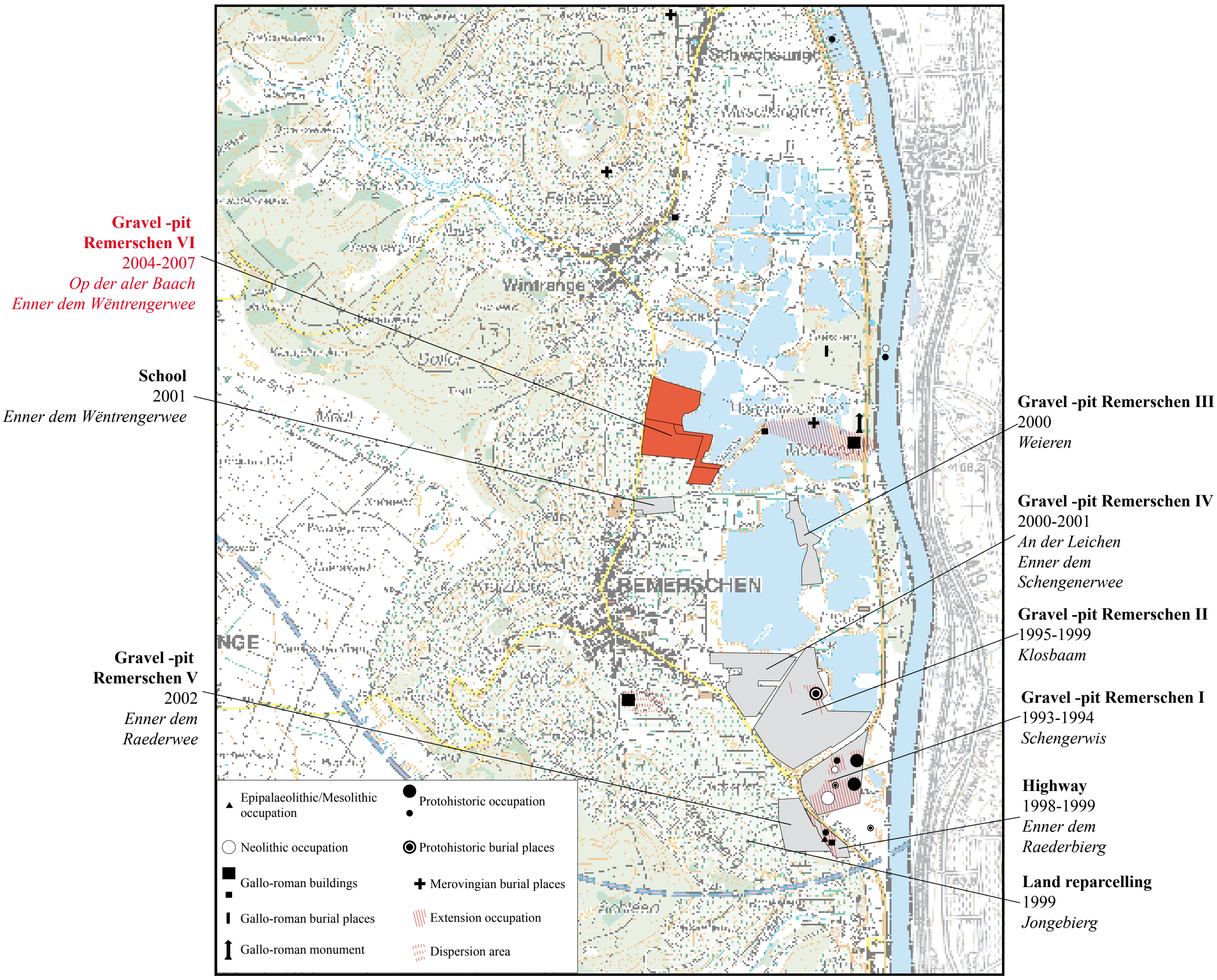


Figure 1.3.1 : Archaeological findings in the Remerschen area (by H.G. Naton)

These three units (A, B and C) correspond with the sedimentary body of the lower terrace M1. Furthermore, the fining-upward trend is typical of the Moselle fluvial deposits (Cordier *et al.*, 2006a).

- Unit D: above the fluvial sediments, Unit D consists of up to 50 cm of sandy loess at Rem IV and Rem V. Whilst calcareous concretions have been found at the bottom, the top of this unit is usually decalcified. Unit D has yielded a terrestrial malacofauna (including *Pupilla muscorum*, *Succinella oblonga* and *Trochulus hispidus*) typical of Pleniglacial loess and associated with cold, wet environments with minimal plant cover. At the *Jongerbierg* site, silty sediments correlated with Unit D have yielded a more diverse fauna, including *Pupilla alpicola*, *Pupilla loessica* and *Columella columella*. This assemblage is typical of wet conditions and suggests a steppe-like tundra (Moine, 2010). The spectrum is intermediate between the poor assemblages found in Northern France, and the rich spectra recognized in the Rhine area (Moine *et al.*, 2011). This molluscan record is richer than those found in Northern France, but poorer than

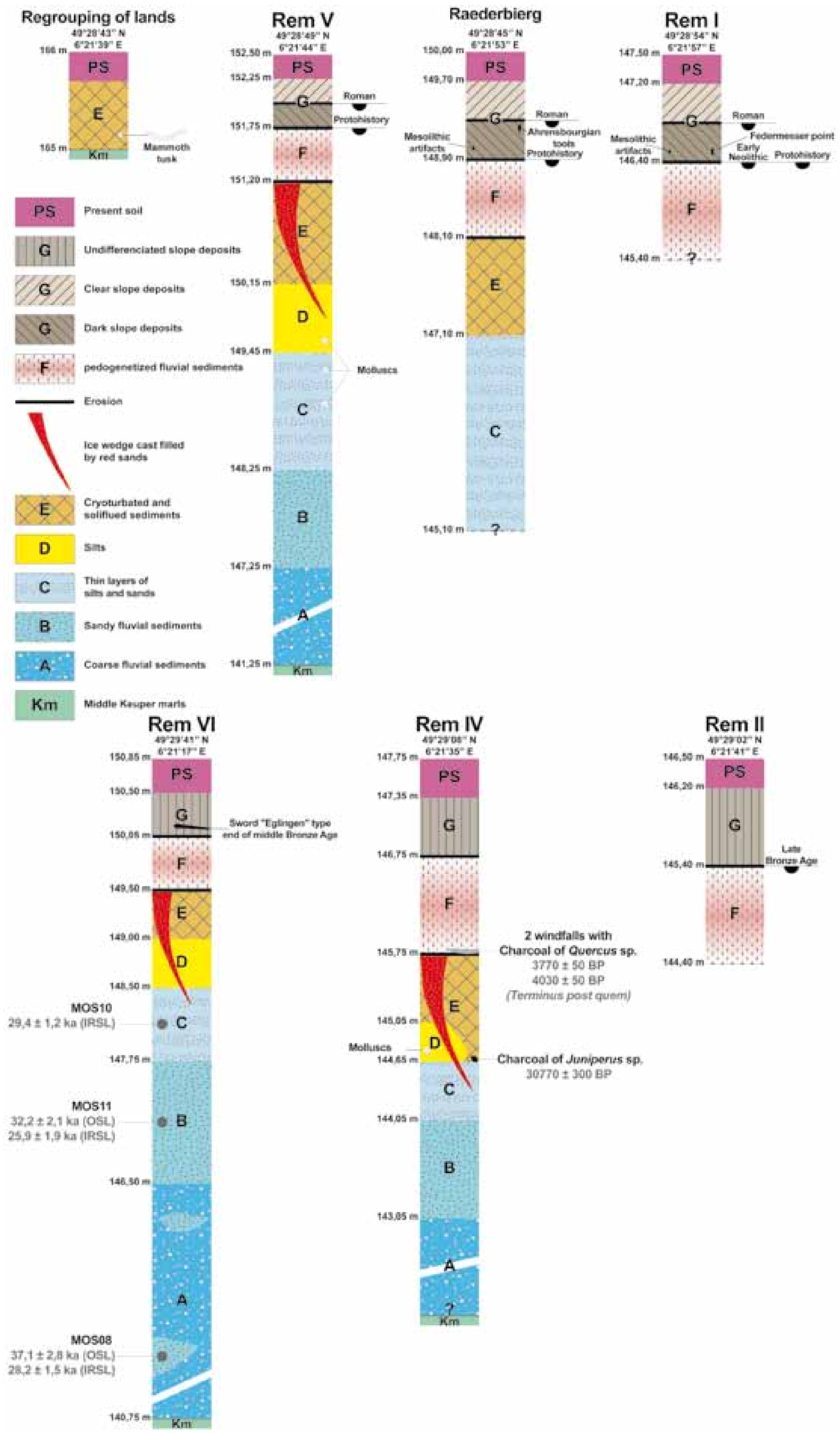


Figure 1.3.2 : Sedimentary logs of the mains sections of the Wintrange basin (by H.G. Naton)

those from the Rhine valley (Moine, 2008). It confirms that an interstadial warming occured during the Weichselian Upper Pleniglacial, as previously shown in the surrounding areas (Moine *et al.*, 2011).
- Unit E: sediments from units C or D are overlain by marly slope deposits (less than 1 m in thickness), soliflucted from the left bank slope of the Moselle River (Keuper marls). The sediments from units D and E exhibit various cryoturbation features (involutions, plications, ice-wedges, etc; figure 1.3.3), allocated to the

1.3.3 a - Involutions

1.3.3 b - Plications

1.3.3 c - Ice-wedge cast

1.3.3 d - Ice-wedge cast

Figure 1.3.3 : Cryoturbation features in the Remerschen sediments © MNHAL

presence of a discontinuous permafrost (Cordier *et al*., 2006a). Ice-wedges are locally filled with well-sorted reddish sands, originating from the older fluvial terraces preserved on the left bank or deposited through a resumption of fluvial activity. These sands may be allocated to Unit F.
- Unit F: this sandy unit is approximately 1 m thick and consists of sands showing alterations resulting from temperate pedogenesis (oxidation, ferro-manganese concentrations, root traces, etc.). The age of this unit remains unclear. Neolithic and Protohistorical archaeological structures have been found at the contact between this unit and Unit G.
- Unit G: this unit is located just below the present soil. It is c.1 m thick and consists of slope deposits. A dark lower layer (subunit G1) can be locally distinguished from a paler upper layer (subunit G2).

Dating techniques have been applied to sediments from several units. Luminescence dating based on quartz (OSL) and feldspars (IRSL) at Rem VI yielded Weichselian Middle to Upper Pleniglacial ages (approximately MIS 3-2 transition) for the fluvial sands of units B and C (Fig. 1.3.2; Cordier *et al.,* 2010). At another site (Rem IV), a *Juniperus* charcoal fragment recovered from between units C and E yielded an AMS age of 30 770±300 BP (Beta-182248). However, the precise location of the charcoal remains unsure as the units are affected by periglacial deformations (wedges, etc). The charcoal may have been transported with the marly deposits (Unit E) originating from the upper slope. Its size (several mm) suggests a mass-transport, which can be younger than the AMS age obtained. However, this result is consistent with the luminescence ages and allows the deposition of units A to E to be allocated to the Weichselian Middle to Upper Pleniglacial. This reconstruction is consistent with the assumed Lateglacial to Holocene age of the present Moselle floodplain M0 (Carcaud, 1992), and with the chronology for loess deposition in surrounding areas (Northern France, Belgium, Upper Rhine Graben).
A series of AMS dates was also been obtained using remains preserved in structures developed in Unit F (Damblon and Hauzeur, 2009). These provided ages of 6320±50 and 6110±60 BP (e.g. 5230 to 5060 cal BC with a 2σ calibration) for the Early Neolithic structures preserved at Rem I. The dating of two *Quercus sp*. charcoal fragments sampled in the lower part of Unit F at Rem IV yielded Sub-Boreal ages (Beta 157202 : 3770±50 BP, Beta 157203 : 4030±50 BP). Even if an old-wood effect (charcoals originating from the vicinity of the sapwood) should not be excluded (especially in the case of oak), these ages are considered to be consistent and provide a *terminus post quem* for Unit F. At the top of this unit occur cremation urn burials dating from the late Bronze Age at Rem II-*Klosbaam*. At Rem I, Early Neolithic structures (Atlantic) cut across sediments supposedly analogous to Unit F, suggesting a diachronic age for this

unit. It has, however, proved difficult to provide reliable correlations between the archaeological sites Rem I, Rem II and Rem IV. The youngest archaeological structures found within Unit F at Rem I-*Schengerwis* date from the Iron Age. A human bone from a silo-burial was dated to 2220 ± 40 BP (Beta 155324) and two beech charcoal fragments were dated to 2155±45 BP (GrA 23808) and 2145±40 BP (GrA 23668).

Finally, research conducted in the Remerschen-Wintrange area has allowed a tentative reconstruction of palaeoenvironments since the Last Glacial Maximum, and provided a chronostratigraphical framework for the archaeological remains found there.

Human occupation in the Wintrange basin

The oldest archaeological remains in the Moselle valley mainly date to the Middle Palaeolithic. They have been found on the surface of Triassic rocks or older terrace deposits. These surface sites have yielded artefacts from various lithic industries including flint knapping by-products (cores, Levallois flakes) as well as tools (e.g. scrapers, denticulates). The raw material was obtained either from terrace sediments (quartzite gravels) or from local rocks (Muschelkalk flints, Bajocian cherts, quartz; Rebmann *et al*., 2001). The Mousterian industries were manufactured using recurrent centripetal knapping technique, with a predominance of the discoidal or Levallois methods (Le Brun-Ricalens *et al*., 2011). Dates for this material range between 300 and 40 ka (Jaubert, 1999; Delagnes *et al*., 2007).

Upper Palaeolithic industries have only been found in tributary valleys and belong to the recent Aurignacian (Brou *et al*., 2009) and the Gravettian. Late Glacial industries are sparsely represented, which is surprising considering their abundance in surrounding areas. In the Remerschen-Wintrange basin (at *Raederbierg*, Fig. 2), an epi-Ahrensbourgian industry (late Younger Dryas-Early Preboreal) and an Iron Age structure have been found within the slope deposits of Unit G and in the underlying Unit F, respectively (Brou 2001). We assume that the slope deposits were transported only a short distance and are related to soil erosion during Roman times. Finds related to the Mesolithic period are sparse and located on the surface. The lack of Mesolithic artefacts can be interpreted as a consequence of natural and/or anthropogenic slope erosion. In contrast, several well-preserved Neolithic sites have been recognized in the Wintrange basin. An Early Neolithic village (upper and late Linear Pottery Culture) at Rem I-*Schengerwis* has been studied since 1993 (Hauzeur 2006). The structures were preserved at the top of clayey sand deposits allocated to Unit F. Anthracological analysis has provided a better knowledge of the forest landscape and its use by humans. Six types of vegetation were identified: shoreline vegetation, alluvial forest, ravine and lower slope forest, forest edge, living hedges and clearings with pioneer stages of the floral succession (Damblon *et al.*, 2007; Damblon and Hauzeur 2009). The predominance of oak is consistent with an Atlantic climate but may also be the result of human preferences (use for building purposes). However, no direct anthropogenic influence on the fluvial dynamics of the Moselle at that time has been clearly recognized.

With the exception of small isolated objects, no signs of human occupation during the Late Neolithic and the Late Bronze Age are known. However, a cremation necropolis attributed to the latter period has been found at Rem II-Klosbaam near the Neolithic settlement (Nicolas and Le Brun-Ricalens, 2010). The structures were found in sandy-clay sediments similar to those on which surface the Early Neolithic and second Iron Age structures were discovered.

Increasing human occupation during Gallo-Roman times is attested by numerous finds. Several clusters of buildings and a large villa have been found. A few kilometres north of the Wintrange basin, a villa was recognized each 1.5-2.5 km. In the Remerschen area, there is evidence for the development of farming (cereal cultivation, vineyards) and, as a consequence, increased soil erosion. This led to the destruction of many features from earlier periods and to the levelling of the microreliefs associated with previous fluvial evolution (progressive filling of small fluvial depressions by slope deposits that may have continued after the Roman period until nowadays). The banks of the Moselle were also stabilized, and a portion of an ancient Roman road has been found at Schengerwis, 100 metres away from the present riverbank.

To summarize, human occupation in the Wintrange basin has been more or less continuous since the Middle Palaeolithic, with a hiatus recognized between the Early Neolithic and the Late Bronze Age. This hiatus is probably due to the presence of many gravel pits in the area, which destroyed about 30% of the land surface before geoarchaeological research could commence. Humanly-induced erosion, local topography and the type of structure (deep pits or postholes) also explain the uneven preservation of these sites. Erosion may have started during the Late Bronze Age and increased during the Iron Age, culminating during the Roman period. The acceleration of soil erosion is confirmed by research conducted in the German Moselle valley: in the Trier area (about 40 km downstream from Remerschen), fluvial sedimentation rates increased from 0,14mm/year before the Roman conquest to 2.6 mm/year during the Roman period (Zolitschka and Löhr, 1999). Accordingly, the slope deposits from subunits G1 and G2 may be attributed to the pre-Roman and Roman/post-Roman periods respectively.

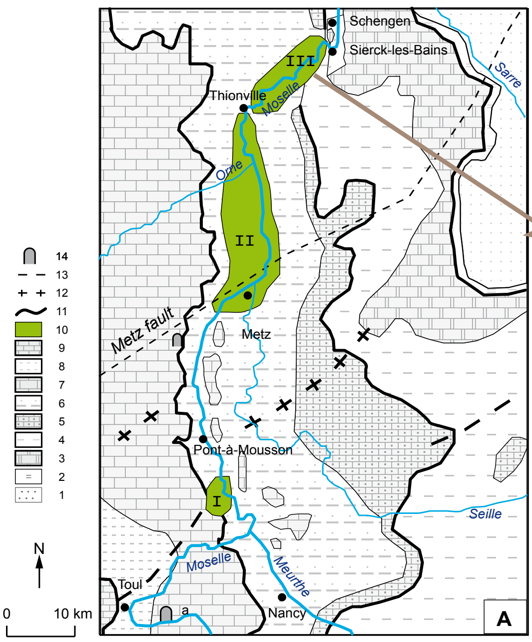
September 5, 2012

Stop 1.4 : The Val de l'Âne palaeovalley

The Upper Moselle palaeaovalley (« Val de l'Âne ») and the Meuse cuesta (picture : S. Cordier)

Stop 1.4 : The Upper Moselle capture area

Between the Moselle-Meurthe confluence at Frouard (North of Nancy) and Schengen, the Moselle flows through a broad valley mainly developed in the Triassic and Liassic marls and clays. Between Frouard and Thionville, the river flows from south to north, parallel to the Dogger cuesta. Downstream from Thionville, it has a SW-NE orientation and drains successively the Liassic and Triassic layers, before forming a gorge in the Buntsandstein sandstones and the Devonian basement between Sierck and Schengen. Except in this gorge, the valley floor is typically wide, and terraces staircases are well preserved in the Dieulouard, Metz-Thionville and Thionville-Sierck alluvial basins (figure 1.4.1; Cordier, 2004).



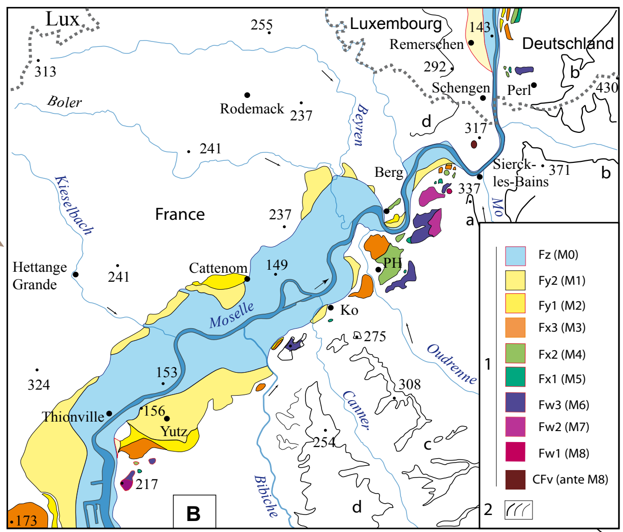


Fig. 1.4.1 : The Moselle fluvial terraces between the Meurthe confluence at Frouard and Schengen : A : the alluvial basins, B : the terrace staircase between Thionville and Schengen

A : 1 : Carboniferous, Permian and Triassic sandstones, Lower and middle Muschelkalk : marls and dolomites, 3: upper Muschelkalk : limestone, 4 : Keuper marls, 5 : Lower Liassic limestone (Calcaires à Gryphées), 6 : Liassic marls, 7 : Bajocian limestone, 8 : Bathonian and Callovian marls, 9 : Oxfordian limestones, 10 alluvial basins A : Alluvial basins : I : Dieulouard, II : between Metz and Thionville, III : between Thionville and Schengen, 11 : cuestas (a : Buntsandstein cuesta, b : Muschelkalk cuesta (cuesta of Lorraine), c : Rhetian sandstone cuesta, d : Hettangian-Sinemurian cuesta (*Calcaire à gryphées*), e : Dogger cuesta (cuesta of Moselle), f : Oxfordian cuesta (cuesta of Meuse), 12 : anticline axis, 13 : synclinal axis, 14 : karstic caves. A *: Altenberg, Ko : Koenicksmacker, PH : Petite Hettange, Ma : Ruisseau de Manderen, Mo : Ruisseau de Montenach;*
B : 1 : fluvial terraces (after Cordier, 2004), 2 : cuesta ridges and outliers

Figure 1.4.1 : The Moselle fluvial terraces between the Meurthe confluence North of Nancy and Schengen

Five to seven stepped terraces have been recognized and labeled from M1 the youngest (+3 m relative height) to M7 the oldest (+70 m relative height; figure 1.4.2). Residual deposits have been locally found at higher relative heights, in particular at the top of the Dogger cuesta. This contrasts with the Rhenish Massif (excursion day 3), where wide terraces associated with thick fluvial sediments are largely preserved above 100 m relative height (see day 3).

Sedimentological evidences for the capture

Petrographical and mineralogical analyses have been performed of sediments from the fluvial terraces preserved in the three above-mentioned alluvial ba-

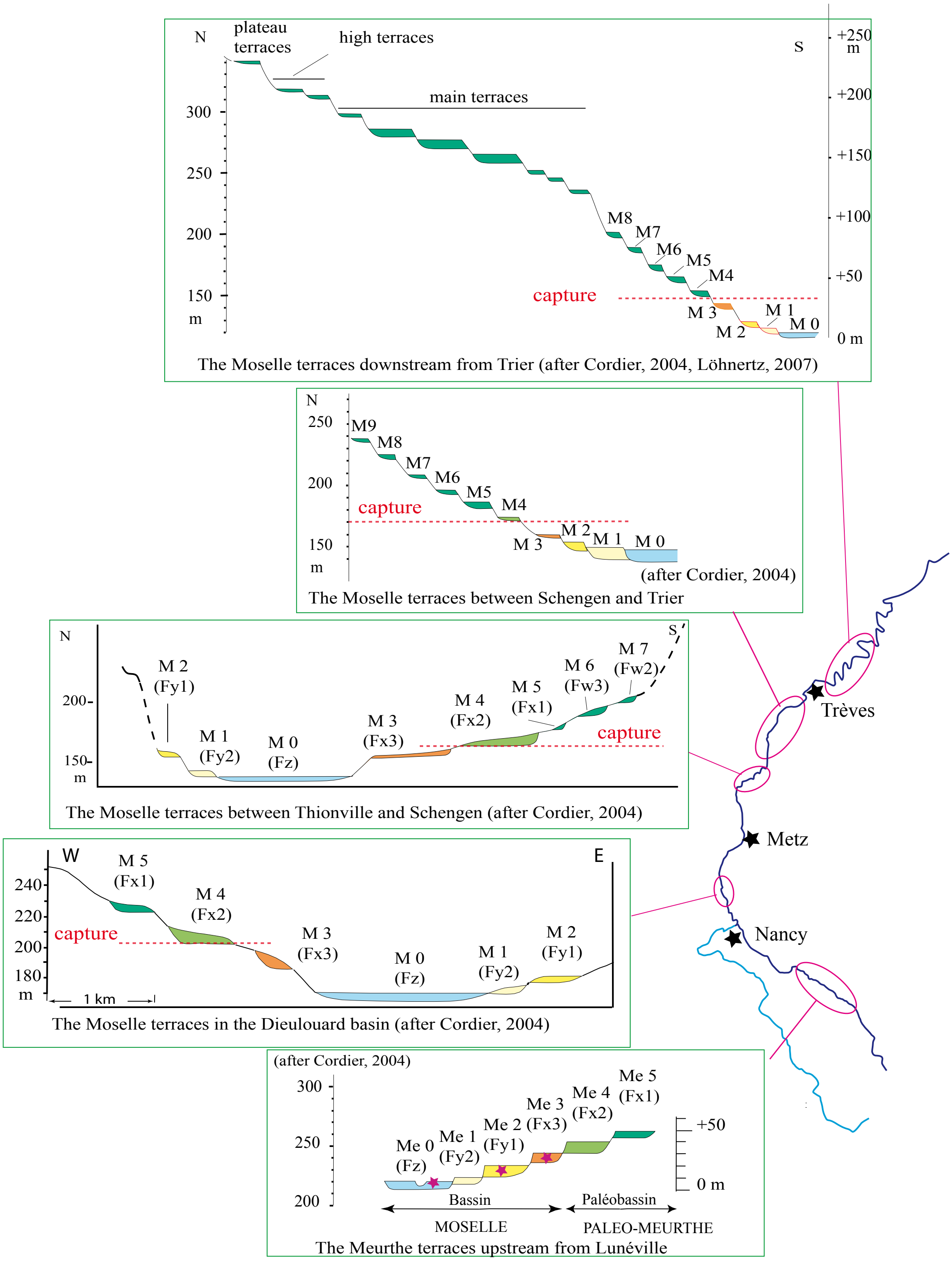


Figure 1.4.2 : The terraces staircases of the Meurthe and Moselle downstream from the Meurthe confluence

sins. The predominance of siliceous sediments first confirms the Vosges Massif as the main sediment source for the Moselle and its tributary the Meurthe in the Eastern Paris basin. However, a major contrast has been recognized between the alluvial formations situated at more than 30-35 m relative height, and the alluvial formations M3 to M0 (figure 1.4.3).

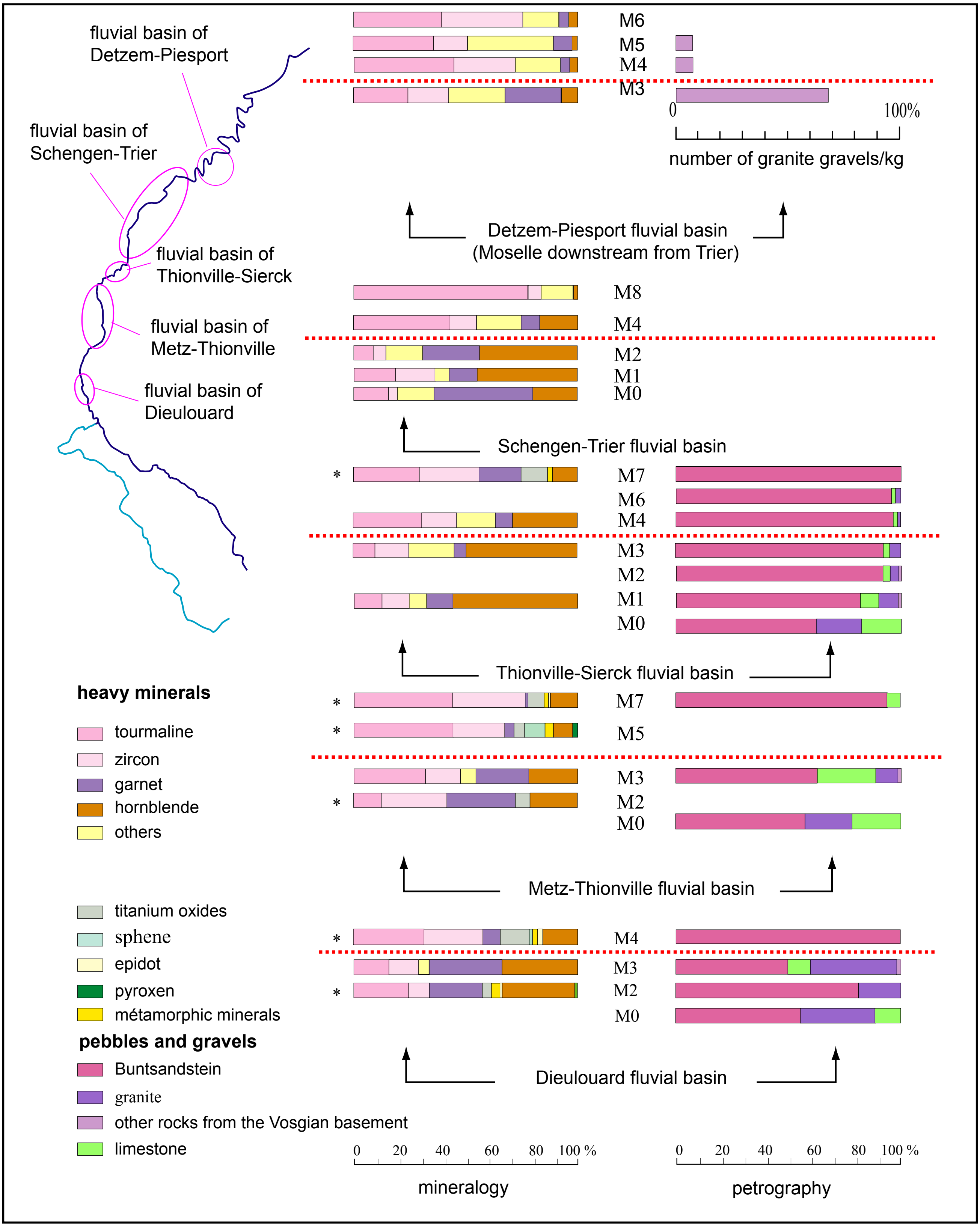


Figure 1.4.3 : Mineralogical and petrographical results for the Moselle terraces between Frouard and Schengen. The major change in sediment composition between M4 and M3 is related to the capture event.

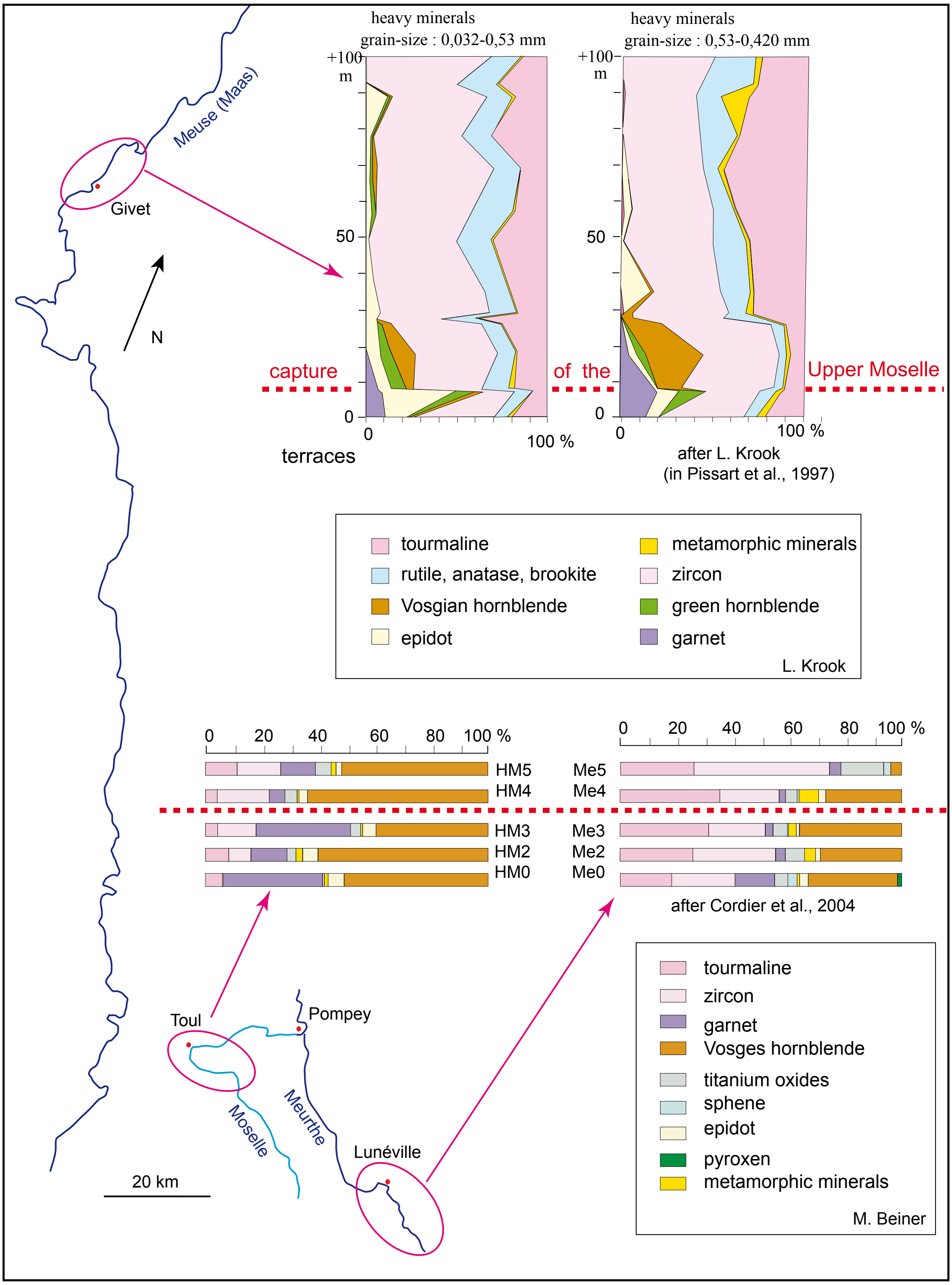


Fig. 1.4.4 : Mineralogical and petrographical results for the Meurthe, the Upper Moselle (Toul area) and the Ardennes Meuse (Givet).

- the older alluvial terraces (M7 to M4) are mainly composed of sediments that originated in the Permo-triassic layers : 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);
- 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, and the proportion of granites may reach 20%.

This change has to be related to the sediment composition of the Moselle and its tributary the Meurthe upstream from their confluence (Cordier *et al*., 2005; figure 1.4.4): the Meurthe fluvial sediments include a high component of tourmaline and zircon, associated with quartz and quartzite gravels. This proves the importance of the Permo-Triassic layers (especially the Buntsandstein sandstones) as a sediment source. For its parts, the Moselle sediments include a significant proportion of sediments coming from the Vosges crystalline basement (hornblende and garnet, granite gravels). This contrast has obviously to be related to the lithology of the Vosgian catchments of both rivers: while 75% of the Meurthe Vosgian catchment is developed in Permo-Triassic layers, 75% of the Upper Moselle catchment is developed in the crystalline basement.

Following from this, the contrast between the M3-M0 formations and the older formations downstream from Frouard is interpreted as a consequence of the famous Upper Moselle capture. This capture event led the Upper Moselle to abandon its former course westwards of Toul towards the Meuse, to reach its present-day course. The capture event should hence be positioned between the formation of terraces M4 and M3 of the alluvial system (Cordier et al., 2005).

The Upper-Moselle capture has also been recognized in the Meuse valley in the Ardennes Massif (Pissart *et al*., 1997): While the present-day Meuse only flows through the carbonate strata of the Paris basin, the fluvial sediments preserved in terraces located at more than 10m above the present Meuse show a significant component of crystalline sediments from the Vosges Massif (especially hornblende), proving that the Moselle previously joined the Meuse. In contrast, the younger sediments only contain little reworked hornblende, showing that they were deposited after the Upper-Moselle capture.

Morphology of the Upper Moselle capture area

From a morphological point of view the Toul area, where the capture took place, associates the presence of two main cuesta ridges with the preservation of many evidences of the capture event (figure 1.4.5). From East to West, the relief is composed of : 1) the Infralias cuesta (East of Nancy), 2) the Liassic orthoclinal depression (where the city of Nancy is located), 3) the Moselle cues-

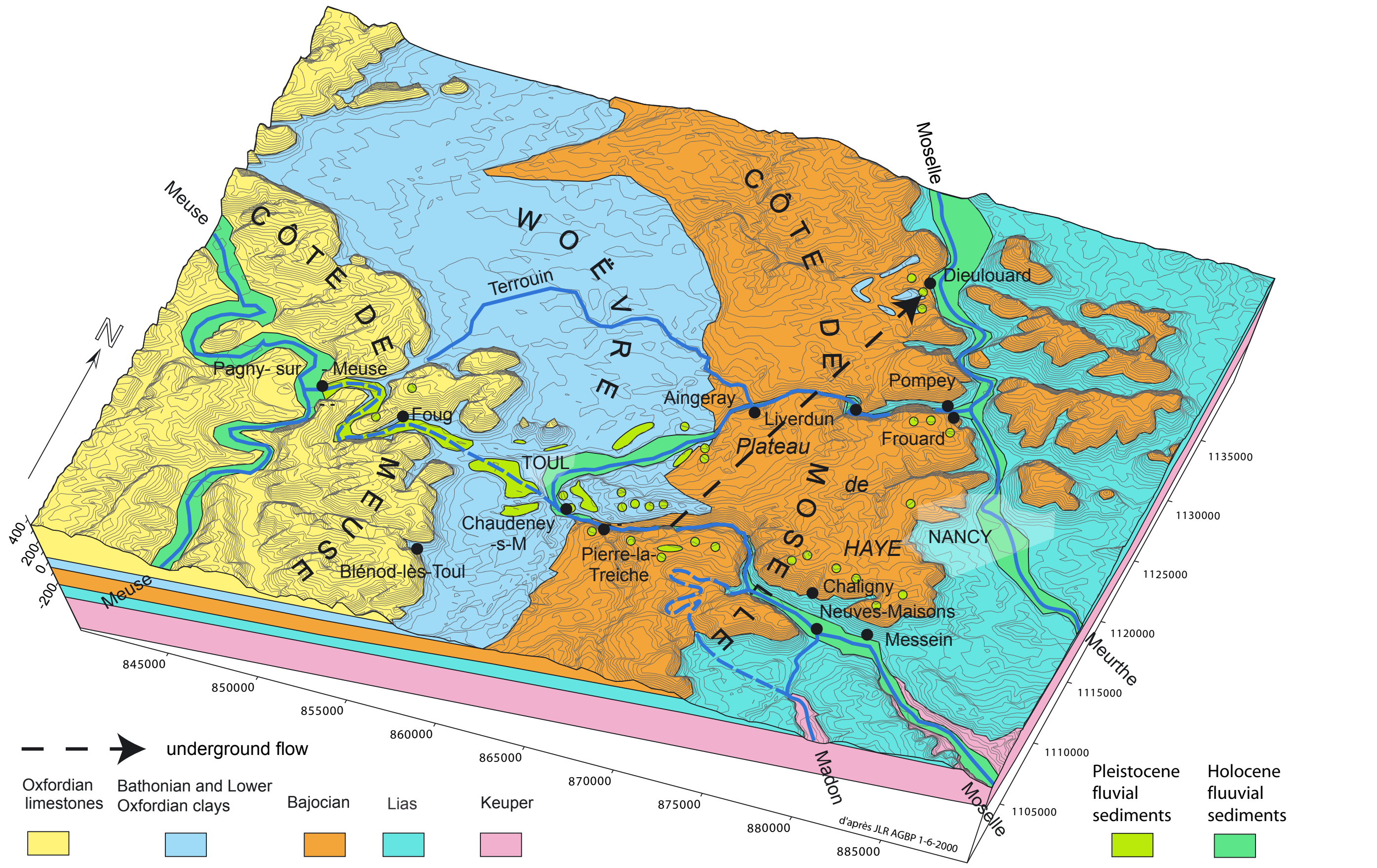


Figure 1.4.5 : Block diagram of the upper Moselle capture area (after Jacques Le Roux, 2006)

ta (Dogger cuesta), crossed by the Moselle at Neuves-Maisons (SW of Nancy, cataclinal breach) and near Frouard (anaclinal breach), 4) the Woëvre clayey orthoclinal depression, 5) the Meuse cuesta with three breaches (from South to North: Val de l'Âne, Val de Trondes and Val de Boncourt), and 6) the Meuse cuesta dip slope.

The Toul-Nancy area corresponds with the easternmost parts of the Moselle and Meuse cuesta (and their associated outliers such as the Mont-Saint-Michel near Toul). The preservation of these "spurs" is explained by their location in the Savonnières-Dieulouard synclinal structure.

Upstream from Toul, the Upper Moselle flows through the Bajocian limestones where fluvial terraces have been preserved (Losson, 2003). Additionally, numerous karstic caves have been formed, some of them being filled with fluvial sediments of the Moselle (see stop 1.5). While the present-day Moselle presents a capture elbow in the vicinity of Toul, the pre-capture river flowed westwards of Toul through the Val de l'Âne valley. This broad valley exhibits well-preserved entrenched palaeomeanders. However, it is now only occupied by two small streams, the Ingressin and the Ruisseau du Vieux Moulin, which join the Moselle and the Meuse, respectively.

The study of the numerous drillings performed in the area (especially along the motorway RN4; Harmand, 1992) and field work allowed a fine geomorphological mapping of the capture site (Harmand et al., 1995; figure 1.4.6). Two fluvial formations are largely preserved near Toul :
-the thickest formation (labeled Fx1) is located at 40 m above the present Moselle. It is associated with the Justice terrace (Flageollet and Vincent, 1985), corresponding with the M5 terrace. Above the Callovian bedrock (located at about 240 m asl), the Fx1 formation exposes up to 4 metres of coarse sediments (quartz and granite gravels), covered by c.5 metres of siliceous sands and silts.
-the second formation (Fx2) is younger. It is associated with terraces at Écrouves and Toul (corresponding with terrace M4, + 30m relative height). These terraces are only residual due to the post-capture dissection by the Ingressin stream. The formation Fx2 is also well preserved in the Val de l'Âne palaeovalley where it has been covered by slope deposits. These slope deposits are a few metres thick in the Choloy-Menillot/Grandmesnil area. In contrast, their thickness may exceed 25 m in the Val de l'Âne palaeomeanders (Harmand, 1992), and reaches 16m near the Meuse confluence (figure 1.4.7).
The morphostructural investigations coupled with the research on fluvial terraces made it possible to propose a reconstruction of the landscape evolution in the vicinity of Toul since the end of the Tertiary (Le Roux and Harmand, 1998; figure 1.4.8).
Before the Pleistocene incision (stage 410-420m), the Upper Moselle and the Palaeo-Meurthe flowed in a landscape without well-developed reliefs. The cuesta ridges were located c.20km further East than today. The subsequent fluvial incision coupled with the westwards recession of the cuesta ridges allowed the broadening of the Woëvre depression and the first changes in the hydrographic network, especially for the Palaeo-Terrouin (stages 370-350m). At stages 300-270m, the erosion of the Woëvre clays allows the development of karst in the Bajocian limestones (see stop 1.5) and the formation of entrenched valleys. Subsequently, the fluvial incision leads to the duplication of the Moselle cuesta North of Nancy (stage 240). At this time, the Meurthe valley is developed in the Liassic marls and its height is lower than that of the Upper Moselle flowing through karstified limestones. Additionally, the incision of the Palaeo-Terrouin allows to lower the altitude of the interfluve between the Upper Moselle and the Meurthe, and the capture of the former. Since the capture event (stages 220-200m), the relief evolution was limited, except the incision of the Moselle (30 m).

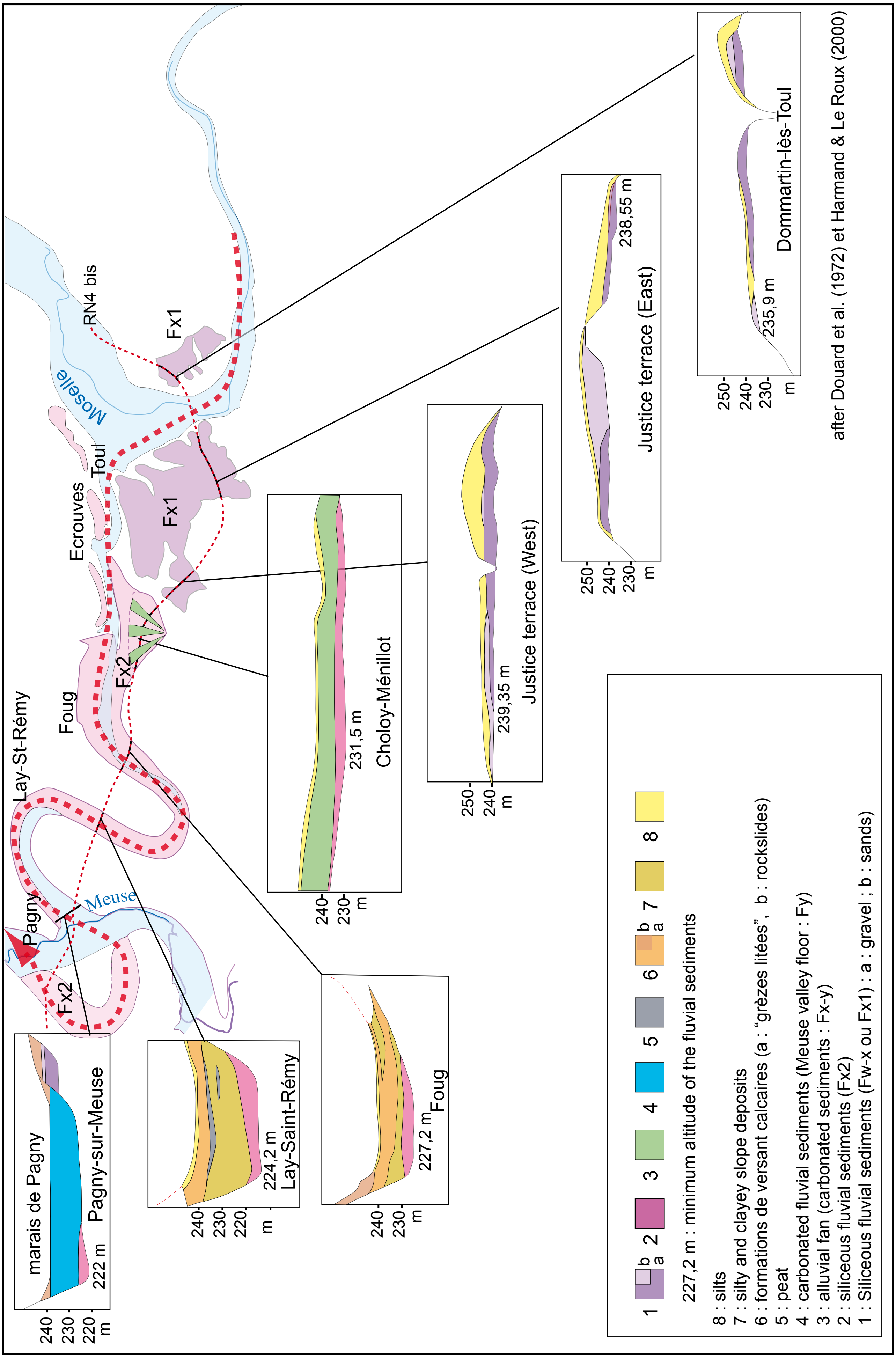


Fig. 1.4.6 : The pre-capture fluvial formations in the Val de l'Âne palaeovalley (along the RN4 motorway)

Figure 1.4.7 : The pre-capture course of the Moselle towards the Meuse : A : ancient cataclinal breach of the Upper Moselle through the Meuse cuesta, B : the Savonnières palaeomeander , C : the Justice terrace, 8 : cross section of the Vosgian fluvial sediments south of the Justice terrace in 2008

Mechanisms for the fluvial capture

The occurrence of the Upper-Moselle capture results from a combination of regional and local factors. At the scale of the Meuse and Rhine catchments (figure 1.4.9), the Pleistocene fluvial incision in the area related to the crustal conditions (Westaway et al., 2009) is more pronounced in the Rhine catchment than in the Meuse catchment. The chronological framework actually suggests that the incision during the last million of years in the southern edge of the Rhenish Massif can be estimated at more than 100m in the Moselle valley (Trier area) but only 20m in the Meuse valley (Charleville-Mézières area). The influence of the structural Barrois threshold was also fundamental. The Barrois threshold corresponds to the border between the Paris basin (stricto sensu) and the Lorraine Triassic basin. It was active during the Jurassic and the Early Cretaceous, but corresponded to a depressed area during the formation of the hydrographic network at the end of the Cretaceous (Le Roux and Harmand, 2003; Harmand and Le Roux, 2009). The Barrois threshold broadly corresponds to the present Meuse catchment in Lorraine. The rivers also has a surelevated location in comparison with the Seine and Moselle catchments, resulting in several capture events (Upper-Moselle capture but also Ornain-Saulx and Aire capture events; Harmand et al., 2002; Harmand, 2007; Harmand and Le Roux, 2009; Harmand and Cordier, 2012, this volume) . The capture events that took place in the Eastern Paris basin should therefore be interpreted as readjustments of the hydro-

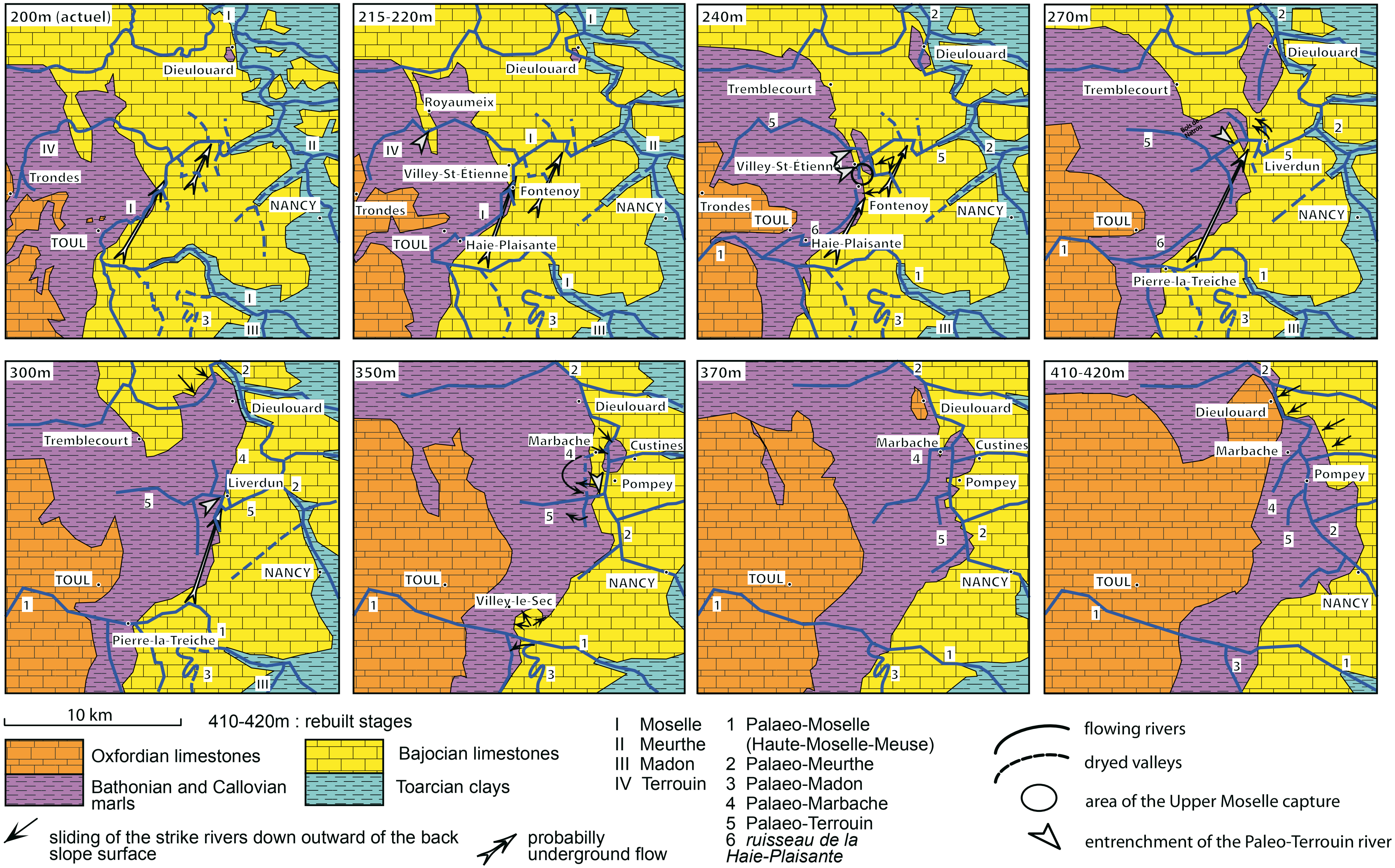


Figure 1.4.8 : Plio-pleistocene landscape evolution in the vicinity of Toul (after J. Le Roux, 2006). The reconstruction underlines the recession of the cuesta ridges and the associated hydrographic changes.

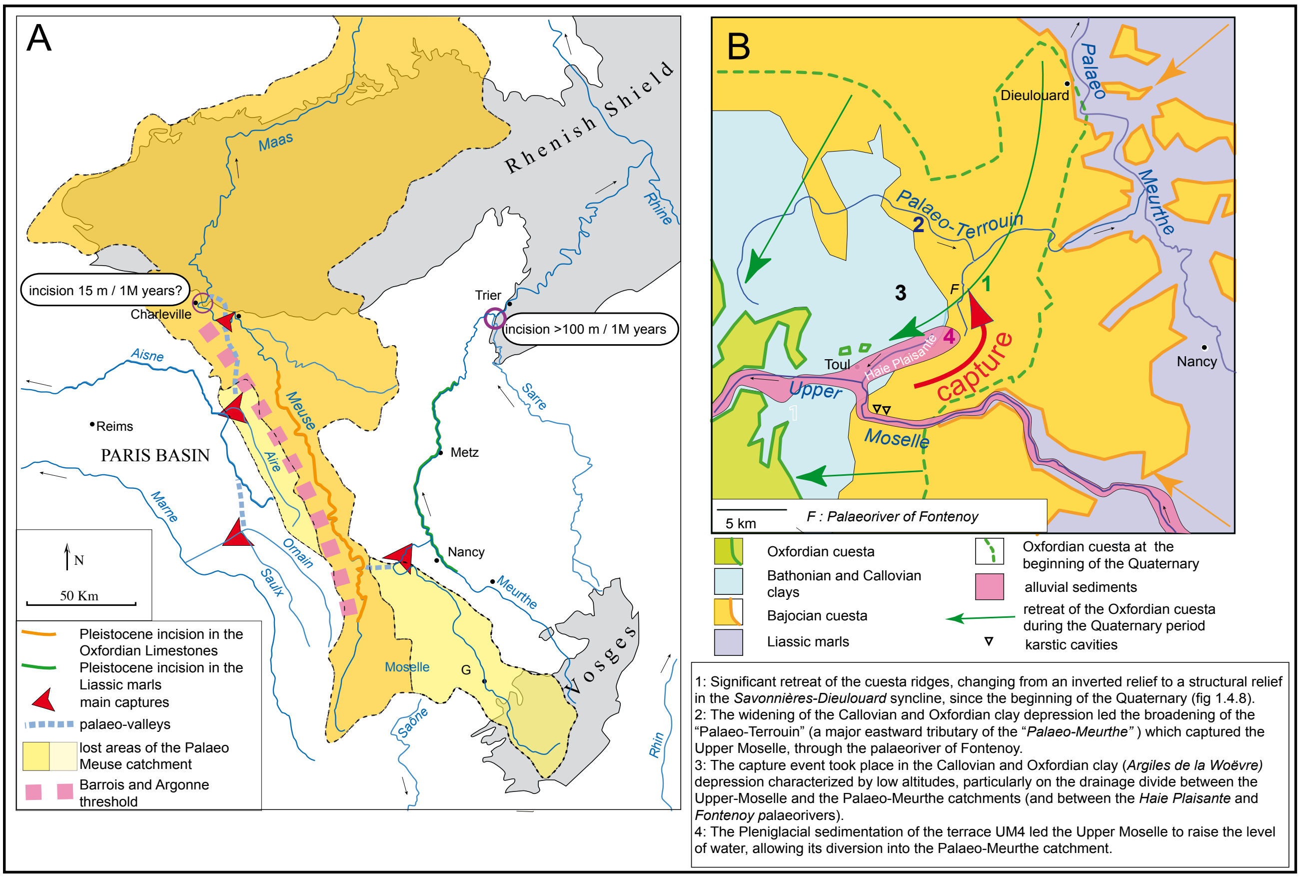


Figure 1.4.9 : General (A) and local (B) factors of the Upper Moselle capture

graphic network to the Cenozoic structural conditions. It is also likely that these capture events and the resulting loss of water partly explain the less pronounced Pleistocene incision of the Meuse in the Rhenish Massif (Pissart et al., 1997).

The climatic conditions should also be taken into consideration: palaeoenvironmental reconstructions suggest that the Upper-Moselle capture took place at the end of cold periods (lato sensu). Following from this, it is likely that this cold-period sedimentation led the river (and their tributaries) to raise the level of water, allowing diversion into another catchment (Harmand et al., 1995, 2002).

At a more local scale, the lithological factor should be taken into consideration: the capture event took place in a clayey depression (Callovian clays), located (when following the pre-capture rivers) upstream from a gorge section (Jurassic limestones exposed west of Toul). In contrast, the downstream section following post-capture rivers is developed in soft rocks (Liassic marls). This contrast led to a more pronounced incision in the Palaeo-Meurthe valley: before the capture, the Moselle (mainly flowing through the Bajocian limestones) flowed at a higher altitude (240 m near Toul) than the Palaeo-Meurthe flowing through the Liassic marls (220m at the present confluence). Finally, the capture event took place in the above-mentioned Savonnières-Dieulouard synclinal structure. This allowed a significant westwards recession of the cuesta ridges during the Pleistocene and a lengthening of the Palaeo-Terrouin course, enabling this small tributary of the Palaeo-Meurthe to realise the capture.

September 5, 2012

Stop 1.5 : Pierre la Treiche

An alluvial filling in a cave of Pierre la Treiche (picture B. Losson)

Stop 1.5 : the Pierre la Treiche caves and their alluvial filling

Just east of Toul, the Moselle flows twice (from SE to NW and from SW to NE) through the Bajocian limestones of the Dogger cuesta, isolating the small Haye Plateau (figure 1.5.1). The limestones are karstified and a complex system of caves is developed upstream from Toul. The caves are located at various heights on the slopes of the Moselle valley (figures 1.5.2). The most developed galleries have been recognized in the vicinity of the village of Pierre la Treiche, on the right bank of the Moselle. They have been formed as the result of pre-capture partial underground defluviations of the Moselle towards the Palaeo-Meurthe. Near Pierre la Treiche as in the vicinity of Toul (see stop 1.4), the younger terraces (from M5 to M1) are well preserved (Losson, 2003; figure 1.5.2). Sedimentological analyses of the associated formations demonstrated that the composition and weathering of the sediments varies from one formation to another. The sediments associated with the last pre-capture terrace M4 (Fr4) have been found just above the caves, while the entrance of these caves is typically found at the level of the formations associated with the post-capture terraces M3 and M2 (formations Fr3 and Fr2).

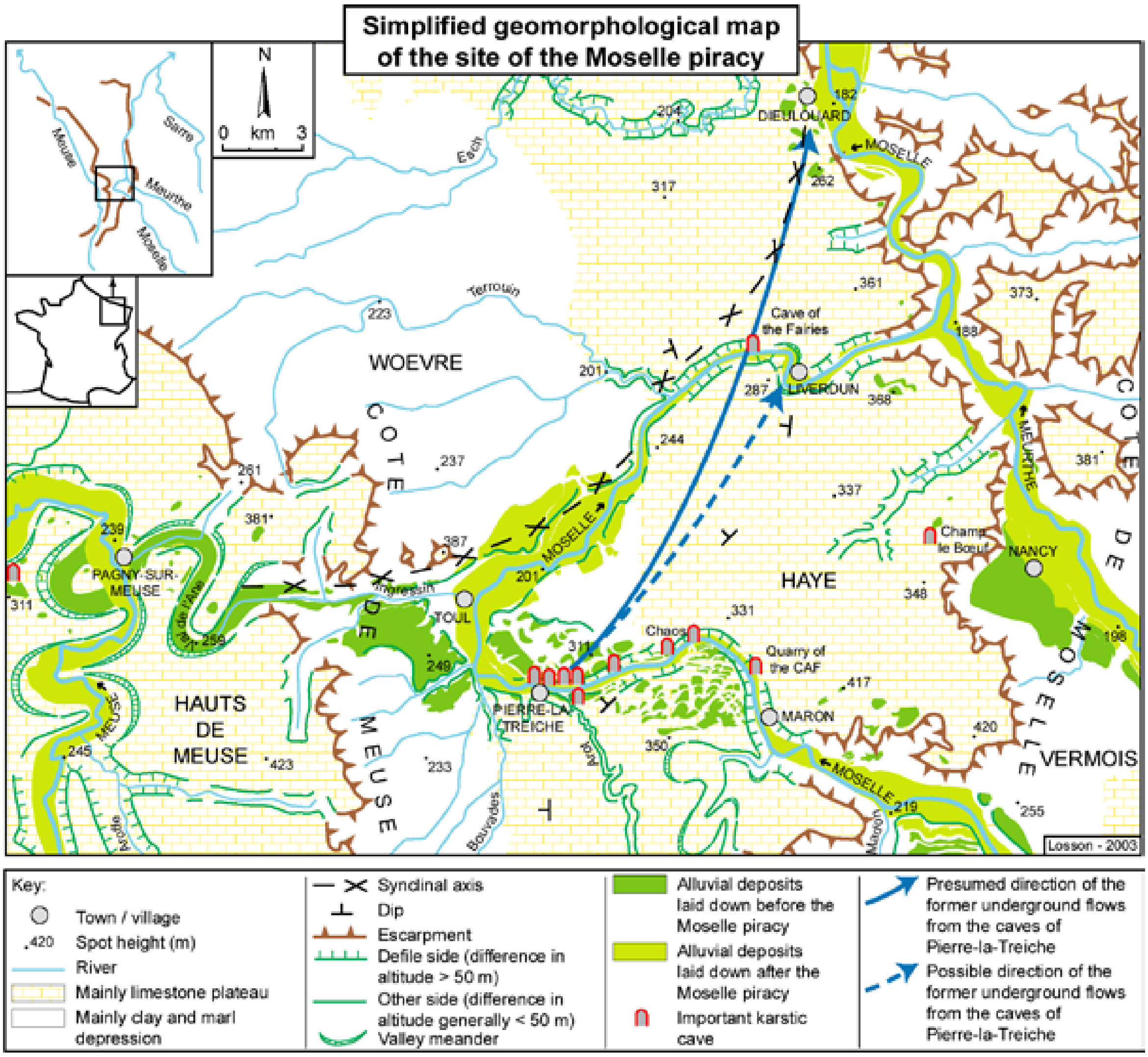


Figure 1.5.1 : Simplified geomorphological map of the site of the Moselle capture

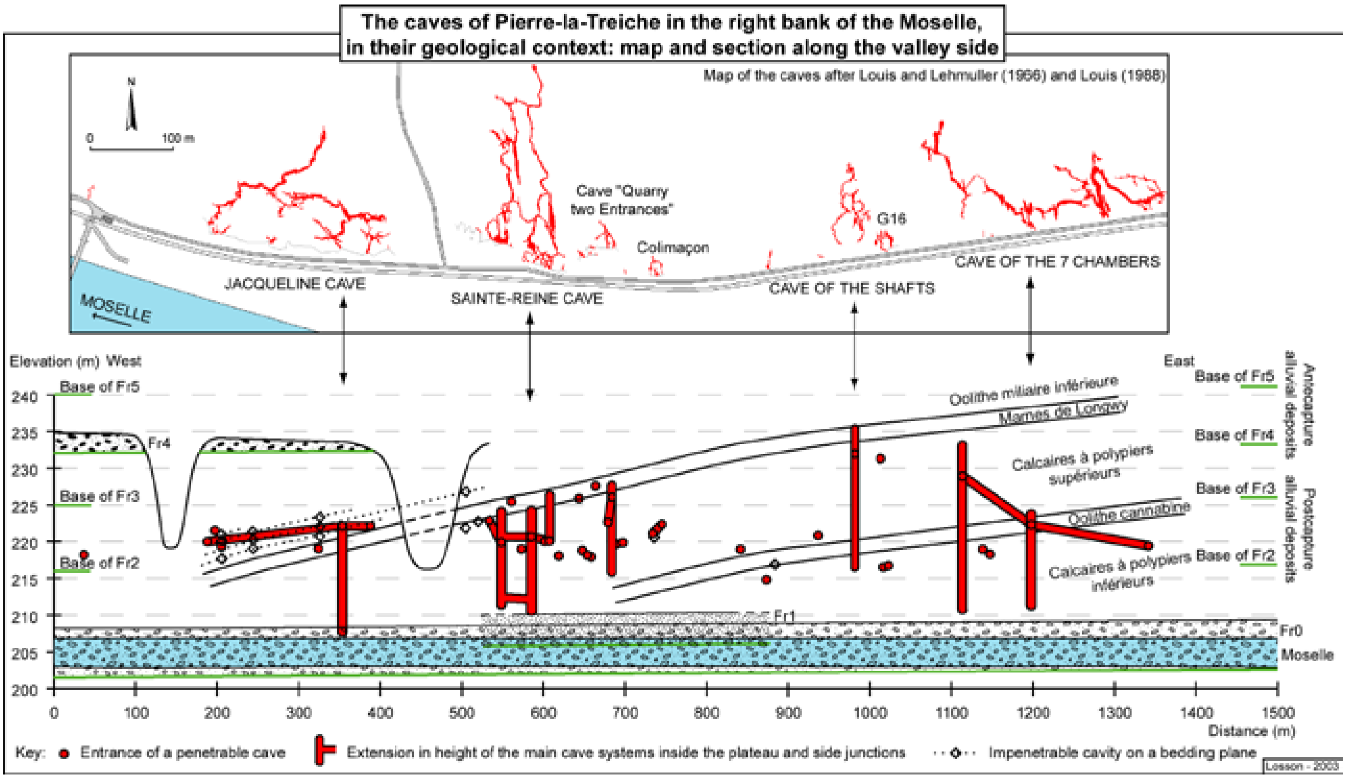


Figure 1.5.2 : The caves of Pierre-la-Treiche in the right bank of the Moselle

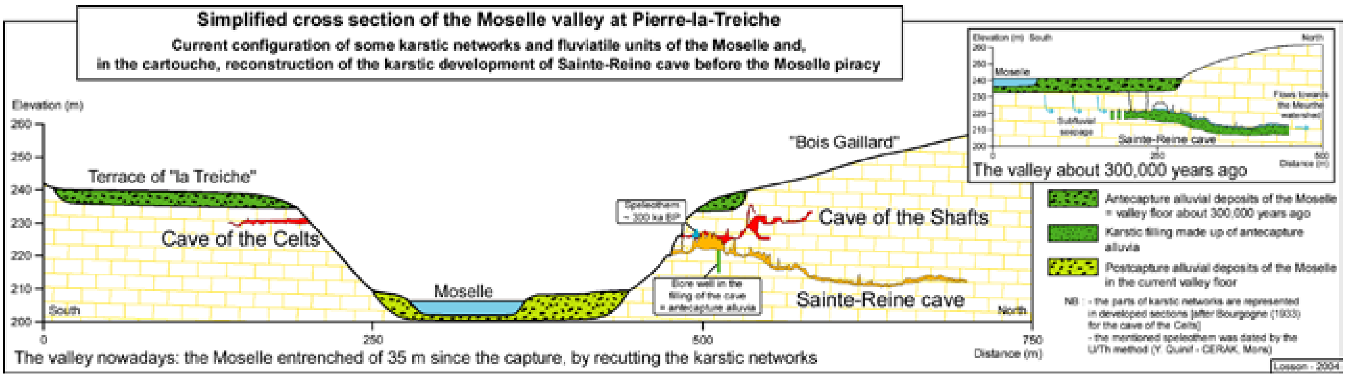


Figure 1.5.3 : Simplified cross section of the Moselle valley at Pierre-la-Treiche

The evolution of karstic network is partly influenced by the lithostratigraphy, as the main caves are developed in the coral limestones of the Middle Bajocian. However, it is noticeable that the location of the fluvial terraces of the Moselle also significantly constrained its altitudinal organization.

Research performed in this area (both at the surface and underground) during the last decades made it possible to recognize (figure 1.5.3):
-the role of the fluvial evolution in the cave formation: morphological and sedimentological (endokarstic fillings) evidences are actually consistent and indicate past groundwater circulation towards the North, towards the palaeo-

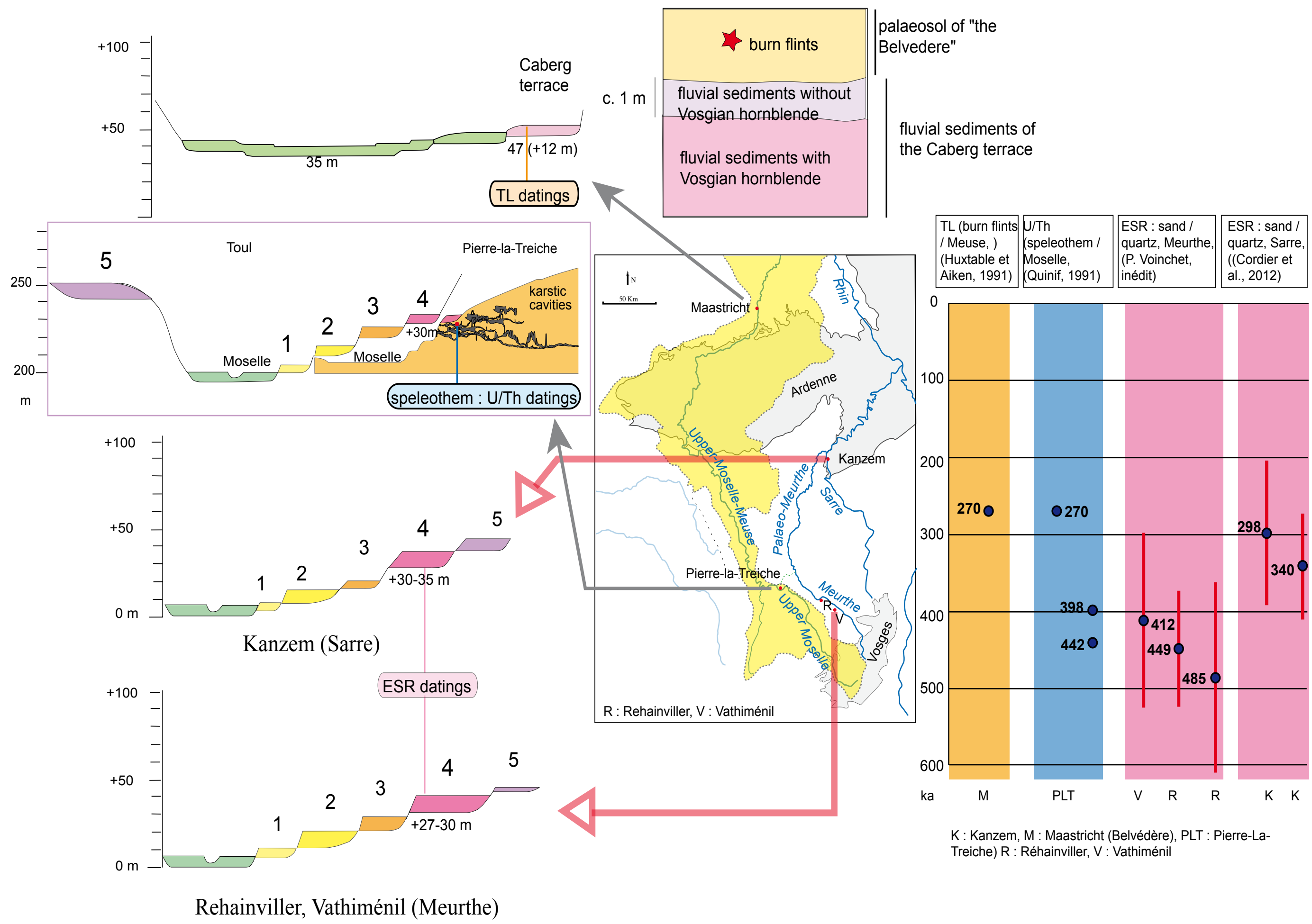


Figure 1.5.4 : Chronological framework for the Moselle capture

Meurthe catchment. Assessment of the hydraulic gradients indicates that these circulations were in connection with the Dieulouard area (North of the present-day Moselle-Meurthe confluence) rather than with the Liverdun area (located in the Moselle valley upstream from the Meurthe confluence; figure 1.5.1);

-the development of an infratalweg karstification: the main periods of caves formation correspond with the times when the Moselle flowed above the karstic network. This situation actually facilitated the water circulation from the alluvial water table (associated with the fluvial sediments of the palaeo-valley floors) to the karst. This assumption is supported by several morpho-logical evidences (alluvial signature, “wells-chimneys” related to withdrawal, micromorphologies related to flooded or epiphreatic regimes etc).

The investigations in the Pierre la Treiche area also made it possible to feed the research on the chronology of the Upper Moselle capture (figure 1.5.4). The first chronological control on the event was obtained at the end of the last century in the Maastricht-Belvédère terrace of the Meuse (the Netherlands). In this terrace the pre-capture sediments (including sediments from the Vosges Massif) are overlain by post-capture sediments and by a palaeosoil. Thermoluminescence dating of burnt flints preserved in this palaeosoil yielded an age of ca 250-270 ka for the capture event (Huxtable and Aitken, 1985; Krook, 1993). This led to assume an MIS 8 age for the last pre-capture terrace formation and for the capture event (Harmand et al., 1995, figure 1.5.4). More recently, a speleothem found at Pierre la Treiche, in a cave containing fluvial sediments related to the M4 terrace has been dated using U/Th (Losson and Quinif, 2001; Losson, 2003). The dating yielded ages of 270 and 398-442 ka (exceeding the limit of the method). The speleothem was situated at the top of the endokarstic detrital filling; so it indicates that the formation of the caves, their filling by the Moselle sediments and the capture event occurred more than 300 ka ago (Losson and Quinif, 2001).

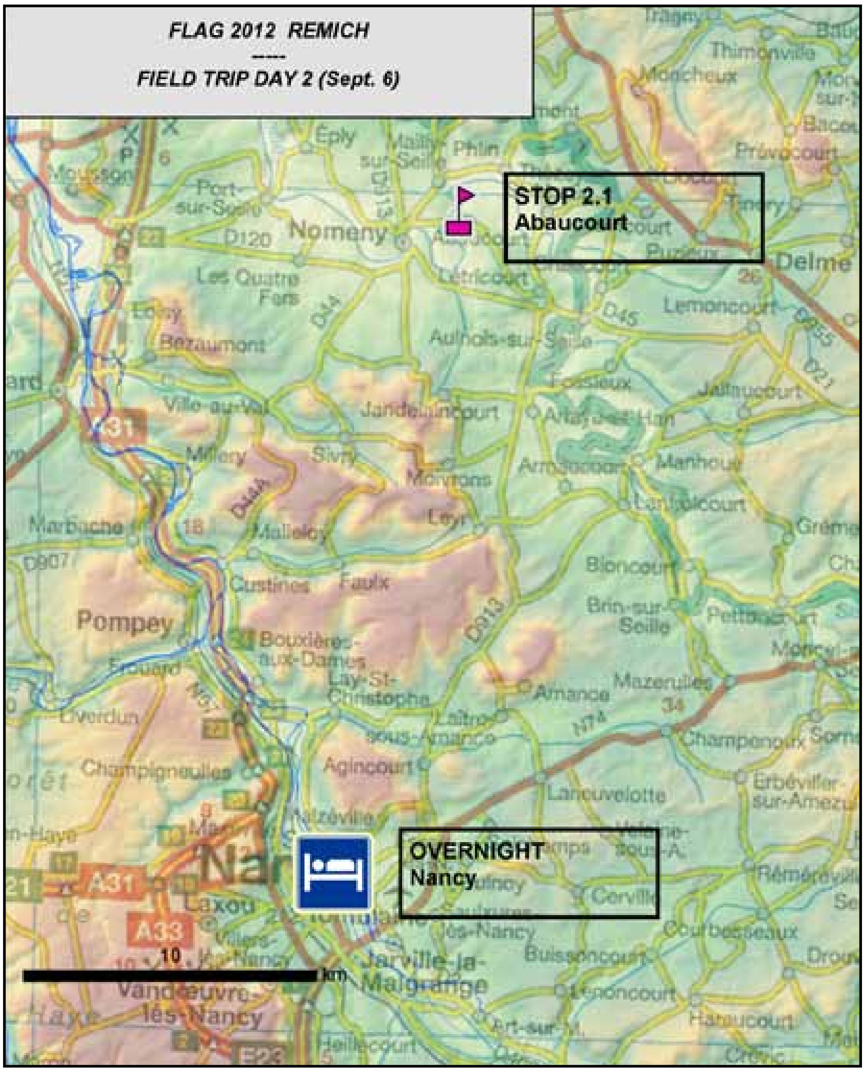
This result is consistent with other U/Th dating of speleothem performed in the Meuse catchment in the Ardenne (Quinif, 2002), which demonstrated that the Meuse and its tributaries had not carved their valley significantly since 400 ka. It is also consistent with the ESR dating of the Sarre terrace Sa4 at Kanzem, which yielded an age of 340 to 298 ka, suggesting a correlation with MIS 11-10 (Cordier et al., 2012). Following from this, the capture event may be significantly older than previously expected.

September 6, 2012

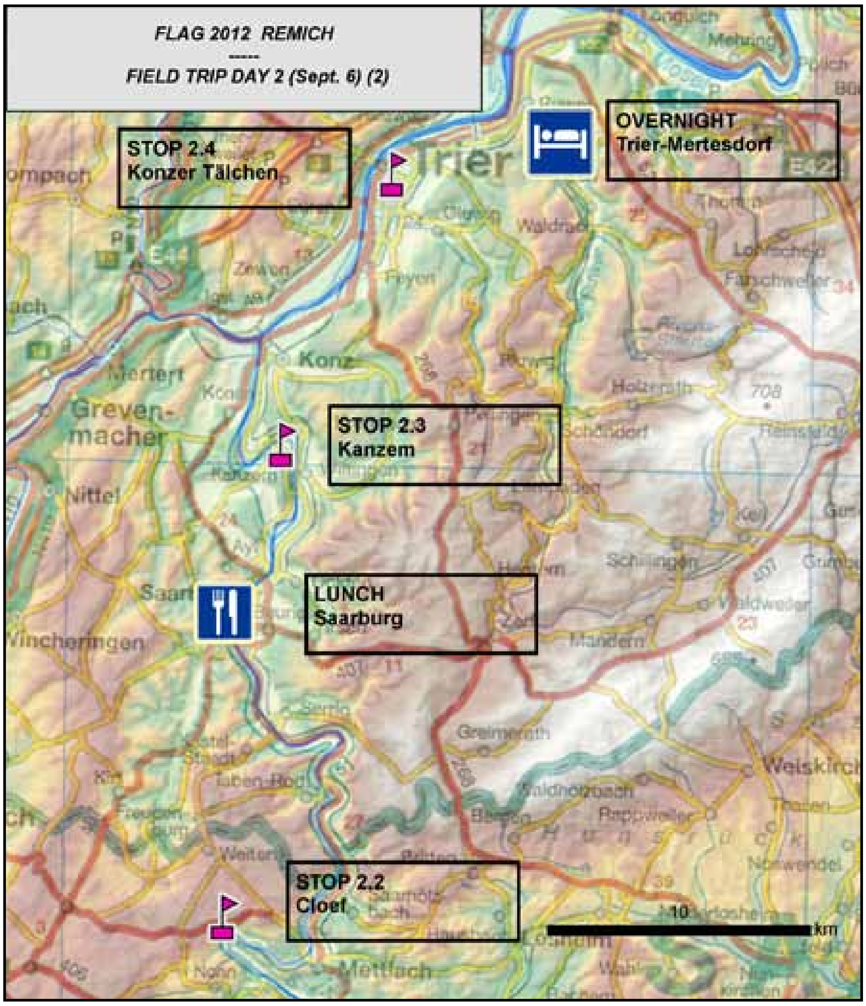
From Nancy to Trier : the Seille and Sarre valleys

Cryoturbation features in the Sarre fluvial sediments (picture S. Cordier)

Day 2


FLAG 2012 REMICH

FIELD TRIP DAY 2 (Sept. 6)
STOP 2.1
Abaucourt
OVERNIGHT
Nancy
10
km


FLAG 2012 REMICH

FIELD TRIP DAY 2 (Sept. 6) (2)
STOP 2.4
Konzer Tälchen
OVERNIGHT
Trier-Mertesdorf
STOP 2.3
Kanzem
LUNCH
Saarburg
STOP 2.2
Cloef
10
km

September 6, 2012

Stop 2.1 : Seille terrace at Abaucourt

The middle Seille valley and the Moselle cuesta upstream from Abaucourt (picture D. Harmand)

Stop 2.1 : Seille terrace at Abaucourt

The Seille River is a right-bank tributary of the Moselle, which mainly flows through the Keuper and Liassic marls and clays. Several entrenched meanders can be recognized along its valley. They allow the preservation of a lower terrace Se2 (+10m above the present floodplain) that morphologically corresponds to the Moselle terrace M2. Older terrace remnants are preserved at +17, +20 and +29m (figures 2.1.1, 2.1.2, 2.1.3). The +20m terrace Se3 is well developed in the lower Seille near Metz where it correlates morphologically with the M3 terrace. In contrast, the +17m terrace corresponds with an intermediate terrace that has not been recognized in the Moselle, Meurthe or Sarre valleys.

In the vicinity of the village of Abaucourt (middle Seille valley), the opening of a sandpit made it possible to study the fluvial sediments of the Se2 terrace (figures 2.1.2 and 2.1.3). The section exposes 2m of cross-bedded siliceous sands (turning to silty sands at the top of the formation), with intercalations of coarse beds (chalky gravels). The fluvial sediments are locally cemented by carbonates. The siliceous sediments are not originating from the Vosges Massif but from the Keuper and Rhaetic sandstones that locally outcrop in the Seille catchment. Similar sediments have also been found in rivers draining the same Triassic and Liassic formations, as the Madon (SE of Toul) or the Nied (NE of Abaucourt).

The presence of these siliceous sediments made it possible to perform an OSL dating that yielded an age of 96±8 ka. This first indicates that the fluvial landscape of the Seille valley was formed during the last glacial-interglacial cycle. The comparison with the chronological framework recently obtained for the Moselle catchment also shows that the sediments of the terrace Se 2 exposed at Abaucourt are contemporaneous with those of the Sarre terrace S 2 located at a similar relative height (Cordier *et al*., 2012). This result suggests a different evolution between the rivers of the Moselle catchment that have been cover by glaciers during the Pleistocene cold periods (as the Moselle or the Meurthe), and those whose catchment remained more or less free of ice (as the Seille and the Sarre).

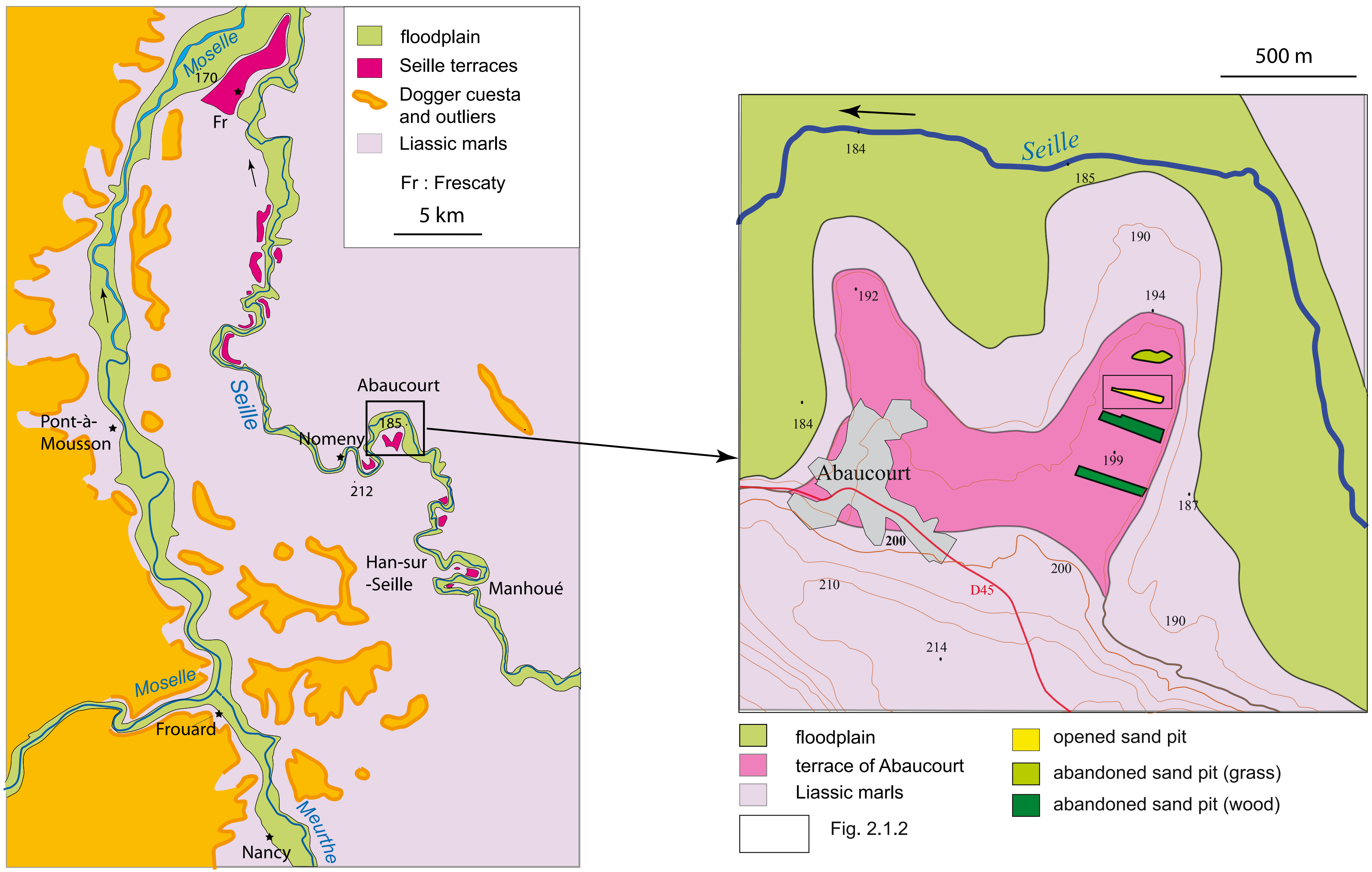


Fig. 2.1.1 : Morphostructural map and terraces of the lower Seille valley and the the terrace of Abaucourt

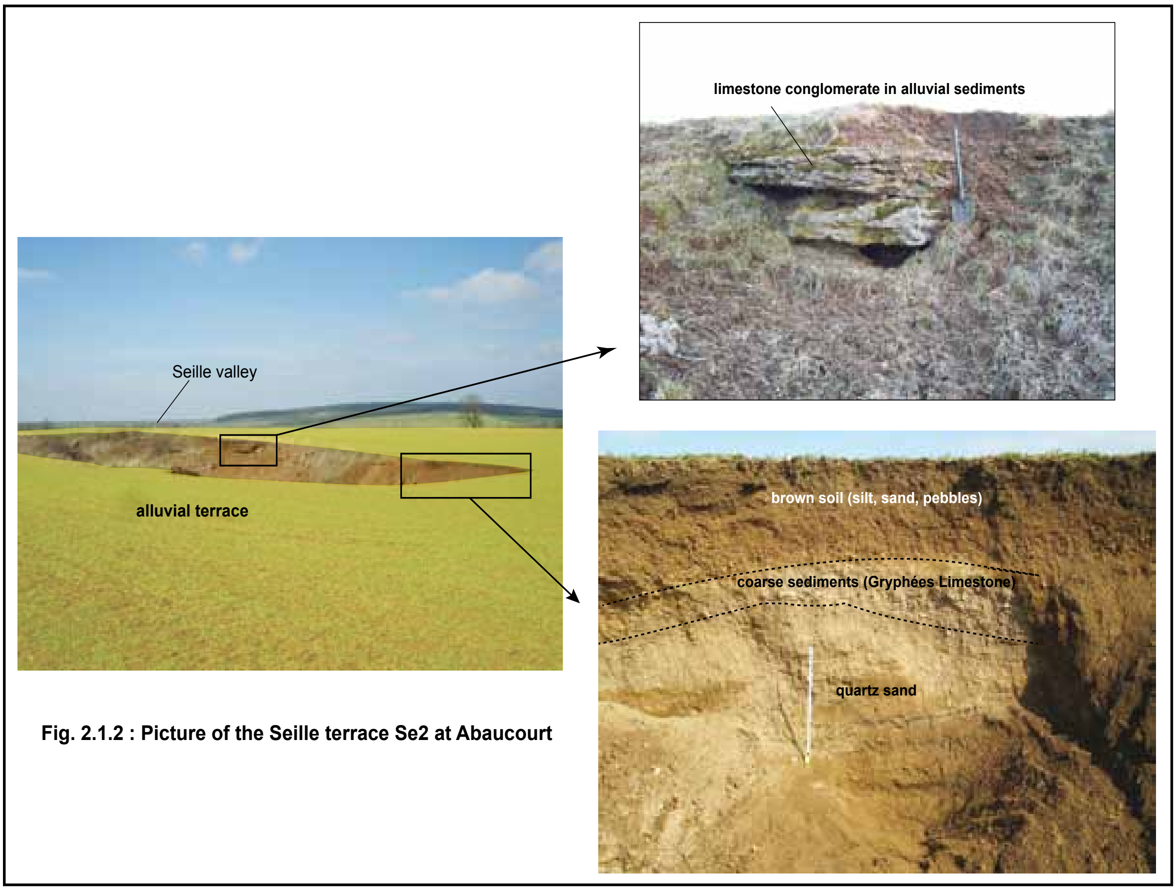


Fig. 2.1.2 : Picture of the Seille terrace Se2 at Abaucourt

Fig. 2.1.2 : Picture of the Seille terrace Se2 at Abaucourt

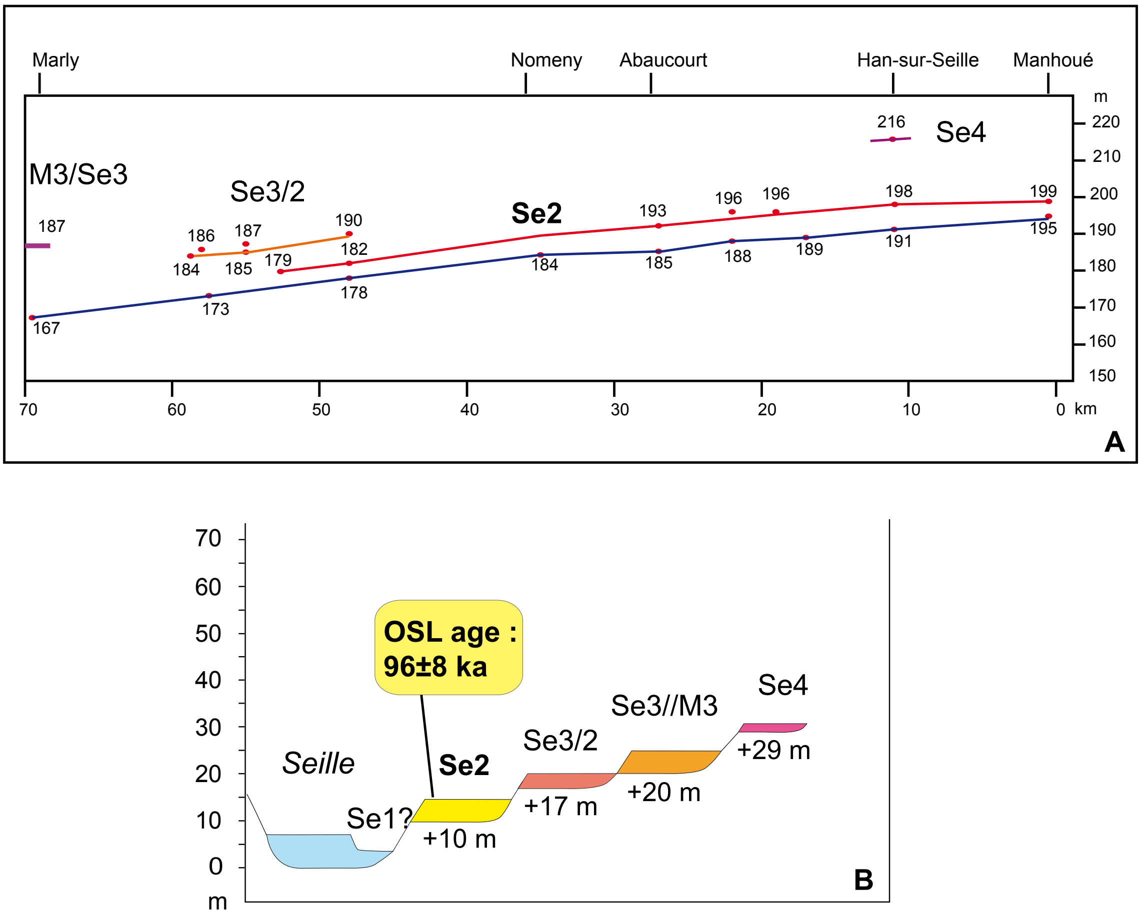


Fig. 2.1.3 : The longitudinal profiles of the terraces of the Seille between Manhoué and Marly (A) and the terraces staircases of the Seille valley (B)

September 6, 2012

Stop 2.2 : Cloef panorama

The Saarschleife (Picture Wolgang Staudt)

Stop 2.2 : Cloef panorama

The Sarre River is the main right bank tributary of the Moselle River, with a 240 km long south–north course in France and Germany. It successively flows through the Vosges Massif, the Paris Basin, the Sarre-Nahe Permian basin, and the Hunsrück (part of the Rhenish Massif, figure 2.2.1).

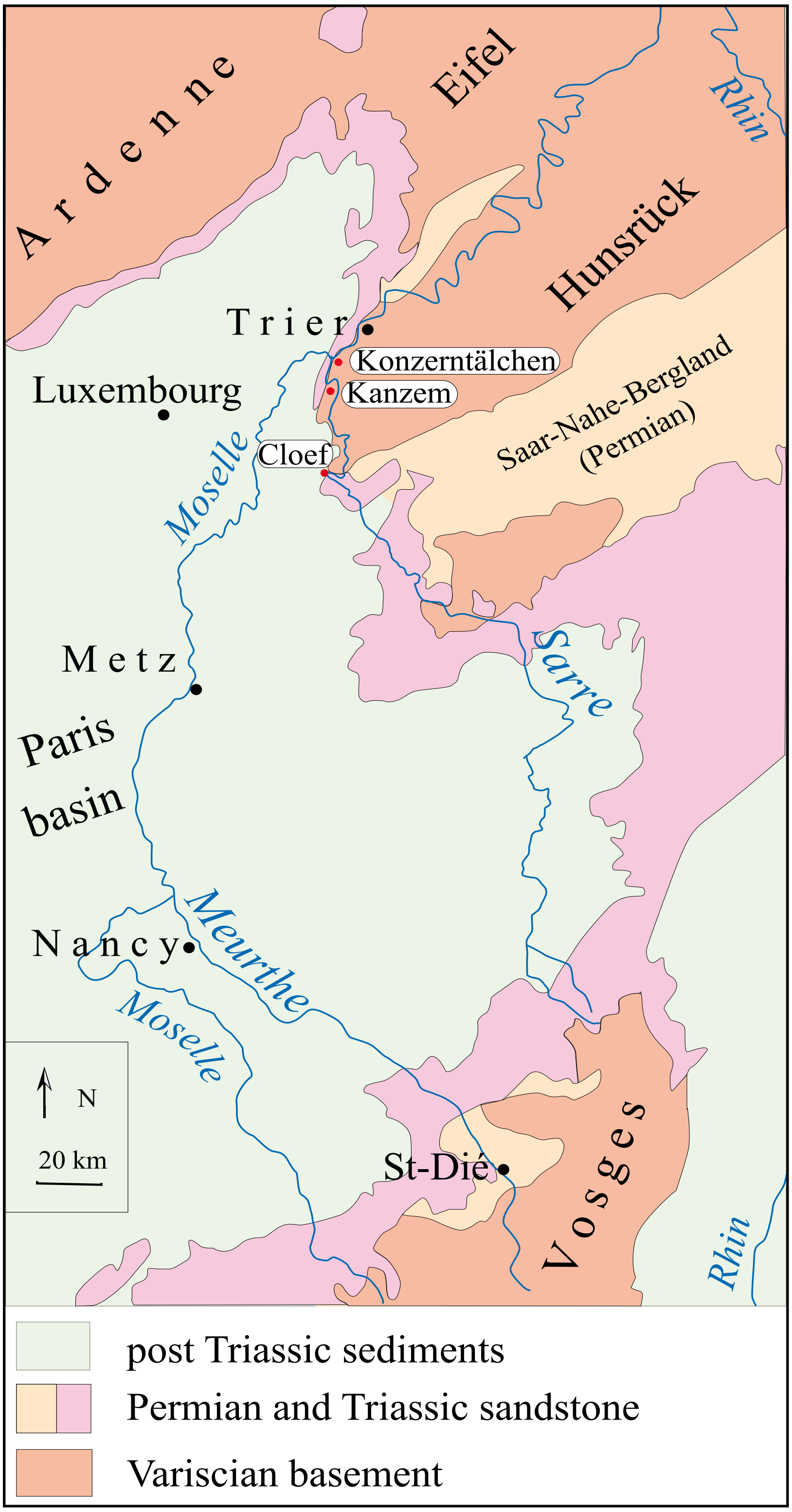


Figure 2.2.1 : Geological map of the Sarre catchement

The Cloef is one of the most beautiful landscapes in Saarland. It exposes the "Saarschleife", a wide hair-pin shape meander formed by the Sarre in the Taunus Quartzites (figure 2.2.2). The valley floor is very narrow (c.100m) and almost fully occupied by the river. The narrowing of the valley starts north of the Merzig depression (developed in the Permo-Triassic sandstones; figure 2.2.3), when the river enters the resistant Taunus Quartzites.
The bottom of the slope is covered by coarse slope-deposits (quartzite boulders), locally termed "Steinrauschen" (howling stones; Preusser, 2010).

Figure 2.2.2 : The Cloef panorama on the Saarschleife (picture D. Harmand)

Figure 2.2.3 : Southerm part of the Saarschleife gorge (picture D. Harmand)

September 6, 2012

Stop 2.3 : Kanzem

The Sarre main terrace sediments near Kanzem, Wawern section (picture Bruno Winckel)

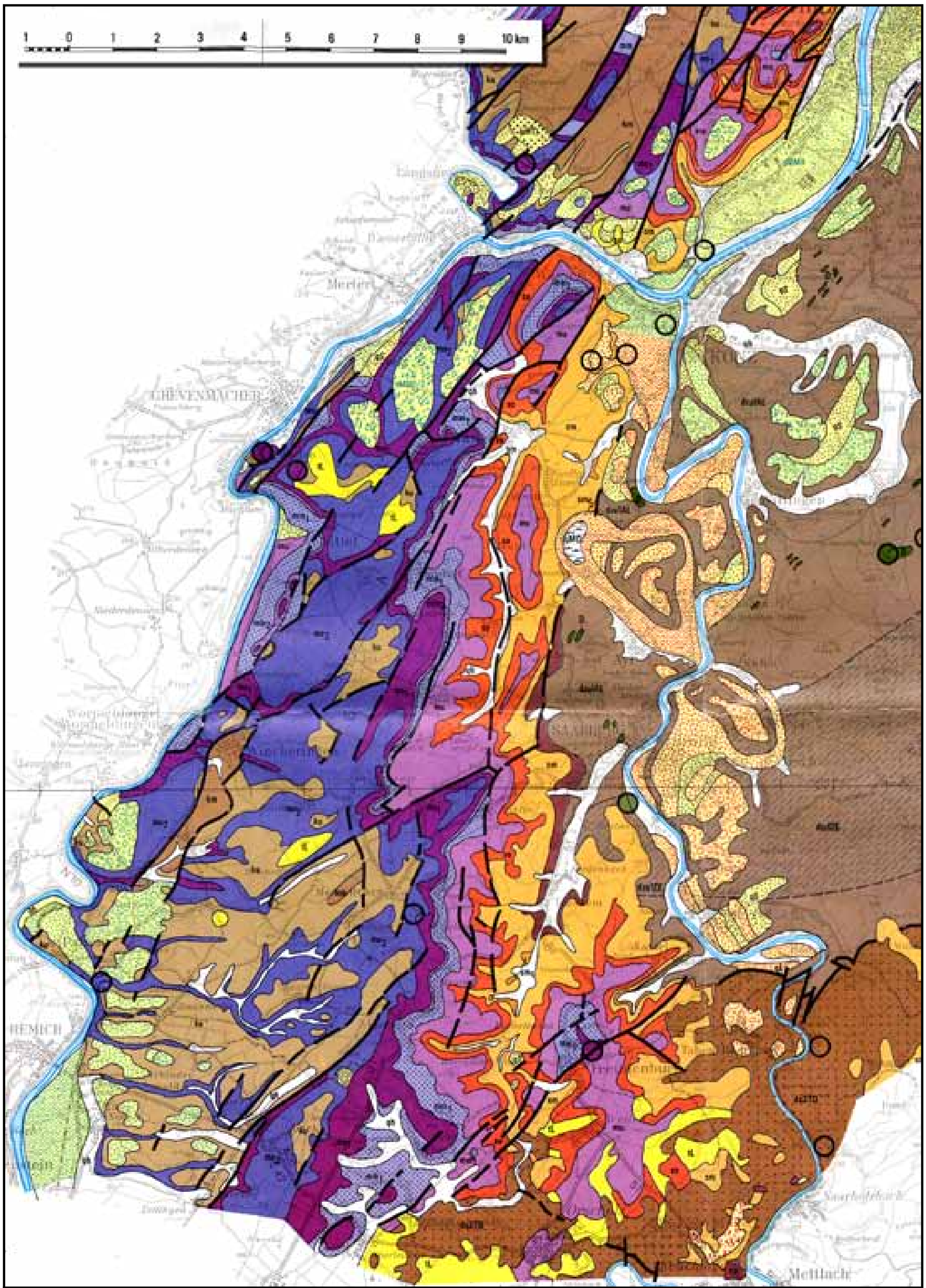
Arrêt 2.3 : Kanzem

Between Mettlach (Saarland) and the Moselle-Sarre confluence at Konz (Rhenany-Palatinate), the Sarre (Saar) flows through the Rhenish Massif in an entrenched valley (figure 2.3.1). Downstream from the Cloef gorge (stop 2.2), the valley enlarges in the Devonian schists. Three palaeomoeanders (Irsch-Ockfen, Ayl-Wawern-Bibelhausen, and the Konzer Tälchen, « small valley of Konz ») can be observed between Saarburg and Konz (figures 2.3.1 and 2.3.2 ; Grebe, 1889). The latter was used not only by the Sarre but also by the Moselle.

In addition to the palaeomeanders, “Umlaufberge” (meander hills) and “Sehnenberge” (confluence hills) can be observed in the landscape (Liedtke *et al.*, 2010). They correspond to meander downcutting and to self-captures of Sarre tributaries, respectively.

Well-preserved terraces staircases have been recognized in the lower Sarre valley for a long time (Rücklin, 1935; Mathias, 1936 ; Fischer, 1957 ; Harmand, 2007). As in the german Moselle valley (day 3), several terraces groups are commonly distinguished, from the older terraces (tertiary terraces, high terraces, main terraces) to the younger terraces (middle and lower terraces ; Müller, 1976 ; Zöller, 1985 ; figure 2.3.2). These terraces are typically associated with several metres of fluvial sediments. Multi-proxy research coupling morphology, sedimentology, and geochronology made it possible to reconstruct the changes in the lower Sarre course since the main terrace formation (Cordier *et al.*, 2012 ; Harmand et Cordier, 2012). In particular, the downcutting of the Irsch-Ockfen and Ayl-Wawern-Bibelhausen palaeomeanders took place after the formation of the Sa9 terrace and during the Weichselian, respectively (figure 2.3.3).

Due to its younger age, the Ayl-Wawern-Bibelhausen meander is the most preserved, even if thick slope-deposits (up to 24m) have been deposited since the abandonment of the meander (Zöller, 1985). Research performed east of Wawern during the building of the Sarre canal made it possible to recognize two main units in the fluvial sediments: a lower coarse unit (2m in thickness) deposited before the meander downcutting (probably during the lower Weichselian), and an upper sandy to silty unit (up to 12 m in thickness) interpreted as floodplain sediments deposited after the abandonment of the meander. The Weichselian age of the upper unit is based on several evidences: 1) the presence of solifluxion layers interbedded with the sandy sediments; 2) the location of the Laacher See tephras (dated to c.11 ka BP) at the top of the formation, 3) the presence of three palaeosoils including interstadial pollens. These palaeosoils have been allocated to the Amersfoort, Brørup and Bölling interstadials (Müller *et al.*, 1983).



Légende :

Hunsrück : lower Devonian : ds2TO : Taunus Quartzites; dzu1ZE : « Zerf-Schichten » : quartzitic sandstones, greywackes, sandy slates ; dzu1AL : « Altlayer Schichten » : Hunsrück slates (D : Diabase) ; ro : Permian : Oberrotliegendes : red sandstones and claystones, fanconglomerates

Saargau : sm : middle Buntsandstein : sandstones, so : upper Buntsandstein (c : « Usch-Schichten » : lower conglomerate) ; mu : lower Muschelkalk : Orbicularis Schichten : sandstone and dolomite ; mm : middle Muschelkalk : Anhydritgruppe (1 : « Gips-Mergel » : gypseous marls, 2 : « Linguladolomit » : dolomite), mo : upper Muschelkalk : « Hauptmuschelkalk » (1 : « Trochtenschichten » : marls, dolomitic limestone and dolomite, 2 : « Nodosusdolomit » : dolomitic limestone) ; ku : lower Keuper : marls and dolomite : km : middle Keuper: « Hauptkeuper, Gipskeuper » : clays and gypseous marls, and sanstone ; tL : « Höhelehm » : old silts.

Valleys of the Moselle and the Sarre rivers (and their tributaries) : qt : fluvial terraces (green : Paléo-Meurthe and Moselle, red : Sarre) ; qh : floodplain sediments, qMO : peat, qS : slope deposits, qL : Loess.

Figure 2.3.1 : Geological map of the lower Sarre valley (Negendank, 1983)

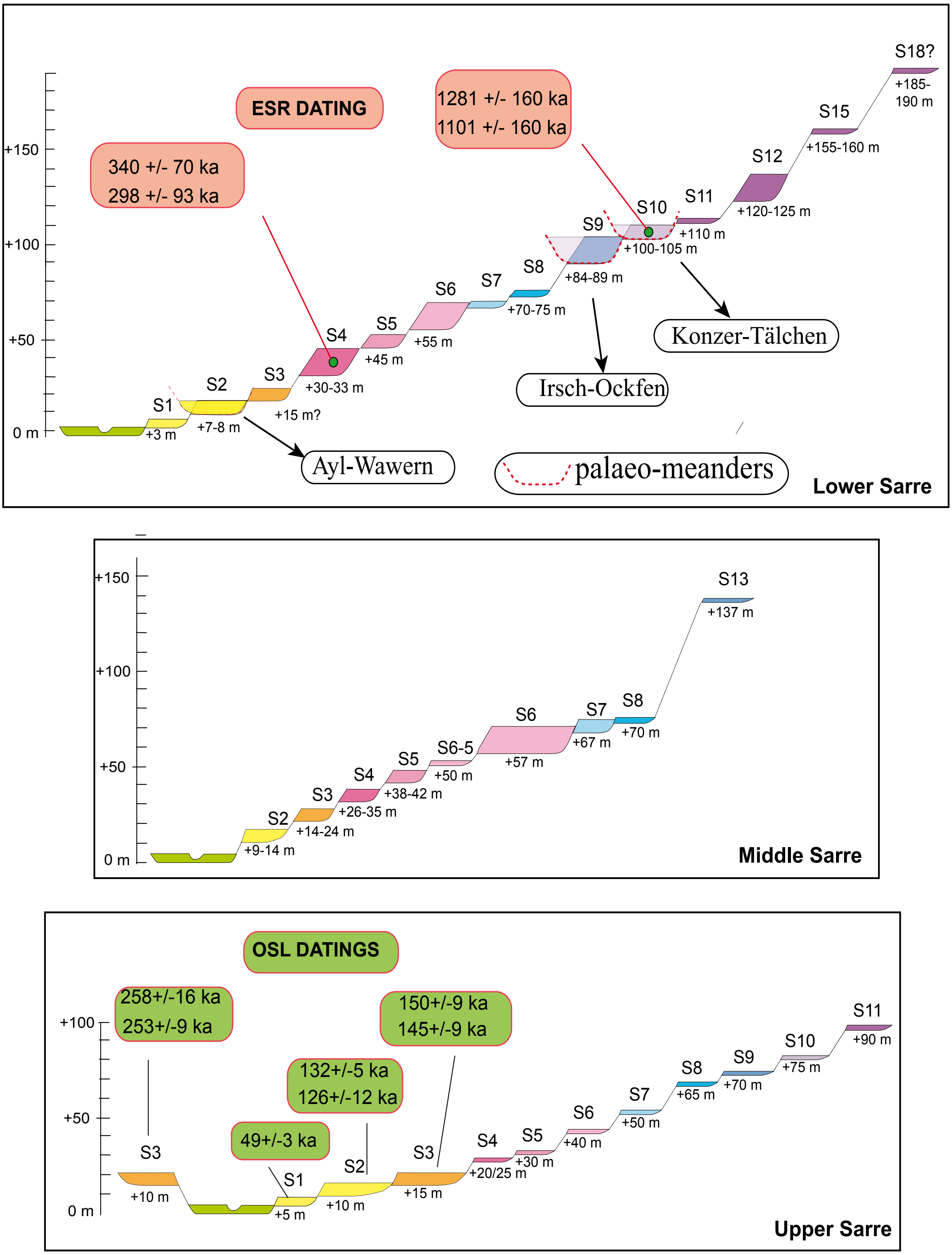


Fig. 2.3.2 : The terraces staircases of the Sarre valley(A : Upper Sarre, B : Middle Saar , C : lower Saar inférieure and datings (Cordier et al., 2012)

Figure 2.3.2 : Cross-profiles of the Sarre terrace staircase

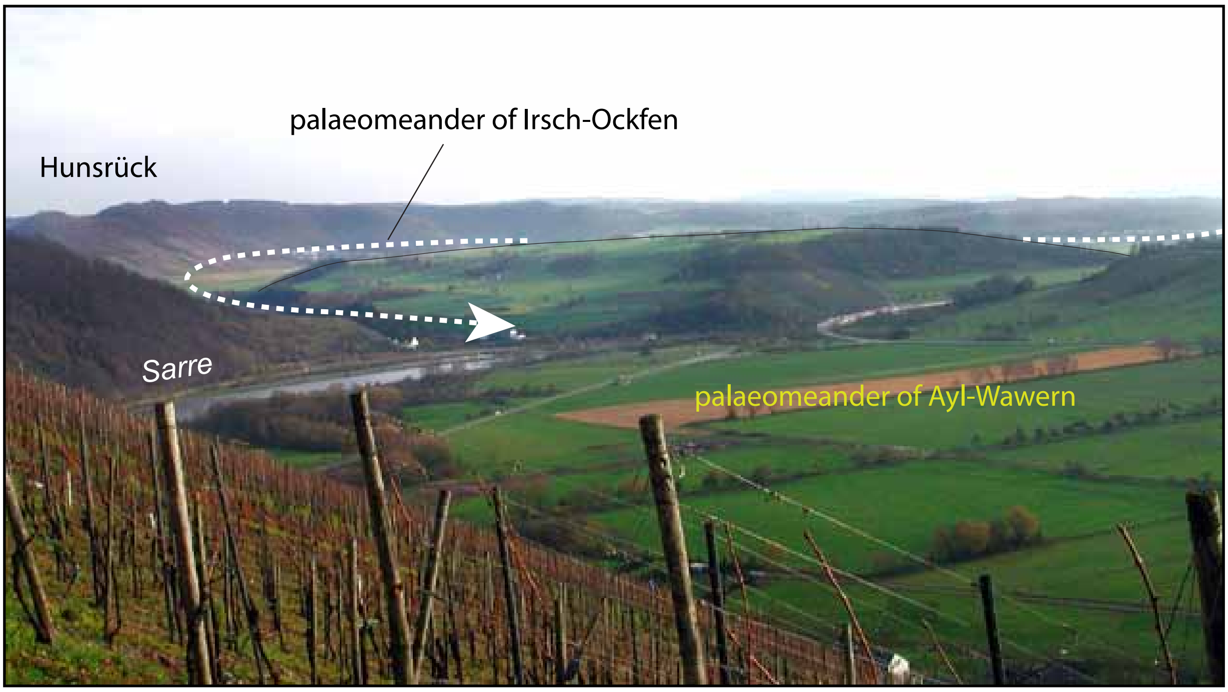


Figure 2.3.3 : The Irsch-Ockfen palaeomeander (picture : D. Harmand)

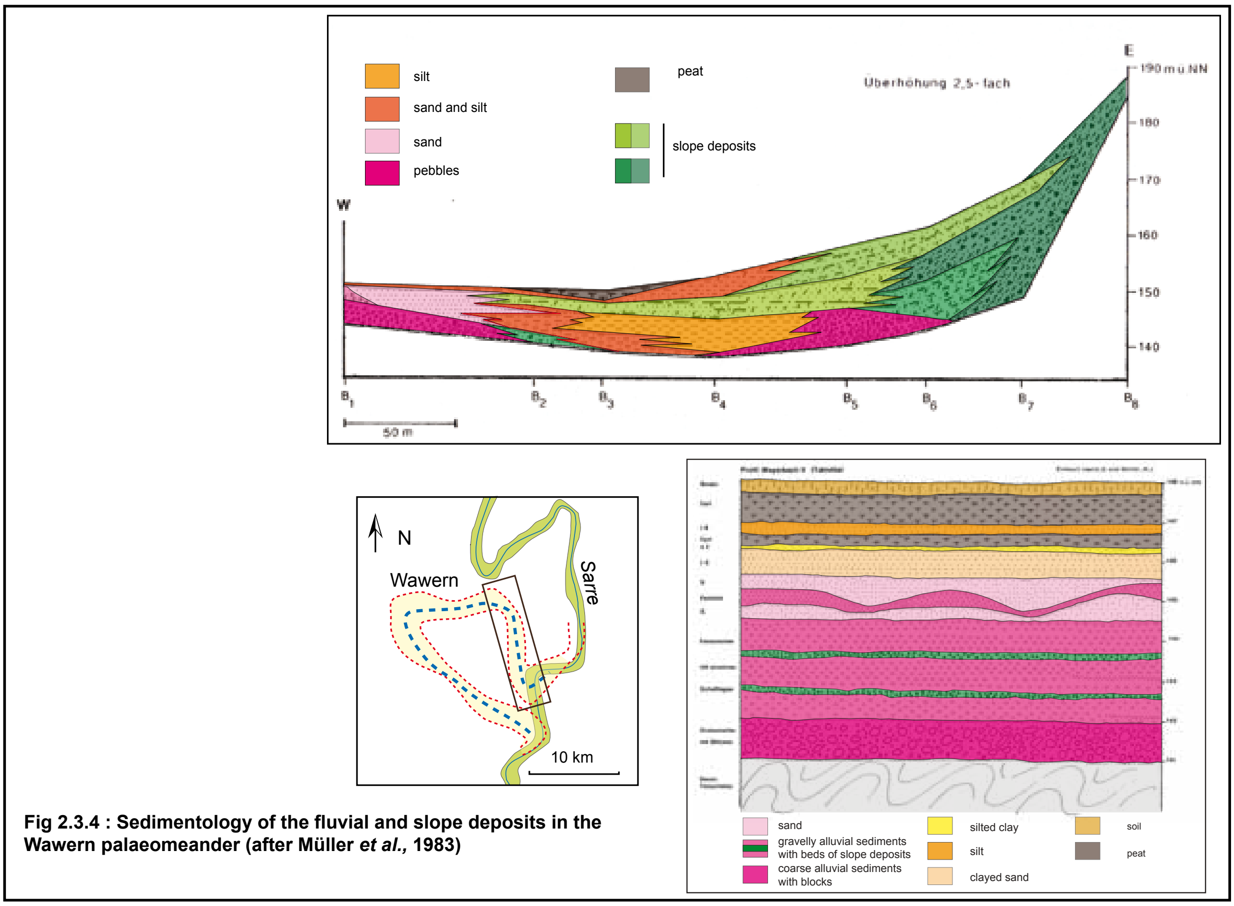


Fig 2.3.4 : Sedimentology of the fluvial and slope deposits in the Wawern palaeomeander (after Müller *et al.*, 1983)

Figure 2.3.4 : Sedimentology of the fluvial and slope deposits in the Wawern palaeomeander

Figure 2.3.5 : The Ayl-Wawern-Bibelhausen palaeomeander (picture : D. Harmand)

However, no chronological evidence makes it possible to confirm this assumption. Furthermore, in another section East of Wawern, in the Weyerbach valley, a piece of pine wood found at the base of the fine grained unit yielded an age of 15 800±800 years BP, and the uppermost two metres include tephras from the Laacher See eruption (figure 2.3.4; Zöller, 1985). This suggests that most of the floodplain sediments were deposited during the Lateglacial.
Above the Ayl-Wawern-Bibelhausen palaeomeander, the terraces Sa12 (122 m relative height, figure 2.3.5) and Sa4 (35 m relative height) are well preserved on the left bank of the Sarre. The sediments associated with the Sa4 terrace have been exposed in 2009 in the Kanzem section (figures 2.3.6 and 2.3.7). Seven units have been observed. Above the Devonian schists, a basal lag of quartzite and schists boulders, with boulders up to 1.2 metre in length, has been identified (unit K1). The boulders come from a sill located a few kilometres upstream. This coarse lag is capped by coarse open-work pebbles and gravels (unit K2). An erosive contact separates this unit from unit K3 which corresponds with open-work cross-bedded sands and gravels. The overlying sequence shows a succession of coarse layers (gravels, pebbles) forming units K4A, K5A, K6A and K7A, separated by sandy lenses (K4B) or continuous sandy beds (K5B, K6B, K7B).
The lower coarse lag is attributed to ice-rafting processes in a context of seasonal frost and spring ice jams under continental climate. It is likely that such

processes strengthened the erosive capacity of the river during the previous Sa5-Sa4 incision. In contrast, units K2 and K3 are typical for rivers with moderate energy, and can be related to the implementation of cold conditions. The upper units K4 to K7 are finally attributed to a periglacial context (pleniglacial phase).
The ESR dating performed on sands from the upper units (K5B and K7B) yielded ages of 433±63 and 298±93 ka, respectively. These ages are consistent with the regional chronological framework (Cordier et al., 2012), even if further investigations are required to improve the precision of the ages.

Figure 2.3.6 : General view of the Kanzem section

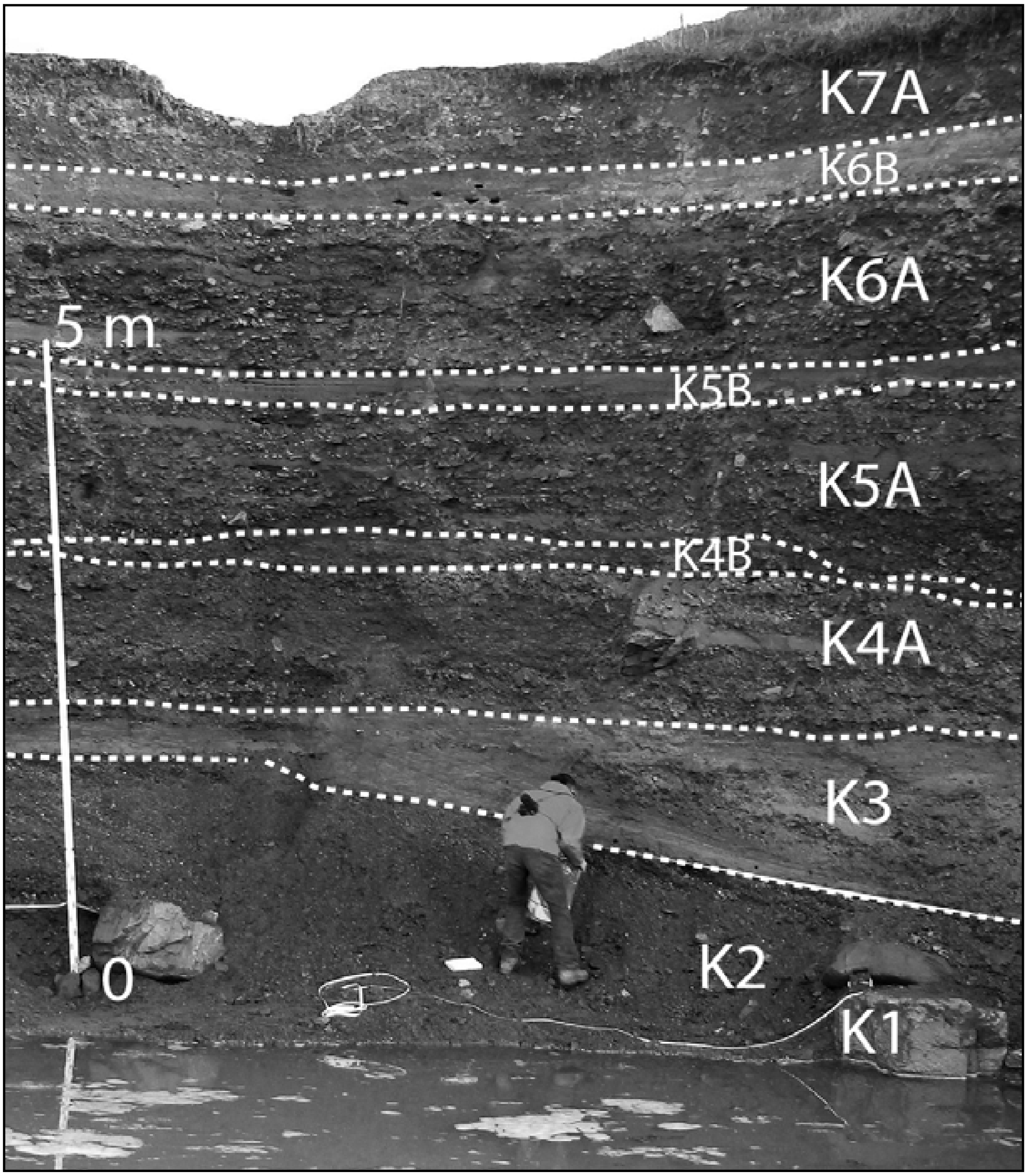


Figure 2.3.7 : Stratigraphy of the fluvial sediments exposed in the Kanzem section

September 6, 2012

Stop 2.4 : Konzer Tälchen

The paleomeander of the Konzer Tälchen (picture : Dominique Harmand)

Stop 2.4 : Konzer Tälchen

The Konzer Tälchen (« small valley of Konz ») is a broad palaeo-meander (500 to 750 m in width) located SW of Trier. It is very well preserved especially in its eastern part (figure 2.3.1 and 2.4.1). In this area, the palaeo-valley is located at c.90m above the present day confluence between the Moselle and the Sarre at Konz. Morphological evidences suggest that this meander was formed by the Palaeo-Meurthe (figure 2.4.2). This assumption is confirmed by the presence in the associated fluvial sediments of ferric oolithe originating from the Toarcian Minette, exposed along the Dogger cuesta between Nancy and Thionville (Müller, 1976). The Konzer Tälchen was also occupied both by the Palaeo-Meurthe and by the Sarre, the confluence between the two rivers being located just upstream, 2km south of the present day Moselle-Sarre confluence. The Oberste Wald terrace (between Wawern and Wiltingen) and the Kommlingen terrace (in the Konzer Tälchen) mark the Sarre palaeocourse. Near Kommlingen, the fluvial sediments were exposed in a gravel pit (figure 2.4.3). The sediments are composed of horizontal or cross-bedded sands. Gravels are mainly preserved at the bottom of the formation. ESR dating of the sediments exposed at Kommlingen yielded ages of 1101±160 and 1281±160 ka (Cordier *et al.*, 2012). This makes it possible to assume a mean fluvial incision rate of 10cm/ka during the last million years for the lower Sarre. This value is consistent with the reconstruction proposed for the Moselle (Cordier et al., 2006b).

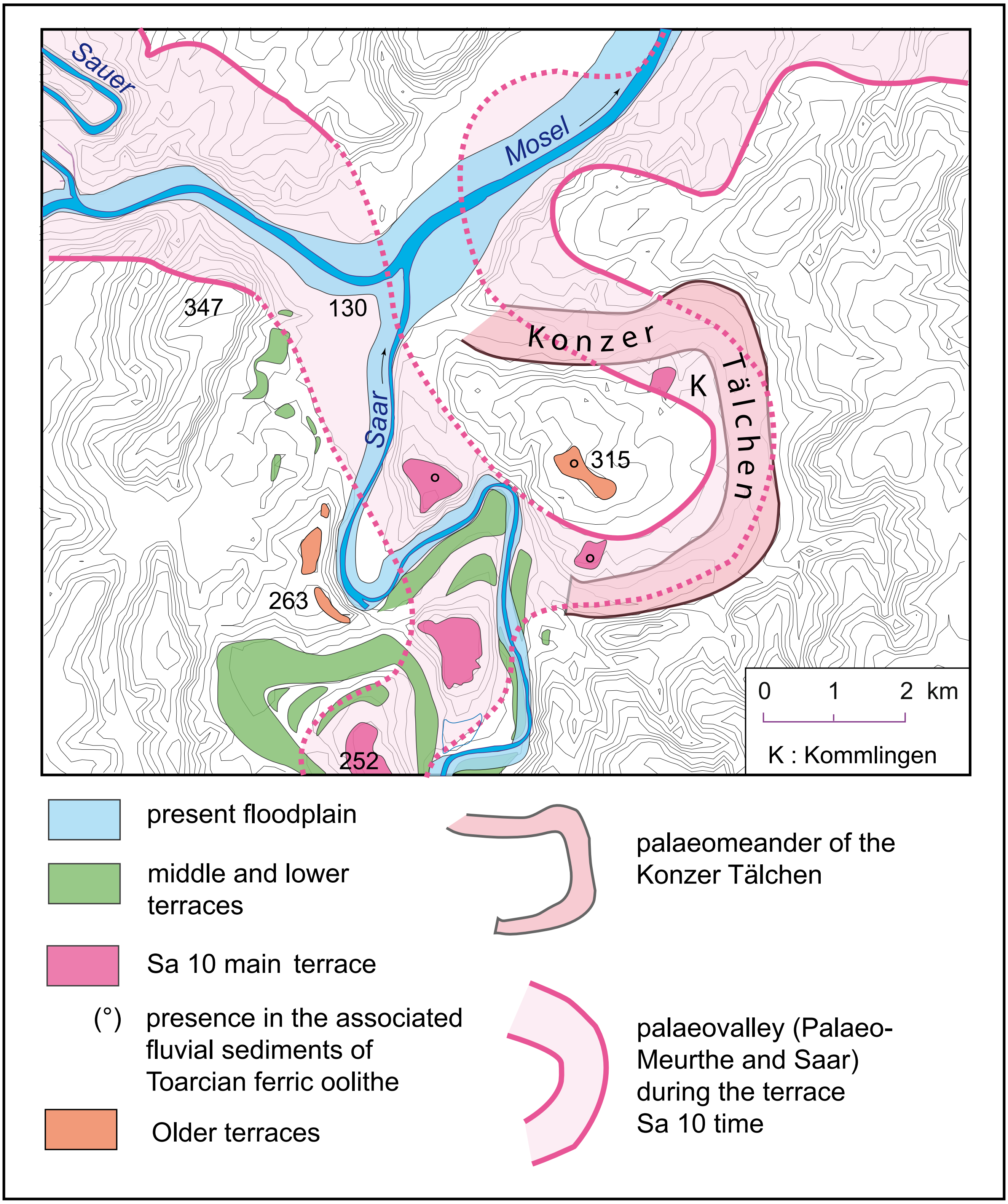


Figure 2.4.1 : General view of the Konzer Tälchen palaeomeander

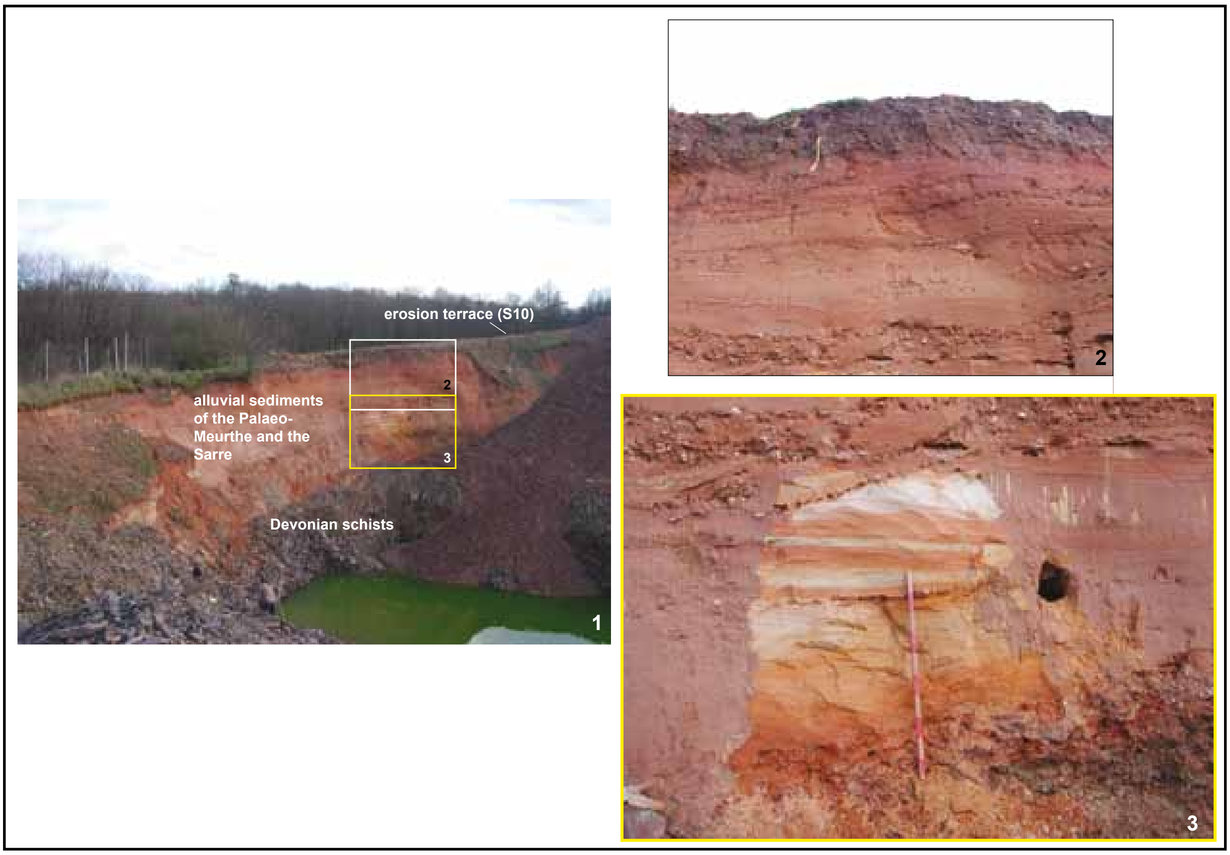
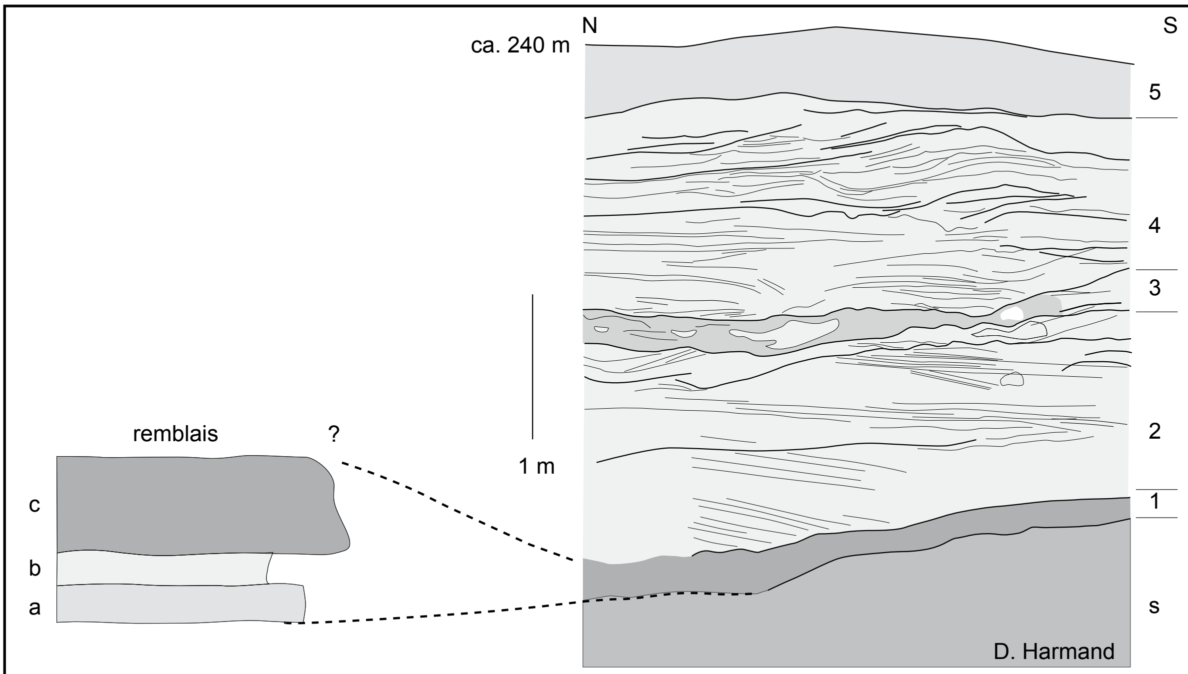


Figure 2.4.2 : General view of the Kommlingen section (Sarre terrace Sa10)



s : Devonian schists, 1 : coarse unit (basement and Main Conglomerate gravels). 1.a : gravels and red sand. 1.b : red sand bed. 1.c : gravels and sands. 2 : horizontal and planar cross-bedded sands (thick line : gravel beds). 3: gravels and sands. 4: sands with thin gravel beds.5 : soil.

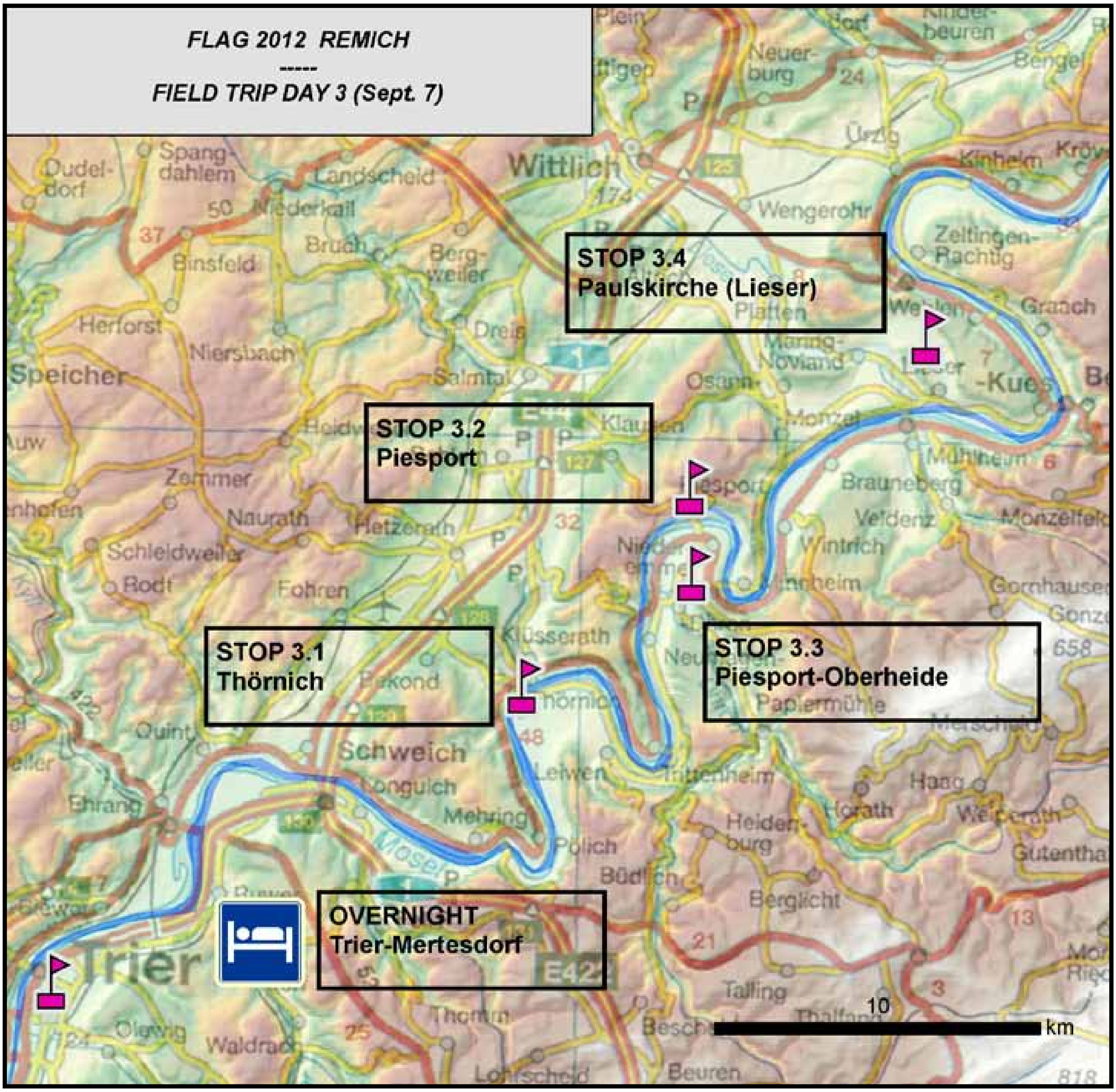
Figure 2.4.3 : Stratigraphy of the fluvial sediments at Kommlingen (terrace M10/ Sa10)

September 7, 2012

From Trier to Luxembourg : the German Moselle valley

General view of the Moselumlaufberge ("meander hills") area (picture S. Cordier)

Day 3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FIELD TRIP DAY 3 (Sept. 7)
STOP 3.4
Paulskirche (Lieser)
STOP 3.2
Piesport
STOP 3.1
Thörnich
STOP 3.3
Piesport-Oberheide
OVERNIGHT
Trier-Mertesdorf
10
km

September 7, 2012

Stop 3.1 : The Thörnich-Hochrech terrace

The Thörnich section, in the Detzem-Leiwen meander (picture S. Cordier)

Stop 3.1 : Thörnich-Hochrech

Location

The Thornich-Hochrech gravel-pit (140 m above sea level) is located on the convex bank of the meander developed between the villages of Detzem and Leiwen (figure 3.1.1). This meander is one of the broadest preserved in the Moselle valley, with a length of ca 12 km and a surface area of 10 km². This size allowed a better preservation of fluvial terraces on the convex bank.

The terrace staircase of the Moselle in the Detzem-Leiwen meander

Previous research (Kremer, 1954; Müller, 1976; Löhnertz, 1982; Negendank, 1983) in the area led to the recognition of three fluvial terraces (figure 3.1.2): the lower terrace (120 to 130 m a.s.l., less than 15m above the Moselle), where the villages have been built; the lower middle terrace (140 to 175 m a.s.l., relative height 25 to 60m) which is the most developed; and the upper middle terrace (180 to 200 m a.s.l., relative height 65 to 85m). These three terraces have been recognized at more or less constant relative height along the whole Luxembourgian and German valleys, between Schengen and the confluence with the Rhine.

Recent research along the Meurthe and Moselle valleys (from the Vosges Massif to the Rhenish Massif) has allowed a more complex terrace staircase to be recognized, with eight terraces (M1 youngest to M8 oldest) being located between the present floodplain (M0) and +90m relative height (Cordier et al., 2005, 2006b). This staircase is particularly well preserved in the Thionville-Schengen area, where we travelled by bus during the day 1.

Following this, is it obvious that each of the three fluvial terraces previously recognized actually includes several terraces levels. This was already assumed for the lower terrace in Trier: in 1999, B. Zolitschka and H. Löhr analysed cores and concluded to the existence of two lower terraces (lower terraces 1 and 2) above the present floodplain (defined as the “lower terrace 3”). This result is consistent with the research performed upstream from Trier. Even if reliable data lacks for the Detzem-Leiwen area, it is therefore possible to assume that the lower terrace also corresponds with two terraces (M1 and M2) above the present floodplain (M0). The opening of several gravel-pits in the “middle terraces” in the Detzem-Leiwen meander and in the Piesport meander located a few kilometres downstream (see stop 3.2) made it possible to reconstruct the geometry of the fluvial terraces. Six middle terraces were distinguished (figure 3.1.1): despite the lack of sections, the terraces M8, M7 and M6 may be quite easily distinguished in the topography. They are located at ca. 195m (+80m), 185m (+70m) and 175m (+60m) above the Moselle, respectively. In contrast, sections were available for the younger middle terraces M5, M4 and

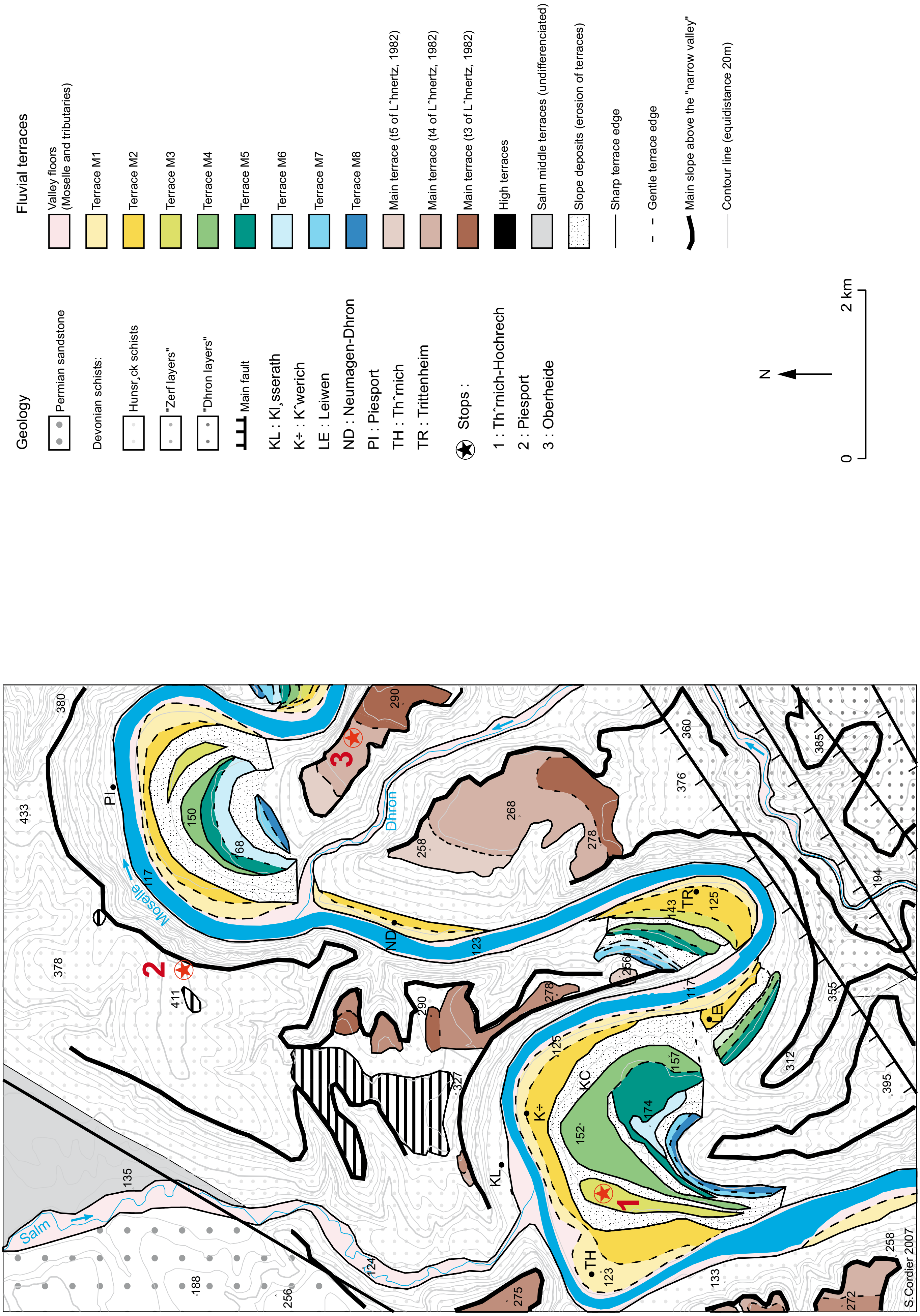


Figure 3.1.1 : The Detzem-Piesport fluvial basin : morphostructural framework, fluvial terraces and stops

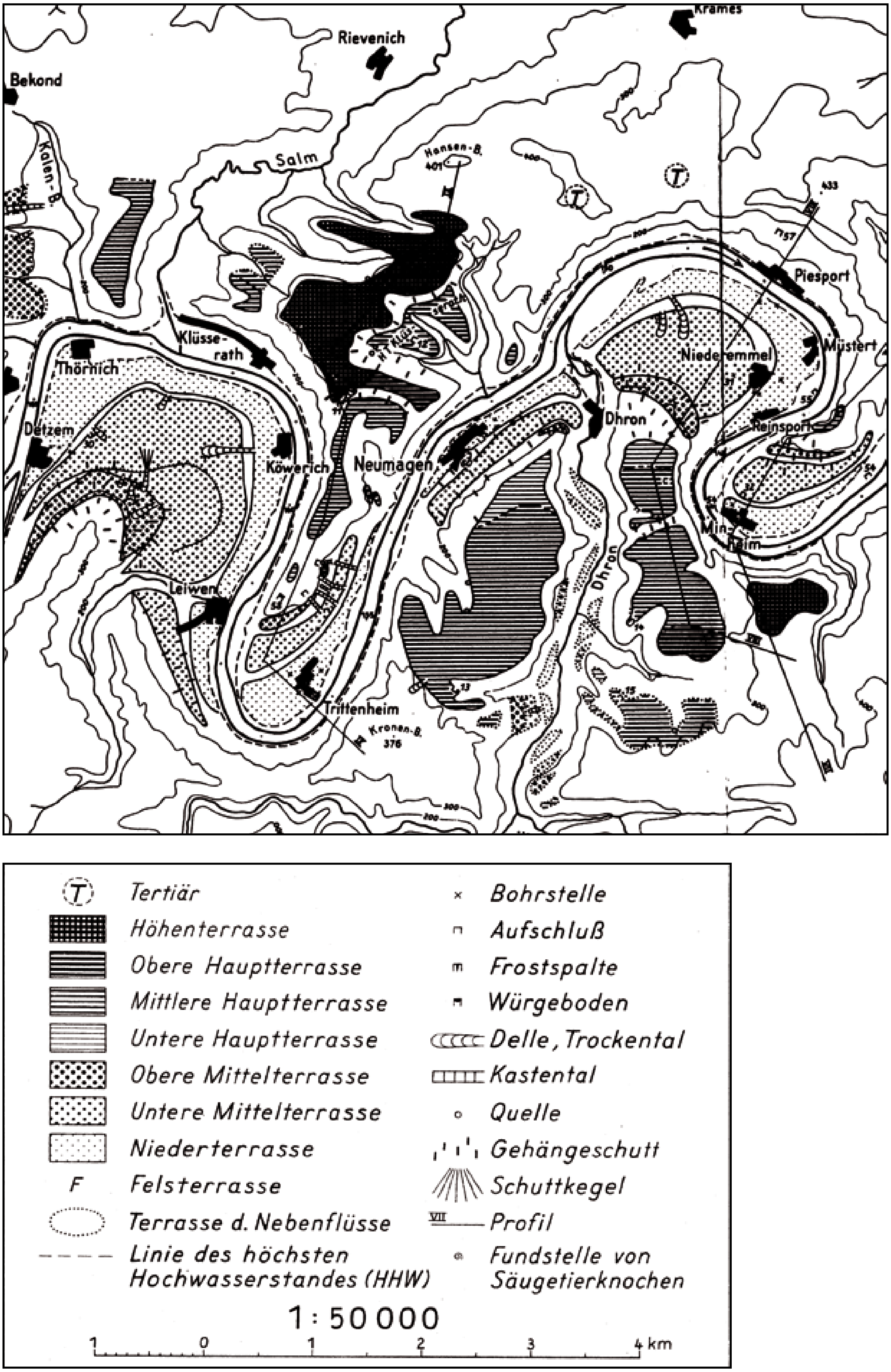


Figure 3.1.2 : the Moselle terraces between Detzem and Piesport after Kremer (1954)

M3. The top surface and bedrock of the terrace M5 are located at 162-166m and 159-160m, respectively (relative height +50-54m). The terrace M4 is separated from M5 by a distinct slope. Its top surface and bedrock are located at 151-155m and 148-150m, respectively (relative height +37-40m).
The fluvial terrace M3 corresponds with the Thörnich-Hochrech gravel pit. From a morphological point of view the terrace is separated from M4 by a gentle slope, while it obviously dominates the lower terrace M2. Its top surface and bedrock are located at 142m and 136m, respectively (relative height +25m). Quarrying performed between 2002 and 2005 made it possible to observe the sediments down to the bedrock in various profiles being representative for the remaining part of the terrace (ca 6 hectares). This allowed sedimentological analyses (grain size, petrography, heavy mineral determinations) and OSL dating to be performed.
The Thörnich-Hochrech gravel-pit must be considered as a key-site for unravelling the Moselle valley evolution, both from a climatic and tectonic point of view.

Sedimentary facies

The mean thickness of the sediments exposed in the gravel-pit is 6m (figure 3.1.3). Four main sedimentary units has to be recognized (figures 3.1.3 and 3.1.4): two coarse units (units A and C), one sandy unit (unit B), and a silty unit on the top (unit D).
The thickness of the lower unit A is about 1.5-2m. It is massive and mainly composed of coarse sediments (pebbles and gravels associated with some blocks of local origin), with only a few intercalations of finer (sands and gravels) sediments. Large trough cross-bedding has locally been recognized. Observations performed in the northern part of the gravel-pit showed that these coarse sediments have been partly eroded and replaced by pure yellow sand (profile 7, figure 3.1.3).
The thickness of unit B is more variable and ranges from 0 to 2m. This unit correspond with beige silty to gravelly sand. Horizontal bedding as well as small planar and trough cross-bedding have been recognized, the laminae being tilted towards the NNE, following the present direction of the river.
The unit C (1 to 2m in thickness) is preserved in the whole gravel-pit. Its deposition took place after an erosive period that locally removed unit B (profiles 2 and 8, figure 3.1.3). This unit is mainly composed of coarse sediment with a predominance of gravels.
Finally the upper unit D corresponds with white to light brown silts. Its thickness may exceed 2m, especially in profile 2 where sediments from unit C have been removed and replaced by silts.
Even if the grain-size of the deposits may be strongly influenced by the local

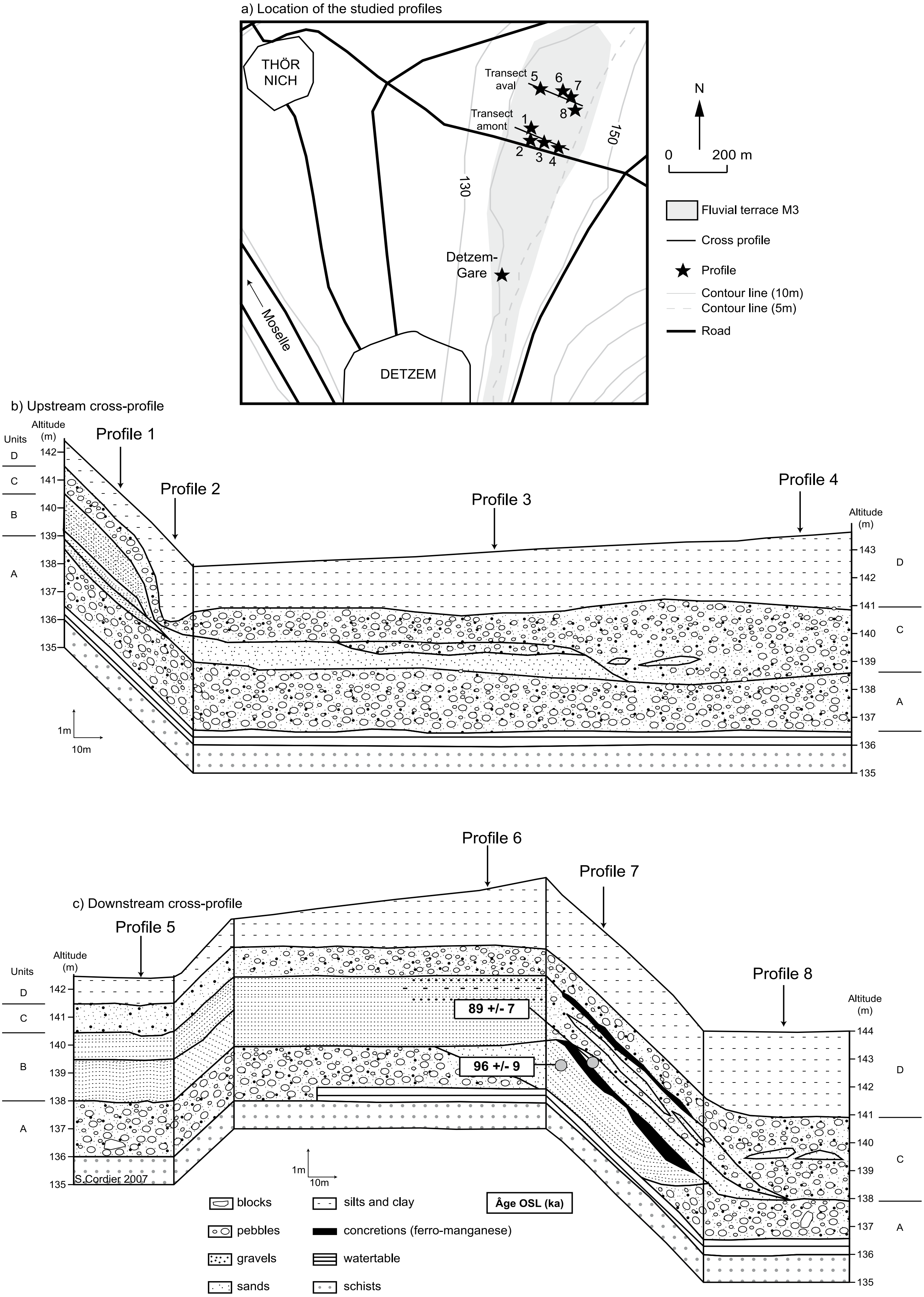
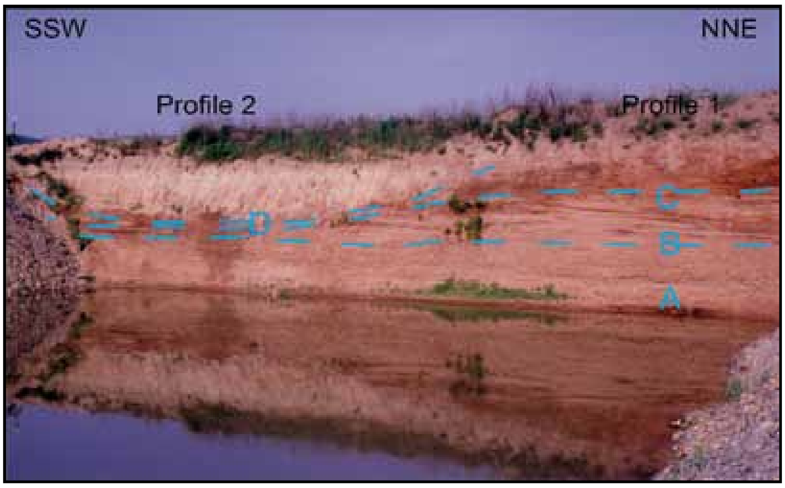
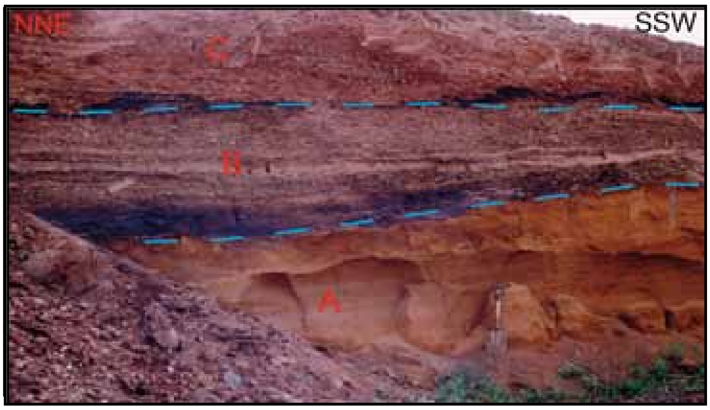


Figure 3.1.3 : The Thörnich-Hochrech section (terrace M3) : location, overview and luminescence ages

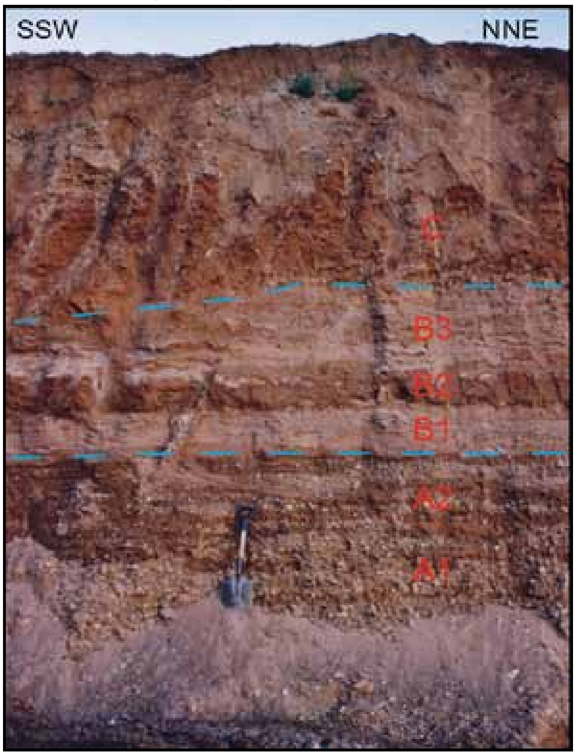


Incision in units A and B before depositions of units C and D (profiles 1 and 2). This erosion is allocated to a change in the river course (meander chute cut-off).

The profile 7 of Thörnich-Hochrech (M3) : contrast between the lower sandy unit A and the upper coarse units B and C.



The profile 1 of Thörnich-Hochrech (M3): the formation include two coarse units (A and C), a sandy unit (B) and fine grained sediments (unit D).



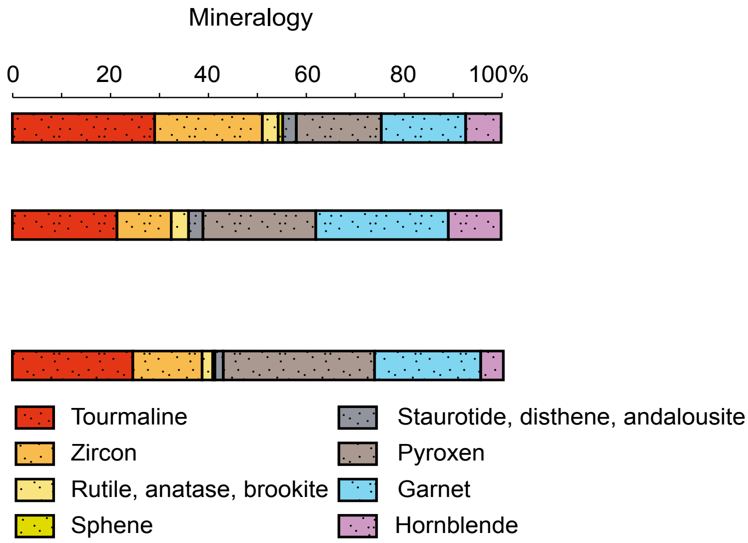
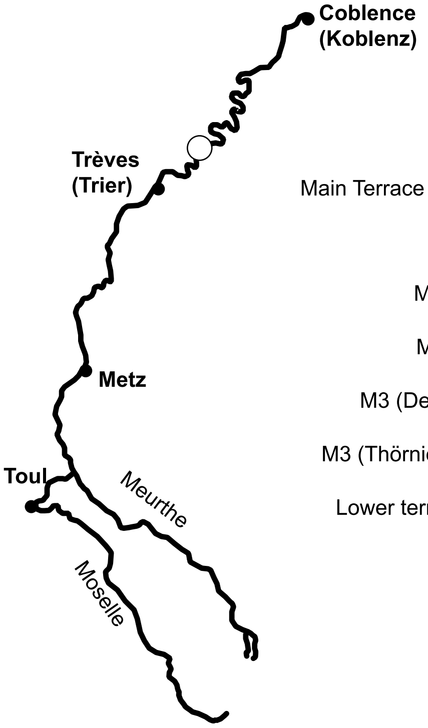
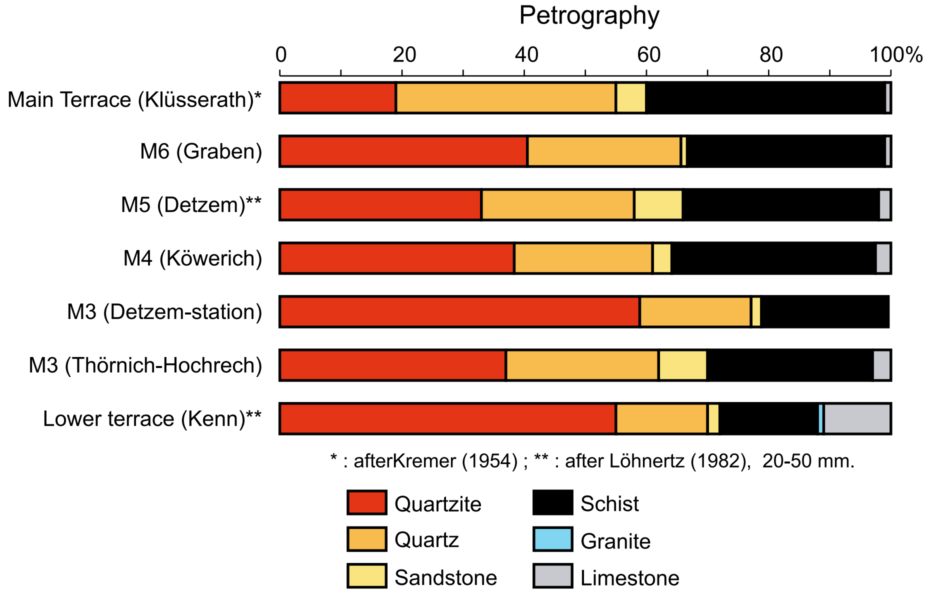
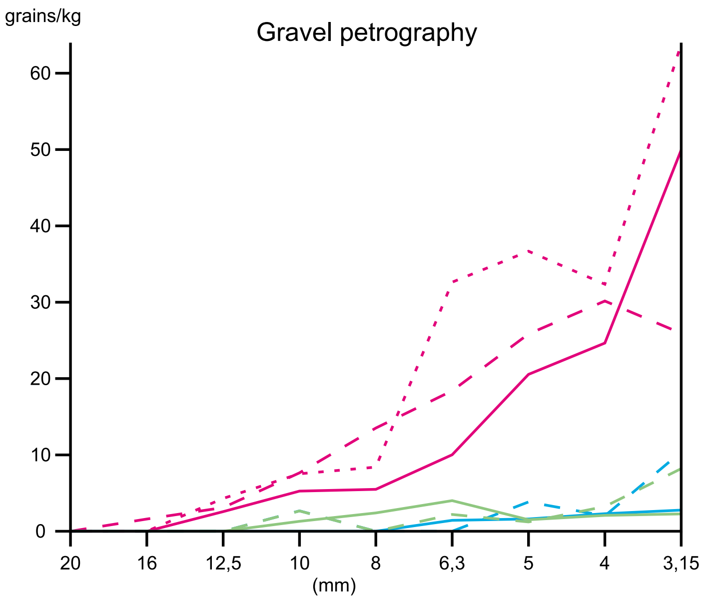


Figure 3.1.4 : The Hochrech section : detailed view of sections 1, 2 and 7 and mineralogical data







	(grains/kg)
Detzem	12,19
Thörnich A	13,94
Thörnich C	14,69
total M3	13,61
Kelter	0,85
Köwerich	1,96
total M4	1,40
Auf der Teichen	1,70
Altwiese	1,34
total M5	1,52

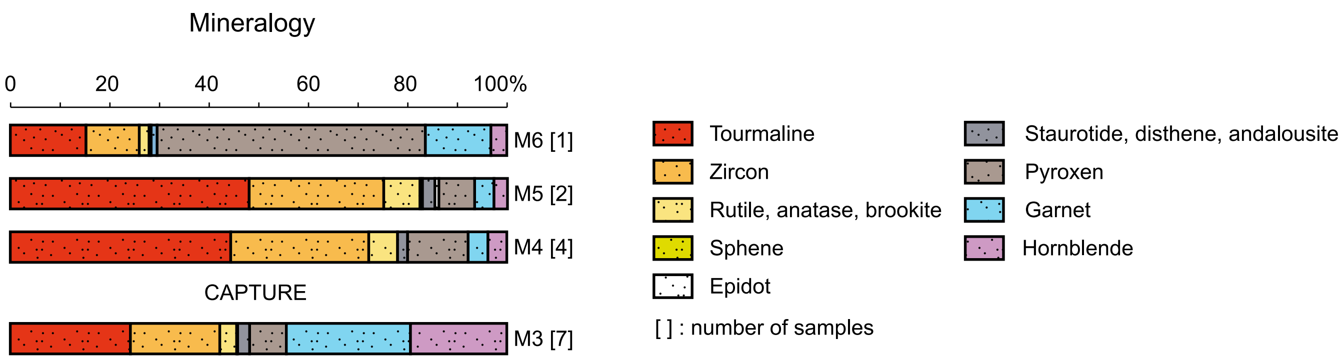


Figure 3.1.5 : Mineralogy and petrography of the German Moselle terraces

sediment supply, it is possible to assume that the sediments correspond with point-bar deposits related to broad but shallow channels. This assumption is based on 1) the morphological context of the area, 2) the decreasing of the grain-size, 3) the sedimentary structure (transition from broad to small cross-bedding, presence of horizontal bedding being related to the decrease of channel depth close to the point bar), and 4) the evidence for downcutting events as shown in profiles 2 and 7 (figure 3.1.4).

The first post-capture terrace

In contrast with the fluvial terraces observed in the Paris basin, where most of the deposits have a Vosgian origin, the Rhenish Massif is obviously the main sediment source for the Moselle downstream from Trier. This explains the coarse size of the sediments (and especially the presence of metric blocks). Whatever the fluvial terrace considered, the pebbles are mainly composed of schists, or poorly rounded quartz and quartzites originating from the Devonian basement (figure 3.1.5). Following this, the distinction between the pre-capture terraces (formed by the Palaeo-Meurthe while the Upper Moselle joined the Meuse) and the post-capture terraces in the Rhenish Massif could not be considered as an easy task. This explains that previous studies focusing on the German Moselle valley did not pay attention to the capture. The only evidence was actually provided by Kremer (1954), who mentions the presence of granite in the “lower middle terrace” and relates this to the capture. However, this observation cannot be considered as useful, since the “lower middle terrace” corresponds with several fluvial terraces (M3 to M5).

In order to overcome this problem, sedimentological analyses focused on gravels (petrography) and sands (heavy-mineral determinations) sampled in the terraces M3 to M6 in the Detzem-Leiwen and Piesport meanders.

The petrographical investigations aimed to assess the density of granite in the gravels (3 to 20 mm fraction). The results (figure 3.1.5) demonstrate that the proportion of granite in the terrace M3 is significantly higher than that in the older terraces M4 to M6 (12 to 15 grains/kg but less than 2, respectively). Similarly, the heavy-mineral determinations show a high proportion and Vosgian garnet and hornblende in the fluvial terrace M3, in contrast with the older fluvial terraces (figures 3.1.4 and 3.1.5).

This sharp increasing of Vosgian sediments in the terrace M3 should clearly be allocated to the occurrence of the Upper Moselle capture. This result is furthermore in excellent agreement with those obtained in the whole Paris basin (and especially in the Toul area, see day 1), which demonstrated the presence of three post capture terraces.

This allows the terraces M4 and M3 found preserved in the Paris basin to be correlated with the M4 and M3 terraces in the Detzem-Leiwen area. The relative heights of the terraces are consistent in the Paris basin (+30-35m and + 20m, respectively) and the Rhenish Massif (+37-40m and +25m, respectively). This result is of great significance since it makes it possible to correlate the youngest terraces (M4 to M1), and possibly the older one (M8 to M5, also located at constant relative height), from the Vosges Massif to the lower Moselle area. From a tectonic point of view, this also demonstrates that the uplift since the capture in the southwestern Rhenish Massif was not significantly higher than that of the Paris basin.

OSL dating and fluvial response to climate forcing

OSL dating of quartz have been performed on sands from units A and B, using the SAR protocol. They yielded ages of 96±9 and 89±7 ka, respectively (figure.3.1.3). These results were confirmed by OSL dating of fluvial sands from terrace M3 at Ürzig (40 km downstream), which yielded ages of 116±10 and 83±7 ka. Following this, the deposition of the M3 sediments in the Rhenish Massif may be allocated to the MIS 5. Even if these data do not allow allocation to any substage, this result is of great significance when compared with those obtained for the M3 terrace downstream from the Vosges Massif: In the Golbey section (70 km upstream from Toul), the fluvial terrace is composed of a basal unit (with mainly sediments of local origin) and a top unit with a high proportion of granite from the upper catchment. The two units are separated by a clear erosive contact. The sediment composition suggest that these two units were deposited during a glacial and late- to interglacial (lato sensu) periods, respectively. Recent IRSL dating (unpublished) confirmed this assumption, the deposition of the lower and upper units being allocated to the MIS 6 and 5, respectively.

We can infer from this comparison that most of the Saalian sediments of the M3 terrace in the Rhenish Massif have been reworked (their presence in the upper pre-capture terrace M4 should actually be excluded, as the capture cannot be younger than MIS 8). It is likely that this reworking took place at the Saalian-Weichselian transition. This result underlines the variable fluvial response to the last climate cycle along the Moselle valley: in the vicinity of the Vosges Massif, the predominance of aggradation upon erosion allows the preservation of both the Saalian and Lower Weichselian sediments. In the Rhenish Massif, where the valley is much narrower, the MIS 6 sediments have been significantly reworked. In the Ürzig section, all the sediments have been deposited during the Lower Weichselian. In Thörnich-Hochrech, only the basal coarse unit might be allocated to the Saalian. However, no numerical age is available for this unit up to present.

Conclusion

The Thörnich-Hochrech gravel-pit is a key-site to reconstruct the Moselle evolution. First, the sedimentary facies are typical for fluvial sediments in the Rhenish Massif, with a predominance of coarse deposits of local origin. Secondly, the significant proportion of Vosgian gravels and sands demonstrates that the associated terrace M3 correspond with the first post-capture terrace. This makes it possible to propose longitudinal correlations at the catchment's scale, indicating that the Middle and Upper Pleistocene tectonic history was similar in the Southwestern Rhenish Massif and in the Eastern Paris basin. Thirdly, the facies and the luminescence dating underline that several periods of sedimentation and erosion took place. In particular, most of the Saalian deposits (MIS 6) have been removed, probably at the MIS 6-5 transition. This contrast with the observation made for the same terrace M3 in the vicinity of the Vosges Massif, highlighting the complexity of the fluvial response to climate change along a given river.

September 7, 2012

Stop 3.2 : The Piesport meander

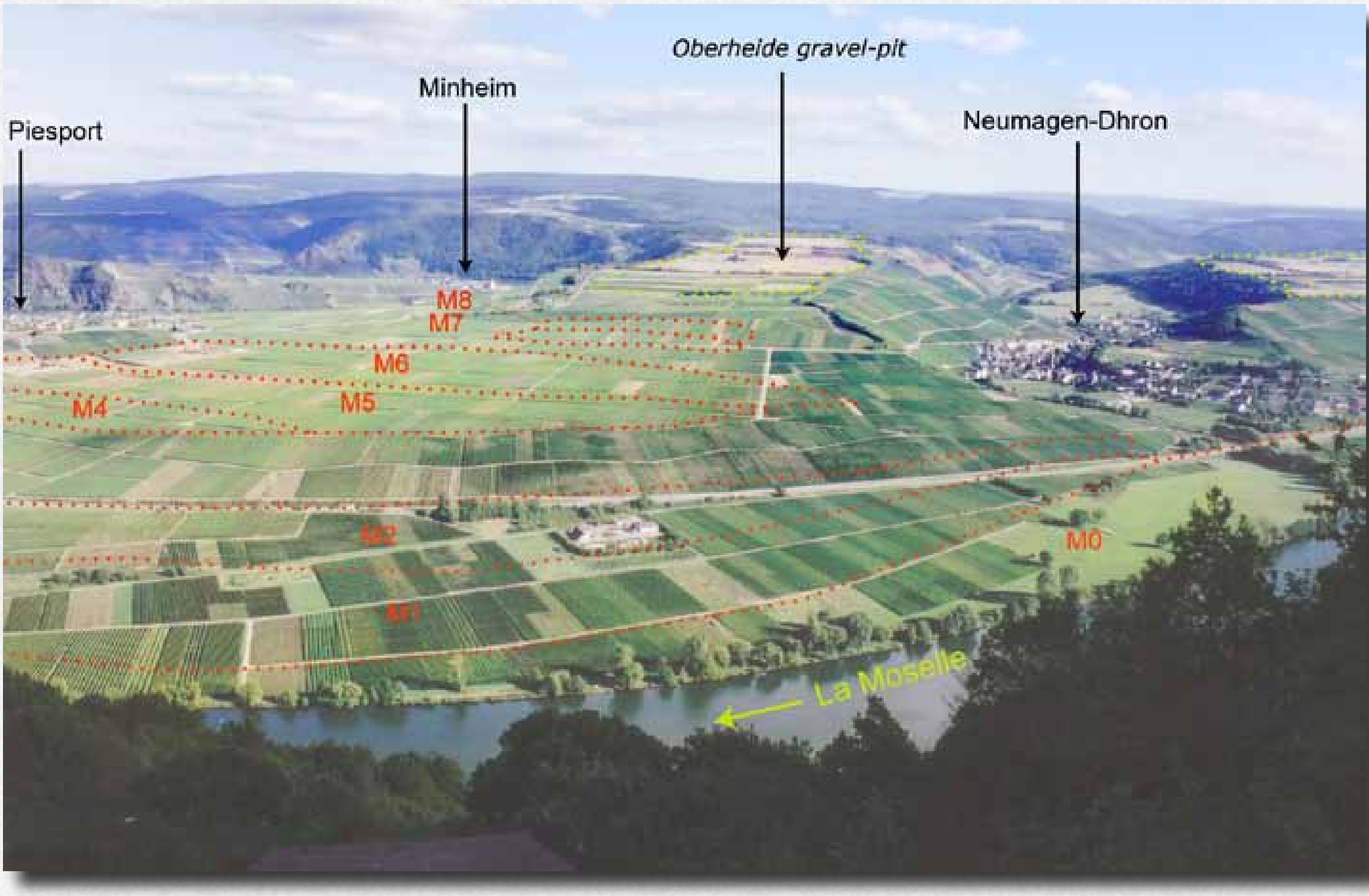


Figure 3.2.1 : The Piesport meander (picture : S. Cordier)

Stop n° 3.2 : The Piesport meander

This stop is located about 15 km downstream from the first one, on the concave bank of the Piesport meander, at about 390 m a.s.l. (280 m above the Moselle). The interfluve separating the Moselle valley and the Wittlich basin is located only a few metres above towards the North.

The Piesport meander can be considered as one of the most beautiful lookout on the Moselle valley ("Groβer Moselblick", figure 3.2.1). It makes it possible to reconstruct the long-term evolution of the valley. Towards the South, it is possible to observe the Cretaceous to Tertiary palaeosurfaces, dominated by the Idarwald quartzite monadnocks which were already described by Davis. Good weather and sight allow having a look just to the Erbeskopf, which is with 816 m a.s.l. is the highest point of the Hunsrück and one of the highest points of the whole Rhenish Massif.

The most impressive surface, dominating the landscape (and including the above-mentioned interfluves), is developed in about 400m a.s.l. On this surface, which delimits the "Moselle trough", the oldest fluvial deposits (only locally preserved) have been found. They correspond to fluvial gravels that are assumed to have been deposited by a Palaeo-Sarre (presence of sediments from the Sarre-Nahe basin) during the middle Eocene (Löhnertz, 1994, 2003). Following from this, it is possible to assume that no main dislocation took place in the area since the Eocene. This contrasts with other areas (such as the Central German uplands near Würzburg) where evidences for significant Pliocene activity have been found. The lack of activities in the Moselle area may be explained by a great valley filling (Louis, 1953; Löhnertz, 1982) that took place during the Eocene and Oligocene, before its removal at the Late Oligocene/ Early Miocene.

As the highest Pleistocene terrace is assumed to be preserved at about 320 m a.s.l., the frame for the Mio-Pliocene evolution is limited to a vertical range of ca 60-80 m (from 320 to 400 m). The contemporaneous sediments, preserved only in the lower valley, correspond with well-rounded quartz (>70%) and quartzite (20-25%) gravels including siliceous oolithe ("Kieseloolith"). The presence of such well-rounded gravels suggests that these sediments are not originating from the bedrock, but from the reworking of previous sediments. The Tertiary age of this formation was inferred from mineralogical analyses (Negendank, 1978) and comparison with the Lower Rhine area where numerical ages have been provided.

The first assumed Pleistocene terrace (high terrace, Kremer, 1954; older main terrace, Hoffmann, 1996, terrace t1, Löhnertz, 1982) is visible looking towards South-East, opposite from the village of Minheim. The terraces located immediately below form the main terrace group. The main terraces are particularly well preserved on the opposite bank on the Moselle, on both sides of the Dhron River. Three main differences may be recognized when comparing the main terraces and the terraces preserved below:

-the main terraces are preserved on broad surfaces, separated from the younger terraces of the “narrow valley” by a sharp edge that is especially visible from the lookout on both sides of the Dhron valley (figure 3.1.1). The main terraces can be easily distinguished from the younger terraces by the land use: the main terrace are actually wooded or used for “normal” agriculture (cereals, potatoes, rapes), in contrast with the vineyards that occupy the lower terraces. The main terraces are also associated with thick fluvial sediments (often more than 10 m).

-The location of the main terraces suggests that the contemporaneous river course was not delimited by the present day meanders, but followed a large palaeovalley that may be associated with braided channels (figure 3.2.2). In contrast, the younger terraces (middle and lower terraces, M8 to M1) and the present day river are developed along the same pattern of meanders. From the stop, the terraces M8 to M4 are especially well-preserved on the convex bank of the Piesport meander, on the opposite side of the Moselle.

-While the slope of the youngest terraces is similar to that of the present river between Trier and the Rhine confluence, the main terraces are located at a constant relative height from Trier to Cochem, both cities being separated by 150 km. Several explanations have been provided to this horizontality, the main ones being: 1) an updoming in the Cochem area (Negendank, 1983), 2) the reactivation of numerous faults along the valley (Hoffmann, 1996; Meyer and Stets, 1998), or 3) the deposition of the main terrace sediments by a river with a very weak slope as is currently the case for the main Siberian rivers (Löhnertz, 2003).

Despite the apparent simplicity of recognizing the main terraces (not only in the German Moselle but also in the Rhine valley), two major issues remain. The first one concerns the number of terraces belonging to this “main terrace complex”. This number is variable (from 3 to 5), according to the different authors who may also have used various names to define these terraces. This difference may be explained by the fact that the main terrace corresponds with gentle slopes tilted towards the present river, with a difference in height of about 40 m between the upper and lower part of the terrace. However, there was never any doubt about the position of the terrace complex in terms of fluvial landforms.

The most important issue concerns the age of the main terraces. Previous research (Hoffmann, 1996) that has been widely accepted (Meyer and Stets, 1998; Gibbard and Lewin, 2009) suggests an age close to 780 ka for the younger main terrace, on the basis of palaeomagnetic age estimates in the Lower

Rhine, extrapolated in the Moselle and Lower Sarre areas. However, ESR dating performed on the lower main terrace in the Lower Sarre valley (Cordier et al., 2012) at Kommlingen (+100m relative height) and in the Lower Moselle valley at Lasserg (+200 m relative height) yielded significantly older ages of ca. 1.2±0.2 and 1.8±0.2 Ma, respectively. As these ages show significant error ranges and incomplete bleaching should not be entirely excluded, the ages must be confirmed (cosmonucleide dating in work). However, they suggests that the main terrace complex in the Sarre and Moselle valleys could be significantly older than previously proposed, probably pre-dating the Matuyama–Brunhes boundary. This new reconstruction closely agrees with the chronostratigraphical reconstruction proposed for the Moselle terraces (Cordier et al., 2006a), which assumed an age of ca. 650–700 ka for the terrace M8 in the Moselle valley (+85 m relative height) and implied that the main terraces (>120 m relative height) could not be younger than 1 Ma. Furthermore, the results indicate that the formation of the main terraces may be diachronic. This new interpretation is consistent with recent cosmogenic exposure age determinations of the main terrace complex of some Meuse tributaries in the Western Rhenish Massif (Rixhon et al., 2011), as well as with the research of W.Löhnertz on German tributaries of the Moselle. As these results make all the previous reconstructions questionable, their confirmation is necessary to improve the knowledge of the timing and conditions of the formation of these terraces.

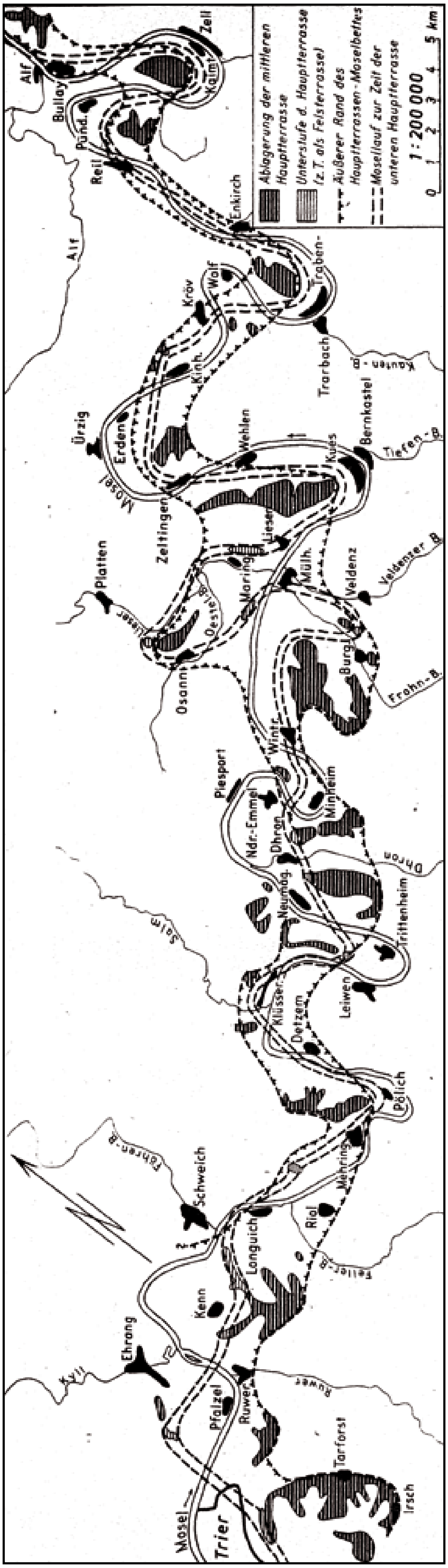


Figure 3.2.2 : The Moselle valley during the main-terrace formation (Kremer, 1954)

September 7, 2012

Stop 3.3 : The Piesport-Oberheide gravel-pit

The main terrace at Oberheide (picture : D. Harmand)

Stop n° 3.3 : The Piesport-Oberheide gravel-pit

The open-gravel pit “Oberheide” is part of the wide main terrace of the Moselle developed between Neumagen-Drhon and Minheim. During the construction of the main road from Niederemmel to Morbach in 1975, it was possible to see the base of the whole terrace over a distance of 2.5 km (Löhnertz, 1982) and to recognize three terrace levels (figure 3.3.1). It seems that a modern analysis of different sequences in the sediments including numerical dating may show more terraces.
The Oberheide pit being located in the middle level. The slope just behind the current open-gravel pit is indicating that the quarry is now located at the outermost bend of the terrace, close to slope leading to the higher terrace. The bedrock is located at ca. 257 m a.s.l. This is 5 to 7 m below the normal base-level of the main terrace in the Piesport area. This may be interpreted as the result of more pronounced vertical erosion in the vicinity of the palaeo-slope.
The present outcrop exposes four main sedimentary units. The lower unit is 4 m thick and correspond with coarse gravels and blocks (up to 1 m in diameter), the latter being probably associated with ice-rafting processes as was already recognized in other parts of the Moselle and Sarre valleys. Petrographic analysis shows the predominance of three main rocks: quartz, quartzites and schists, each representing ca 30% of the sediment. The quartz and quartzite pebbles are well-rounded. This suggests that the sediments are only partially a product of the Pleistocene erosion, but mainly the result of the removal of a thick layer of Tertiary sediments. Only in the upper part of this unit is it possible to recognize angular quartz pebbles with holes (“cavernous quartz”) originating from the Devonian bedrock. This may be allocated to an increasing influence of the Dhron river flowing into the Moselle.
The second unit consists of an alternate structure of sand (with horizontal or cross-bedding) and open-work gravels and pebbles. The increasing proportion of Devonian schists and sandstones (>40%) and the angular shape of the quartz suggest that the Dhron river played a major role in sediment deposition (Kremer, 1954; Müller, 1976).
In the third unit, pebbles are again imbedded in a red sandy matrix. Most of the quartz pebbles are rounded, while the angular Devonian rocks represent less than 20% of the sediment. The sediments also include limestones, basaltic pebbles and flints (Kremer, 1954; Müller, 1976). This makes it possible to assume that the third unit was mainly deposited by the Moselle.
The upper unit is composed of a silty and sandy yellow loam which is ca 10 m thick (fig.3.3.2). Samples analysed by W.Löhnertz were found to contain only 1% of limonitoolite (originating from the Lorraine-Luxembourg Minette formation). This demonstrates that the upper unit should not be allocated to Moselle floodplain deposits. It is interpreted as washed loess mixed with weathered and eroded material originating from the Devonian slope (Negendank, 1978).

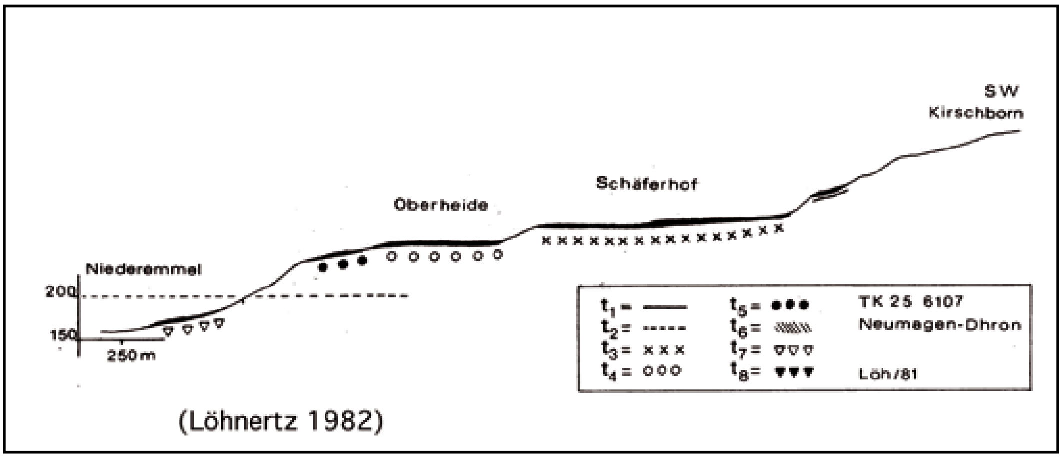


Figure 3.3.1 : The terrace staircase of the Moselle valley at Oberheide

Figure 3.3.2 : General view of the upper unit of the Oberheide section

September 7, 2012

Stop 3.4 : The Moselle palaeovalley from the Paulskirche

The Paulskirche site (picture S.Cordier)

Stop n° 3.4 : The Moselle palaeovalley from the Paulskirche

In contrast with the meanders which have been recognized in the Detzem-Leiwen and Piesport areas (see stops 3.1 and 3.2), the Paulskirche dominates one of the palaeo-meanders that were formed by the Moselle between the villages of Brauneberg and Lieser. Two main meanders may be recognized. They are located south (Veldenz palaeomeander, figure 3.4.1) and north (Noviand-Siebenborn and Platten palaeomeanders) of the present-day river, respectively. They form a ca 28 km long palaeo-valley, which almost reaches the Wittlich Permian basin near Platten. The fact that the Moselle did not really enter the basin may be explained first by its assumed superimposition, and by the presence of a locally important tributary, the Lieser, coming from the Wittlich basin. Three meander downcutting events led to the formation of the present day course and to the formation of elongated hills termed “Umlaufberge” (“meander mountains”). These palaeomeanders were already described more than one century ago (Lepsius, 1887; Penck, 1887; Dietrich, 1910). In the second part of the last century, research made it possible to get a precise morphological mapping of the fluvial sediments in the area (Kremer, 1954; Löhnertz, 1984). The main terraces are only preserved locally on top of the hills, contrasting with the broad surfaces observed in the surrounding parts of the valley (Wintrich-Brauneberg area, Bernkastel-Kues meander). In contrast, the sediments found at the bottom of the pallaeovalley were allocated to the upper and lower middle terraces. The finding of rare granite pebbles from the Vosges Massif in the lower middle terrace between Maring and Noviand (145 m a.s.l.) led Kremer to assume that the palaeo-valley was still in use after the Upper-Moselle capture. The results obtained upstream (stop 3.1) however demonstrate that this interpretation was not reliable. Based on his new results, Cordier (2004) proposed an attempt of correlation between the terraces preserved along the palaeo-valley and those recognized in the Detzem-Piesport (figure 3.4.2) The sediments whose basis is located at about 145 m a.s.l. near Osann are thus correlated with M4 (basis in Piesport : 147 m). The cut-off of the “Platten meander” could thus have occured between the terraces M4 and M3 time. Owing to the height of the present pass located in the North-East of Noviand (145 m), the “Paulskirche meander” was on the contrary probably still active during the M3 formation.

The upper height of the pass located in the “Veldenz meander” (more than 180 m) finally suggests that its cut-off is probably older than that of the other meanders. This relative chronology evidences that the Moselle capture had no main influence in the evolution of the Moselle course in the “Umlaufberge” area, since only the last meander downcutting have occurred after the capture. Further investigations are necessary to reconstruct the geometry of the flu-

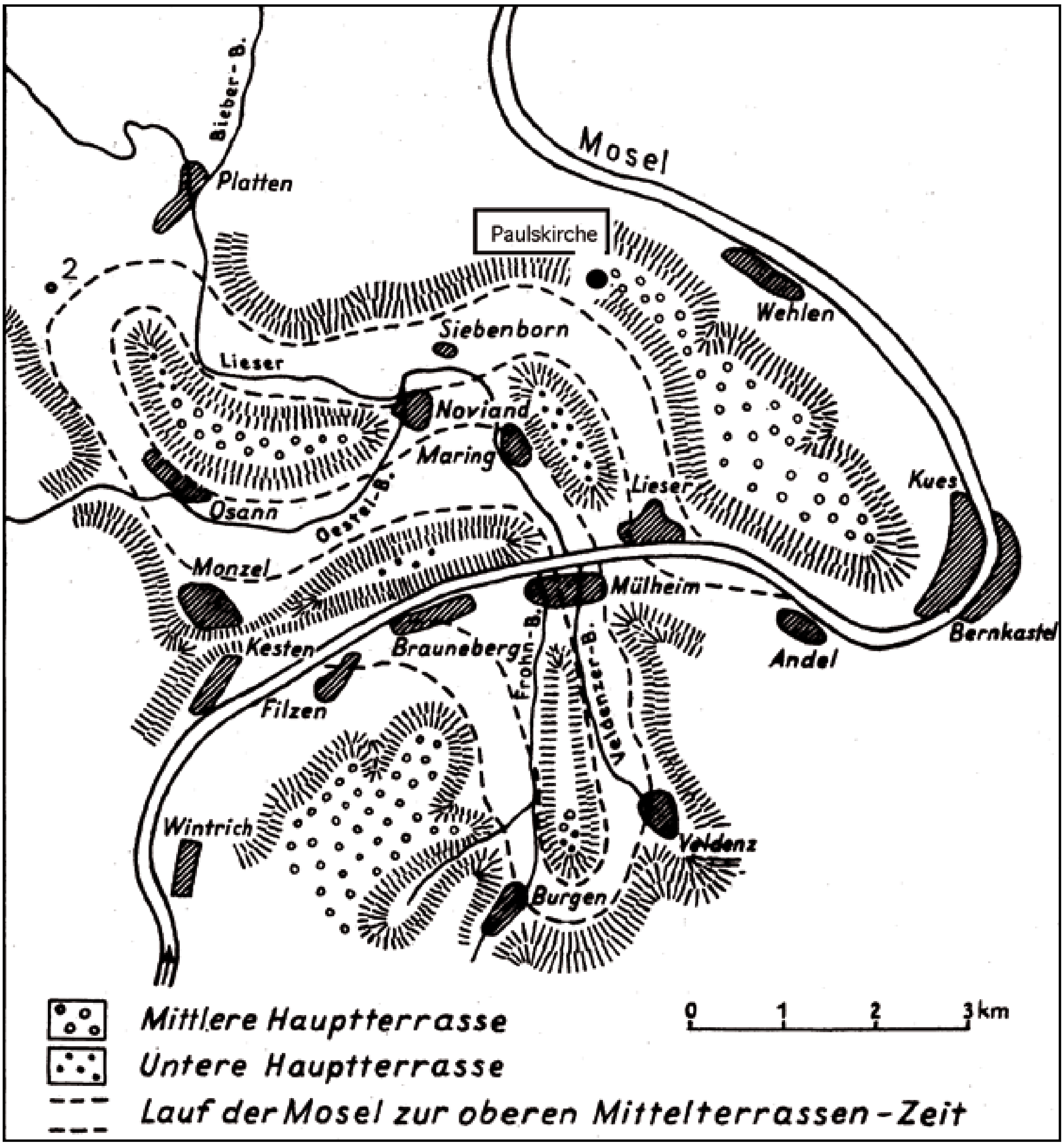


Figure 3.4.1 : The palaeomeanders of the Moselle valley between Wintrich and Bernkastel (after Kremer, 1954)

vial sediments in the palaeo-valleys: cores performed in the area actually demonstrated that the fluvial sediments were covered by thick slope deposits after the Moselle left the area (as shown in the Val de l'Asne valley, see day 1). Furthermore, several Moselle tributaries flow through the paleo-valley, sometimes in an opposite direction of the Moselle. The main ones are the Lieser and Oestal-Bach (North of the present day Moselle), and the Frohn-Bach and Veldenzer-Bach (in the Veldenz palaeo- meander). In contrast, no younger stream occupied the part of the former Moselle valley located in the Paulskirche area, enabling the shape of the former channel to be more or less preserved (except the deposition of slope-deposits originated from the older terraces and the bedrock; figure 3.4.3).

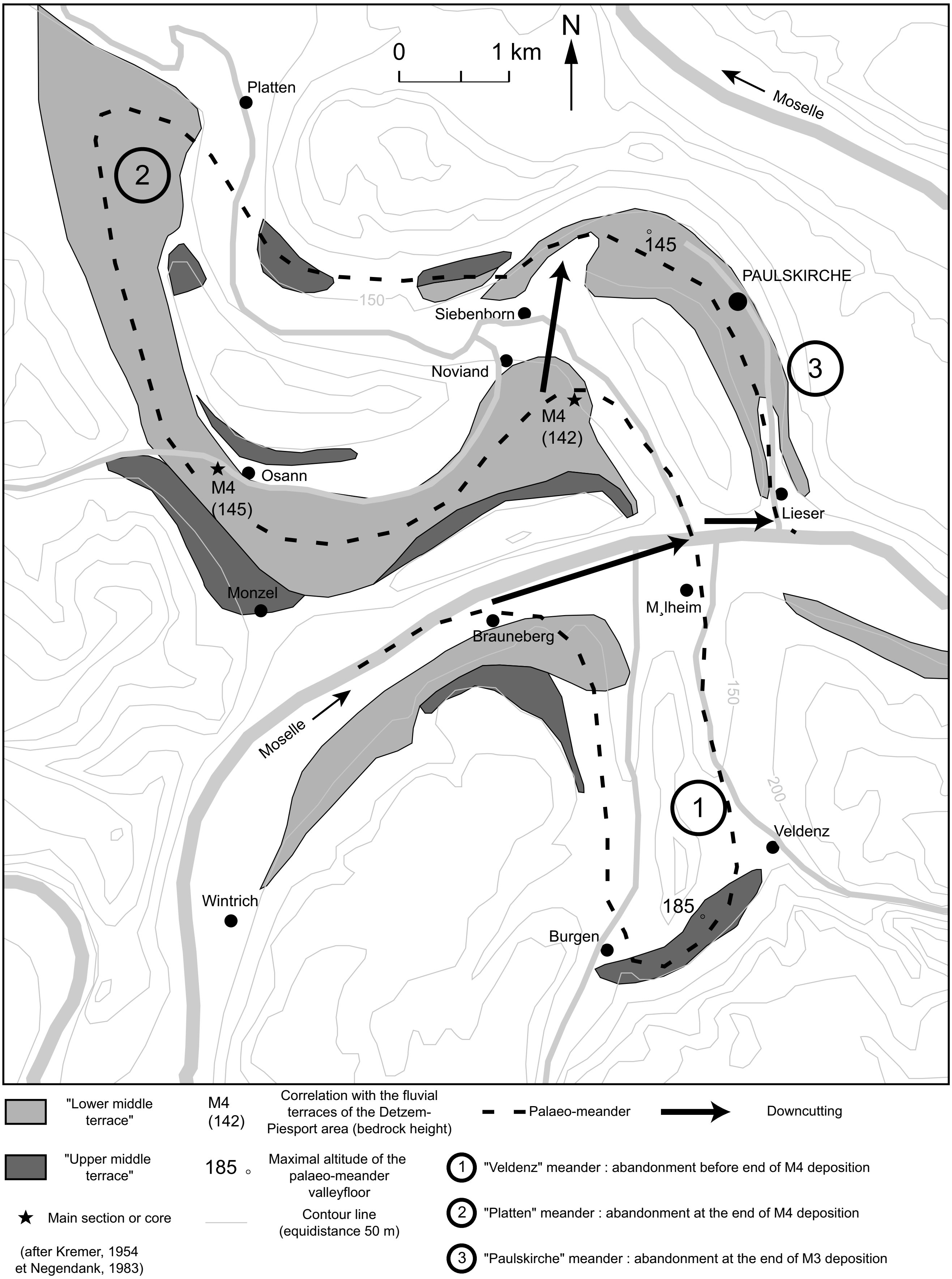


Figure 3.4.2 : The Moselle palaeomeanders : general frame work and chronogical reconstruction

Figure 3.4.3 : The Moselle palaeovalley from the Paulskirche (picture S.Cordier)

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