# International field workshop on ”The Triassic of Eastern France”, october 2-7, 2006

Sylvie Bourquin, M. Durand

**Pan-European correlation of the epicontinental Triassic**

# International Field Workshop on 'The Triassic of eastern France'

**October 2 — 7, 2006**

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# Excursions

### Tuesday, 03.10 2006

**Stop 1.1** **Haut-Barr** Middle Buntsandstein (‘Grès vosgien’ and ‘Conglomérat principal’ Fms)
**Stop 1.2** **Niderviller** (Metzger quarry): Upper Buntsandstein (‘Grès à Voltzia’ Fm)
**Stop 1.3** **Héming** (Holcim quarry): Upper Muschelkalk (‘Calcaire à entroques’ and ‘Calcaire à cératites’ Fms
**Stop 1.4** **Raon-l'Etape** (Côte de Beauregard): Middle Buntsandstein (‘Conglomérat inférieur’ Fm and ‘Grès vosgien’ Fm, with aeolian facies)
**Stop 1.5** **Housseras** (‘Poterie lorraine’ quarry): Middle Muschelkalk (‘Couches rouges’ Fm)

### Wednesday, 04.10 2006

**Stop 2.1** **Dompaire-Racécourt** (road cutting): Lower Keuper = Lettenkohle
**Stop 2.2** **Relanges** (quarry along D164 road): Middle Buntsandstein (‘Conglomérat principal’ and ‘Zone limite violette’ Fms)
**Stop 2.3** **Suriauville** (road cutting): Lower Keuper (‘Dolomie de Vittel’ Fm= ‘Dolomie inférieure’ of the Lettenkohle)
**Stop 2.4** **Crainvilliers** (gullies in forest): Eo-Cimmerian unconformity (‘Argiles bariolées dolomitiques’ Fm / ‘Grès à roseaux’ Fm)
**Stop 2.5** **La Neuville-sous-Chatenois** (old quarry): Upper Keuper (‘Grès rhétiens’ Fm)
**Stop 2.6** **Poussay** (D55 road cutting): Upper Keuper (‘Argiles de Levallois’ Fm and Triassic-Jurassic boundary)
**Stop 2.7** **Florémont** (N57-E23 road cuttings): Middle Keuper (‘Marnes irisées moyenne’ and ‘Marnes irisées supérieures’ Fms, with Eo-Cimmerian unconformity)
**Stop 2.8** **Xirocourt** (S.R.D.E. quarry): Middle Keuper (‘Dolomie de Beaumont’ Fm)
**Stop 2.9** **Mangonville** (old gypsum quarry): Middle Keuper (‘Formation salifère’)

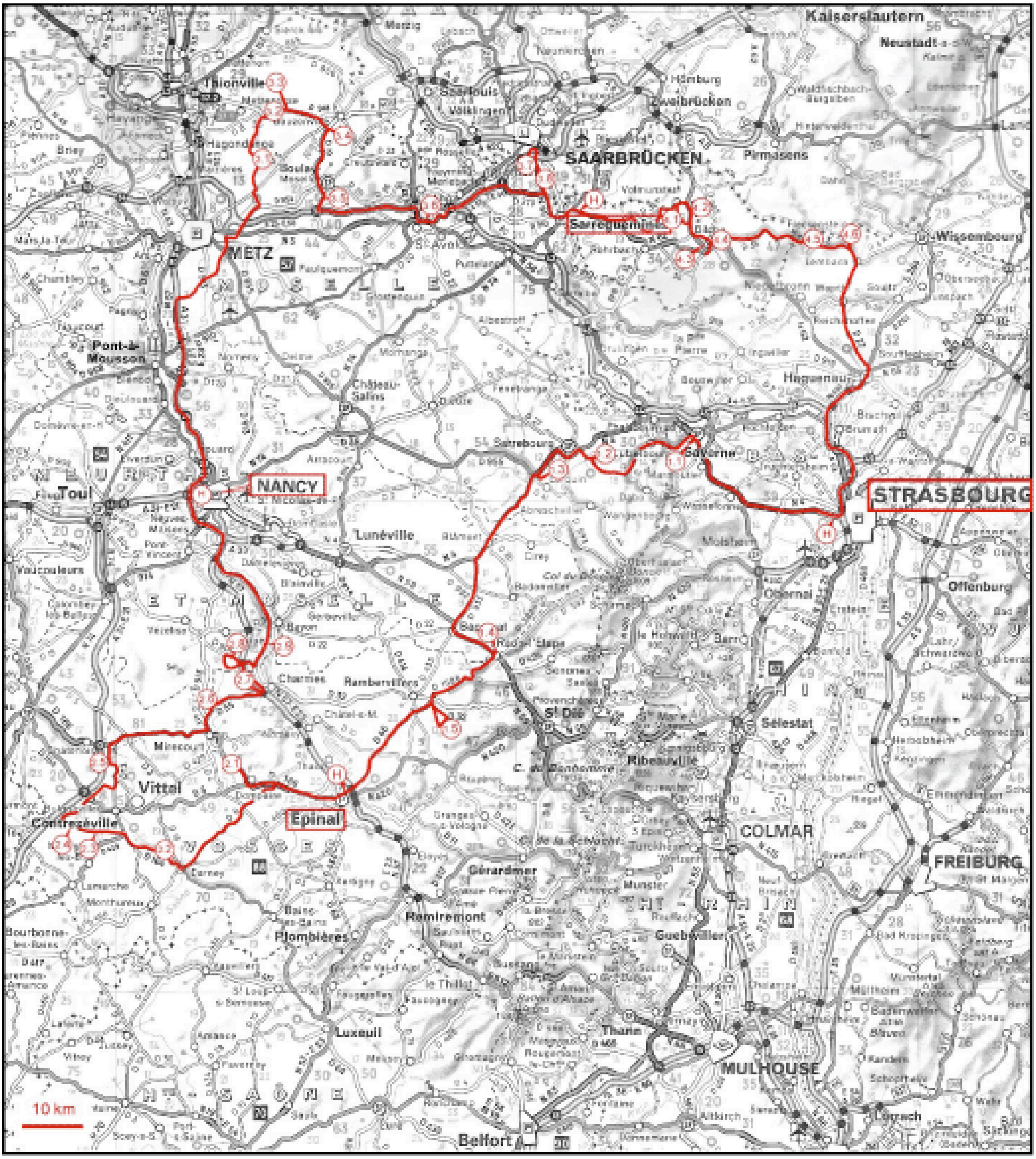
### Thursday, 05.10.2006

**Stop 3.1** **Saint-Hubert** (old quarries): Upper Keuper (‘Grès rhétiens’ Fm)
**Stop 3.2** **Hombourg-Budange** (D978 road cutting)**:** Middle Keuper (‘Dolomie de Beaumont’ Fm, marginal facies)
**Stop 3.3** **Kemplich** (old gypsum quarry)**:** Middle Keuper (‘Marnes irisées supérieures’ Fm, with Eo-Cimmerian unconformity)
**Stop 3.4** **Rémelfang:** Middle Keuper (basal part of the ‘Grès à roseaux’ Fm)
**Stop 3.5** **Helstroff** (D19 road cutting): Uppermost Muschelkalk (‘Calcaire à cératites’ and dolomitized ‘Calcaire à térébratules’ Fms)
**Stop 3.6** **Saint-Avold** (N3 road cutting): Middle Buntsandstein (‘Conglomérat principal’ and ‘Zone limite violette’ Fms)
**Stop 3.7** **Sankt-Arnual** (cliffs in Stiftswald)**:** Upper Buntsandstein (‘Couches intermédiaires’ Fm)
**Stop 3.8** **Grosbliederstroff** (N61 road cutting): Hardegsen unconformity (between Middle and Upper Buntsandstein)

### Friday, 06.10.2006

**Stop 4.1** **Weiskirch:** Lower Muchelkalk (‘Grès coquillier’ Fm, with ball-and-pillow structures)
**Stop 4.2** **Volmunster-Lengelsheim:** Lower Muschelkalk (‘Volmunster’ Formation, Wellenkalk facies)
**Stop 4.3** **Bitche** (N62 road): Hardegsen unconformity (between Middle and Upper Buntsandstein)
**Stop 4.4** **Bitche** (Citadel): Middle Buntsandstein (Karlstal facies of the ‘Grès vosgien’ Fm)
**Stop 4.5** **Niedersteinbach** (forest trail): Permian: ‘French Lower Buntsandstein’ (‘Grès d'Annweiler’ Fm) on Rotliegends
**Stop 4.6** **Fleckenstein Castle: ‘**Grès d'Annweiler’ Fm. and Trifels facies of the ‘Grès vosgien’ Fm

# Itinerary and outcrop locations



# The Triassic of eastern France

## I. - Introduction

The Triassic of the Paris Basin was deposited in an intracratonic peri-Tethyan basin (Perrodon & Zabek, 1990) and its succession is characterized by (Dubois and Umbach, 1974; Courel et al., 1980): (i) fluvial and playa deposits during the Early Triassic, *i.e.* Buntsandstein facies, (ii) evaporite and marine deposits during the Middle Triassic, *i.e.* Muschelkalk facies and (iii) mainly evaporite and fluvial deposits during the Late Triassic, *i.e.* Keuper facies. During the Early and Middle Triassic, the Paris and Bresse-Jura basins formed the western end of the Germanic Basin. The Paris Basin only existed as an independent basin from the Middle Carnian onwards (Bourquin and Guillocheau, 1993, 1996).

The terminology used in the eastern part of the Paris Basin is indicated in the Table 1.

| | | | |
|---|---|---|---|
| **Keuper** | **Rhaetian** | | Argiles de Levallois |
| | | | Grés rhétiens |
| | **Marnes irisées** | **Marnes irisées supérieures** | Argiles bariolées dolomitiques |
| | | | Argiles de Chanville |
| | | **Marnes irisées moyennes** | Dolomie de Beaumont |
| | | | Argiles bariolées intermédiaires |
| | | | Grés à roseaux |
| | | **Marnes irisées inférieures** | Couches à esthéries |
| | | | Formation salifère |
| | | | Couches à pseudomorphoses |
| | **Lettenkhole** | | Dolomie-limite de la Lettenkohle |
| | | | Argiles de la Lettenkohle |
| | | | Dolomie inférieure de la Lettenkohle |
| **Muschelkalk** | **Upper Muschelkalk** | | Calcaire à terebratules |
| | | | Calcaire à ceratites |
| | | | Calcaire à entroques |
| | **Middle Muschelkalk = Groupe de l'anhydrite** | | Couches blanches |
| | | | Couches grises |
| | | | Couches rouges |
| | **Lower Muschelkalk** | | Dolomie à *Myophoria orbicularis* |
| | | | Complexe de Vollmunster |
| | | | Grès coquillier |
| **Buntsandstein** | **Upper Buntsandstein** | | Grés à *Voltzia* |
| | | | Couches intermédiaires |
| | **Middle Buntsandstein** | | Zone limite violette |
| | | | Conglomérat principal |
| | | | Grés vosgien |
| | | | Conglomérat inférieur |
| | **Lower Buntsandstein** | | Grès d'Annweiler Grès de Senones |

**Table 1**: Terminology used in the eastern part of the Paris Basin (after Courel et al., 1980

The study of the Paris Basin was focused until the years 1990 on outcrops data. The development of sequence stratigraphy concept allowed to propose a sequential analysis of the Mesozoic formations of the Paris Basin from outcrop data (Guillocheau, 1991). Like this, this author describes during the Triassic three major stratigraphic cycles. However, the study of the Triassic outcrops does not allow to understand the evolution of the Paris Basin without the help of correlations with the central and western part, which display proximal facies (sandstone and clay). In fact, the Triassic crops out only in the eastern part of the Paris Basin. The outcrops are discontinuous and it is sometimes very difficult to determine the stratigraphic position. Only well-log data can provide a continuous record.

The numerous well-log and core data in the Paris Basin allow to realize correlations from western and eastern part of the basin, and make a comparison with outcrop data. By studying the complete set of wells in the Paris Basin, we can carry out correlations and propose paleogeographic reconstruction for the Triassic. In subsurface studies, it is essential to use complete sets of log data to identify and correlate genetic sequences, especially in continental environments (Bourquin et al., 1990, 1993). For example, sandstones that include large amounts of radioactive minerals (potash feldspar, heavy minerals, etc.) may produce high gamma-ray values similar to those obtained from clays. Consequently, the use of gamma-ray and sonic logs alone may lead to misinterpretation. Similarly, a density log coupled with a photo-electric factor log is required to distinguish between dolomitic and anhydritic shales. Neutron-porosity, density and photo-electric factor logs, used with high-resolution logs (dipmeter or Formation Microscanner) are necessary (1) to determine sedimentary facies, (2) to calibrate cores and outcrops with well logs and (3) to obtain correlations.

The analysis of around 700 wells in the Paris basin has allowed (1) to define pre-Triassic topography, (2) to propose sequence stratigraphy correlations of the Triassic series and a comparison with data from other west-European basins (Bourquin and Guillocheau, 1993, 1996; Bourquin et al., 1998, 2006), (3) to characterize two major discontinuities (Hardegsen and Eo-Cimmerian unconformities) induced by long wavelength deformation, (4) realize isopach and lithological maps to reconstruct the 3D evolution of the basin cycle by cycle and to investigate the influence of tectonic movements (Bourquin et al., 1997, Guillocheau et al., 2000), (5) to estimate the influence of deformation, eustasy and sediment supply in the Keuper stratigraphic record from 3D accommodation variation analysis (Bourquin et al., 2002) (6) to reconstruct paleoenvionmental maps and climate simulations to investigate the impact of climate on continental sediment preservation (Péron et al, 2005). Like this, recent study (Bourquin et al., 2006) allows to recognize the Hardegdsen unconformity and redefine the three major cycles of Guillocheau (1991): the Scythian, Anisian-Carnian, and Carnian-Liassic cycles (Fig. I.1).

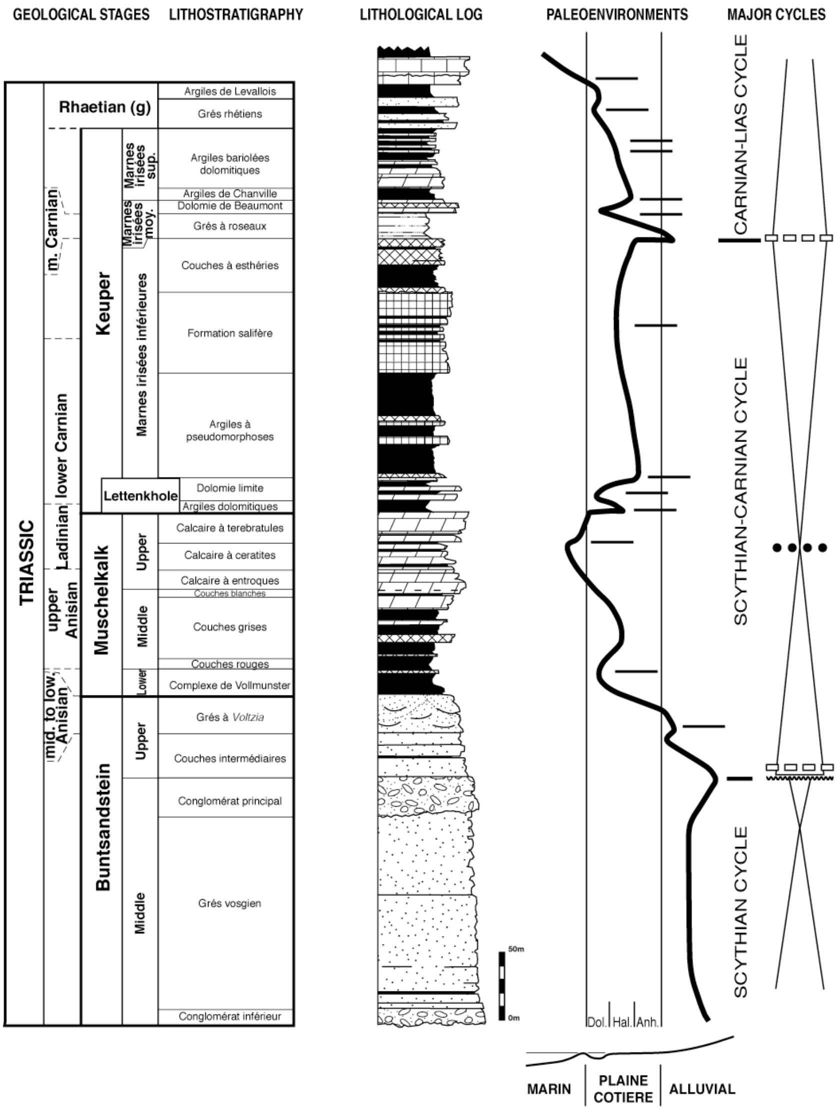



**Figure I.1**: Lithostratigraphic column, sedimentary environment variations and biostratigraphic data of the Triassic succession in the eastern part of the Paris Basin based on the Francheville well. See Fig. II.1 for location. After, Bourquin and Guillocheau, 1996, modified.

In this document, we present in a first part the geological setting and the sequence stratigraphy correlation results for each period of the basin evolution. In the second part we present all the stops of the field excursion.

## II. - The Buntsandstein

All these results are mainly published in the paper of Bourquin et al. (2006)

### II.2. - Geological setting

During the Early Triassic, the Paris and Bresse-Jura basins formed the western end of the Germanic Basin. In the Vosges (Fig. II.1), the Lower Buntsandstein units (Senones Sandstones or Anweiller Sandstones) can be attributed to the Uppermost Permian, *i.e*. Zechstein equivalents (Durand et al., 1994). Whereas in the major part of the Germanic basin the 'Buntsandstein Group' is separated from the

Rotliegends by the typical-Zechstein carbonate-evaporite facies (Uppermost Permian), in France the latter are completely lacking. This is why the French geologists place the base of their ‘Buntsandstein’ at the level of a major unconformity between fanglomerate prone deposits, localised in relatively restricted basins, and widespread fluvial deposits (Courel et al. 1980). Such a concept of ‘Buntsandstein’ prevailed in South Germany until the adoption of a unified lithostratigraphic scale (Richter-Bernburg, 1974). Thus, in the French sedimentary basins, deposits referred to as ‘Buntsandstein’ can be attributed either to Permian or to Triassic (Durand, 2006). Actually, the ‘Lower Buntsandstein’ of the Vosges (Senones Sandstone and Anweiller Sandstone) can be attributed to the Upper Permian, *i.e.* Zechstein equivalents (Durand et al., 1994).

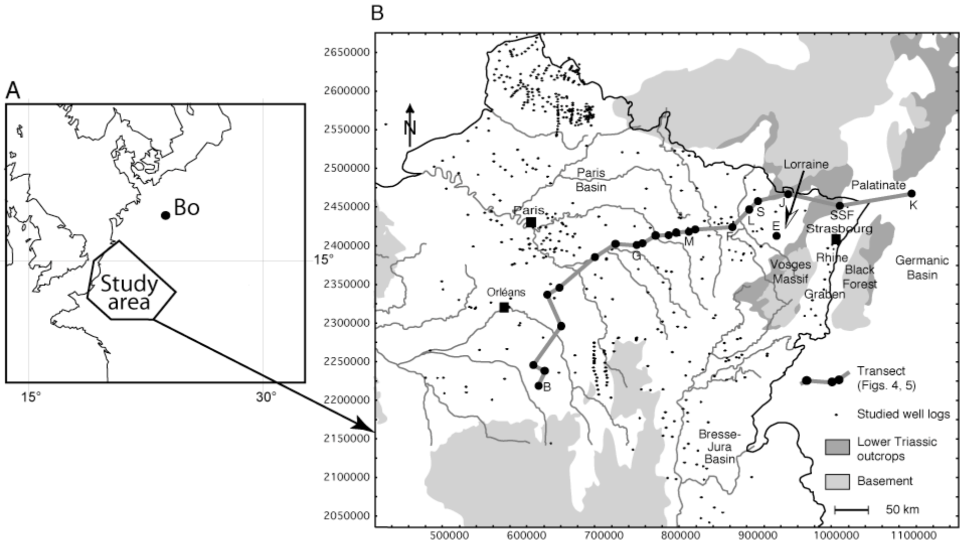



**Figure II.1**: (A) Location of the studied area and the Bockenem well (Bo) and (B) Location of studied wells and lower Triassic transect. B: Bertray1; G: Granville 109; M: Montplone1; F: Francheville1; L: Lorettes1, S: Saulcy; J: Johansweiller; SSF: Soultz-sous-Forêts, K: Kraichgau; E: Emberménil. After Bourquin et al., 2006.

Therefore, the Middle and Upper Buntsandstein units are attributed mainly to the Lower Triassic. These facies are characterized by fluvial deposits that make up the following formations (Fig. II.2), from base to top (Courel et al., 1980): ‘Conglomérat basal’, ‘Grès vosgiens’, ‘Conglomérat principal’, ‘Couches intermédiaires’, and ‘Grès à Voltzia’. The ‘Couches intermédiaires’ Formation is commonly separated from the ‘Conglomérat principal’ by the ‘Zone limite violette’ Formation that is characterized by the first occurrence of Triassic soils in this area. The bed-load fluvial systems of ‘Conglomérat basal’, ‘Grès vosgiens’ and ‘Conglomérat principal’ are attributed to braided type networks developed in an arid climatic environment, as indicated by the occurrence of reworked and *in situ* aeolian sand dunes and wind worn pebbles (Durand, 1972, 1978; Durand et al., 1994). The bed-load fluvial deposits of the ‘Couches intermédiaires’ correspond to low sinuosity rivers with transverse bars (Durand, 1978), and are associated with hydromorphic paleosols (Durand 1978; Durand and Meyer, 1982). The ‘Grès à Voltzia’ shows an evolution from low sinuosity fluvial systems in the ‘Grès à meules’, with weak marine influence, to the fluvio-marine environment of the ‘Grès argileux’ (Gall, 1971; Durand, 1978; Courel et al., 1980; Durand et al., 1994). The only biostratigraphic evidence in this Buntsandstein series concerns the ‘Grès à Voltzia’, where macrofauna and palynoflora allow the attribution of a Lower to Middle Anisian age according to location (Durand and Jurain, 1969; Gall, 1971). Paleocurrent directions obtained from fluvial facies indicate a mainly eastward flow (Durand, 1978).

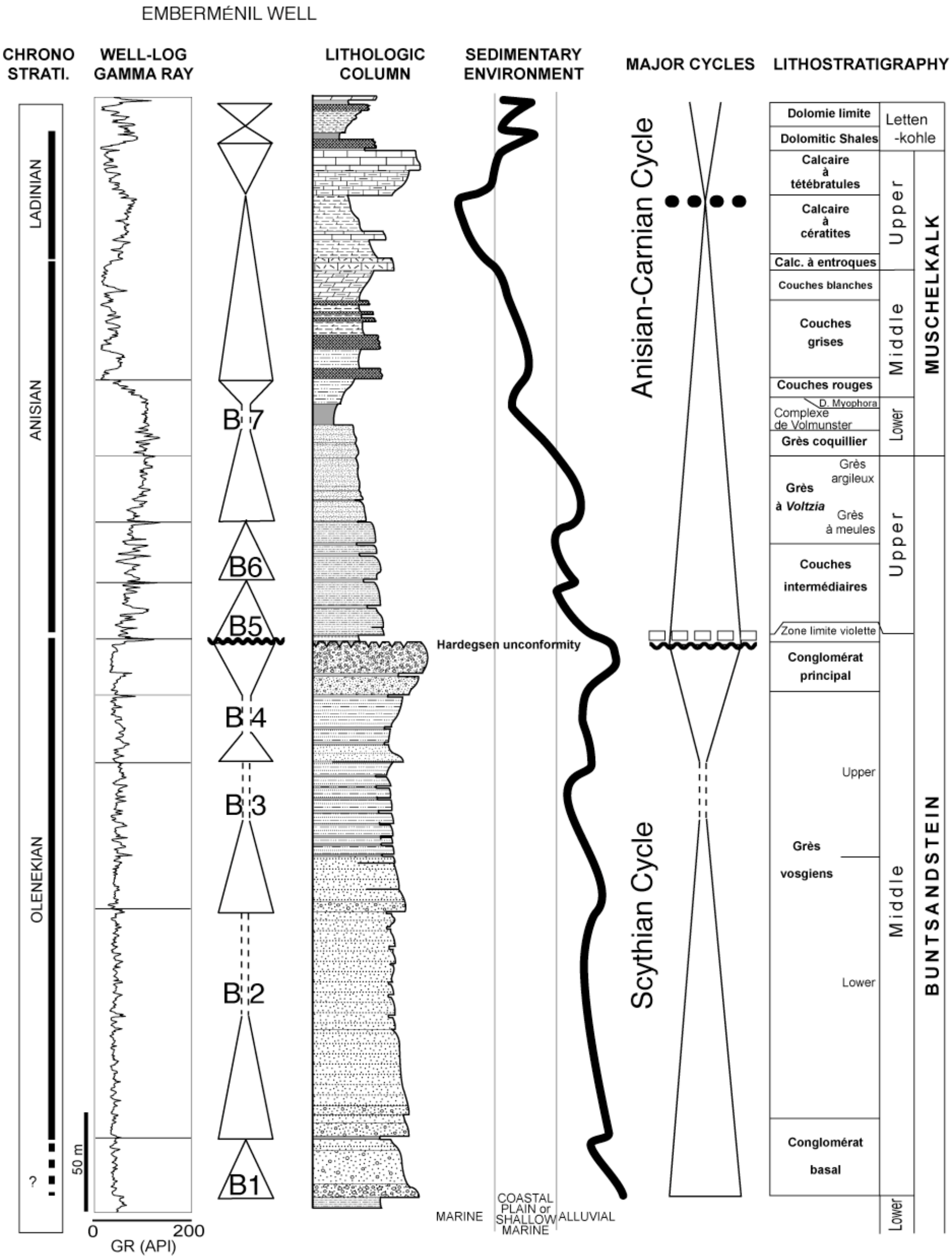



**Figure II.2**: Lithostratigraphic column, sedimentary environment variations, major and minor stratigraphic cycles for the Lower Triassic succession in the eastern part of the Paris Basin based on Emberménil well (after Bourquin et al., 2006).

The terminology used for the Buntsandstein formations in the Palatinate is not the same as that applied in the Paris Basin. The equivalent of the 'Grès vosgiens' Formation is divided into three units, which are, from base to top: the Trifels, Rehberg, and Karlstal formations. These three units are characterized by increasing clay content.

Recent study from well-log data for the Triassic west of the Black Forest (Paris Basin, Rhine Graben and Bresse-Jura Basin) allows us to propose correlations and define the stratigraphic context of the Lower Triassic units (Bourquin et al., 2006).

### II.2. – High-resolution sequence stratigraphy correlation of the Lower Triassic from well-log analysis

The Lower Triassic crops out only in the western part of the Paris Basin, in the Vosges Massif and in the Black Forest. The outcrops are discontinuous and if the basal unit (with Permian-Triassic boundary) or uppermost unit (‘Conglomérat principal’) are not present, it is almost impossible to determine the stratigraphic position.

The results of the correlations the 580 wells studied in the Paris basin and Rhine Grabben are summarized on a NE-SW section between the Rhine Graben (Soultz-sous-Forêts well) and the area south of Orléans (Figs. II.1B, II.3, II.4).

The transect (Figs. II.3, II.4) and the maps allow us to quantify the 3D evolution of the Triassic series and to characterize (1) the geometries of sedimentation units infilling the basement topography, (2) the general onlapping of these series, (3) the retrogradational pattern of the playa deposits, (4) the progradation of the ‘Conglomérat principal’ Formation, (5) the diachronism of the Middle Buntsandstein formations (Trifels, Rehberg, Karstal, ‘Conglomerat basal’, and ‘Conglomérat principal’ formations, Figs. II.3, II.4).

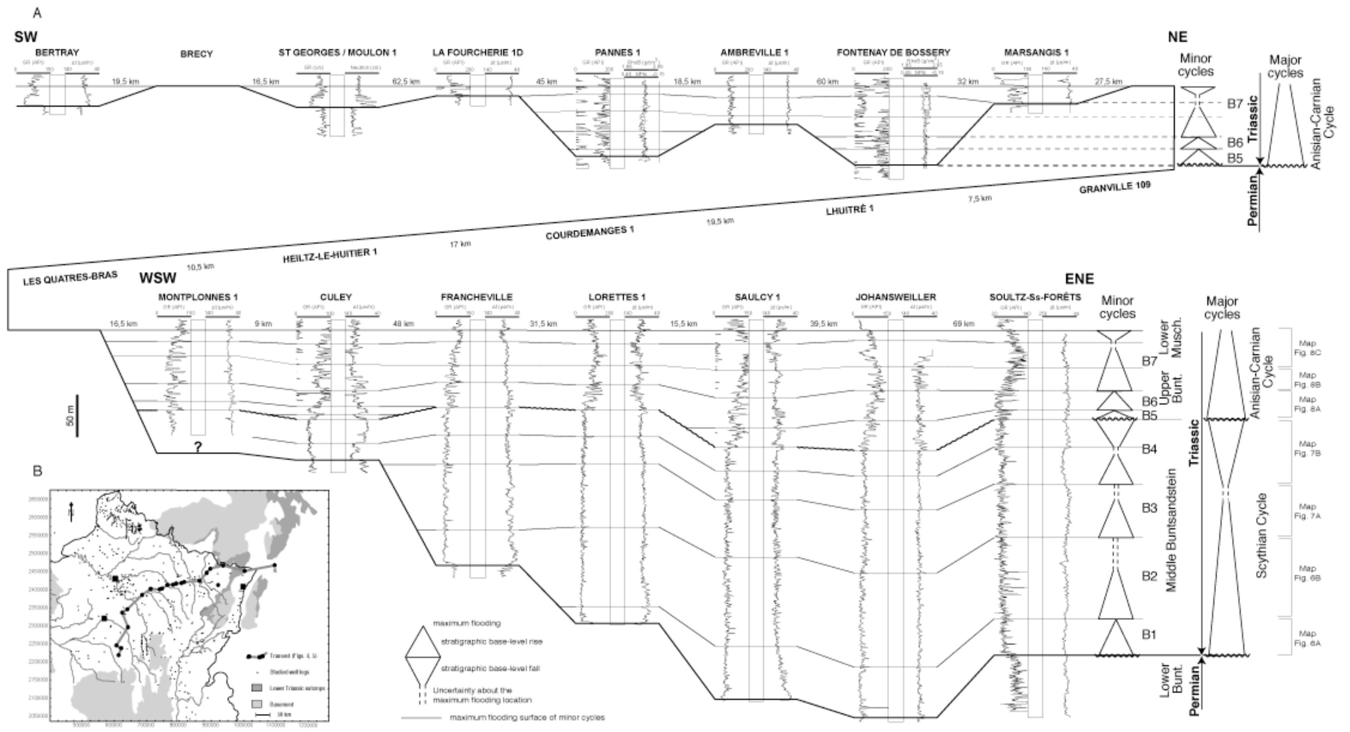



**Figure II.3**: (A) WSW-ENE correlations of Lower Triassic stratigraphic cycles, between the south of Orléans (Bertray well), and the Rhine Basin (Soultz-sous-Forêts well) in the western part of the Germanic Basin. (B) Transect location. See figure II.1B for more details. After Bourquin et al., 2006.

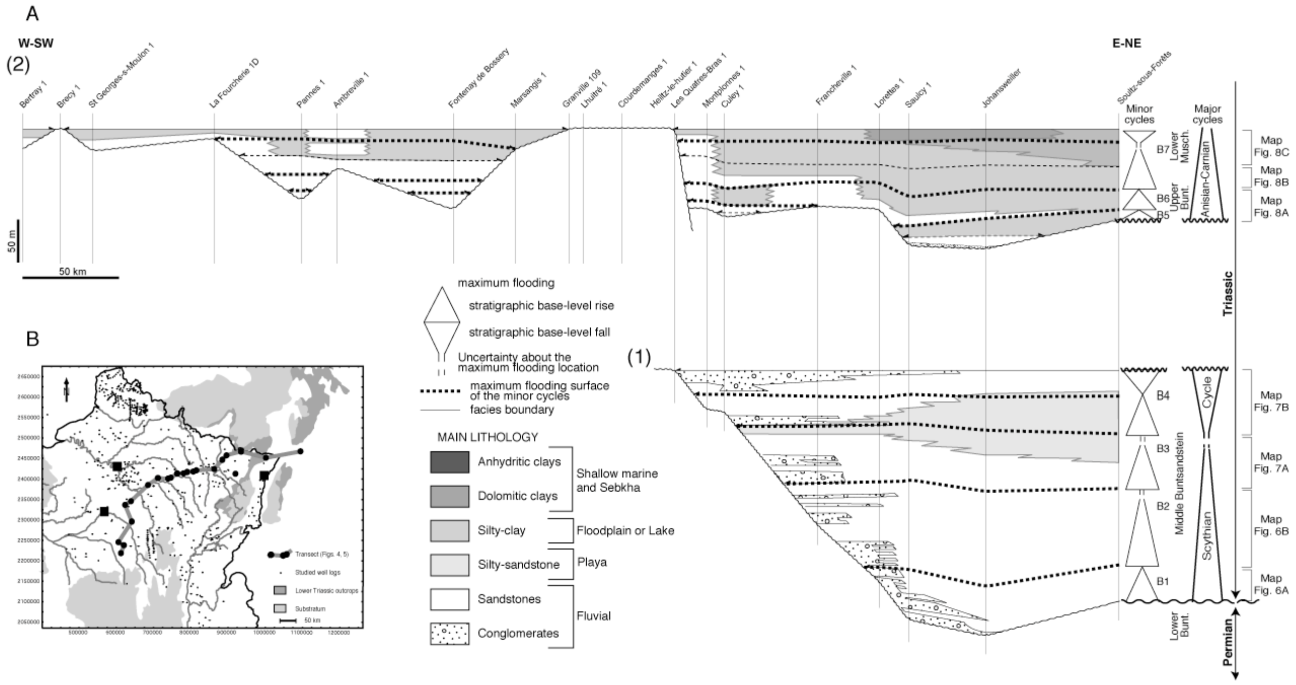



**Figure II.4**: A) Geometries and lithology of the Lower Triassic stratigraphic cycles, along the transect between the area south of Orléans (Bertray well) and the Rhine Basin (Soultz-sous-Forêts well) deduced from well-log analysis: (1) Geometries from Variscan basement or pre-Triassic deposits to the Hardegsen unconformity (Fig. 3), (2) Geometries from the Hardegsen unconformity to the basal anhydrite bed of the "Couches grises" Formation defined in the eastern part of the Paris Basin (middle part of the Middle Muschelkalk, Fig. 3). (B) Transect location. See figure II.1B for more details. After Bourquin et al., 2006.

### *II.2.1. - Middle Buntsandstein cycles*

The Middle Buntsandstein formations ('Conglomérat basal', 'Grès vosgiens' and 'Conglomérat principal') exhibit one major cycle divided into four minor cycles (noted B1 to B4, Figs. II.1C).

The correlations reveal the onlap of the Triassic sedimentation onto the basement (Figs. II.3 and II.4). The bed-load fluvial sediments, attributed to braided rivers, came from the west: present-day Armorican Massif (Durand, 1978; Durand et al., 1994) and progressively filled in the topographic depression. Floodplain deposits are rare and characterized by clay layers a few centimetres thick. The conglomerate deposits are mainly located in the western part of the sedimentation area. The four minor stratigraphic cycles (B1 to B4) can be correlated across the Paris Basin up to the Rhine Graben in the east, showing that the 'Conglomérat basal' Formation is diachronous.

The B1, cycle corresponds, in the Vosges Massif outcrops and Emberménil well, to the deposits of the 'Conglomérat basal' Formation (Figs. II.3 and II.4). This cycle is characterized by the vertical passage of well-preserved fluvial conglomerates into floodplain deposits. In more distal parts of the basin, the conglomerates grade eastwards into sandstones.

The B2 and B3 cycles (Figs. II.3 and II.4), are intra – 'Grès vosgiens' Formation, and record well-preserved fluvial sandstones to floodplain deposits, the basal conglomerate facies being located in the westernmost area. From cycles B1 to B3, we observe a general backstepping of conglomerate facies.

The isopach maps drawn up for each cycle (Figs. II.5 and II.6A) indicate the basement-sedimentation area boundary, as well as the location of conglomerate facies through time and space. The more proximal facies are located to the west. These maps show the general backstepping of conglomerate facies and their lateral eastward evolution to sandstone deposits (Figs II.5A, II.5B and II.6A).

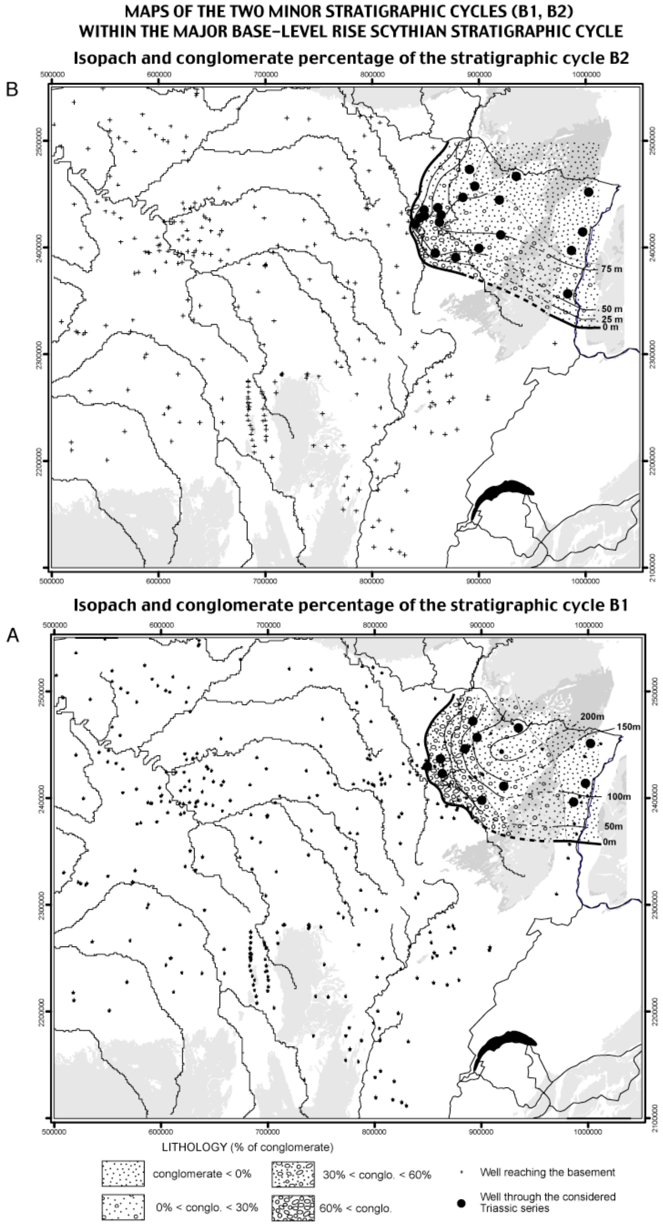



**Figure II.5**: Isopach maps with superimposed lithology (% of conglomerate) for stratigraphic cycles B1 and B2 (see Figs. II.2, II.3, II.4), constructed from well-log data and outcrops information. After Bourquin et al., 2006.

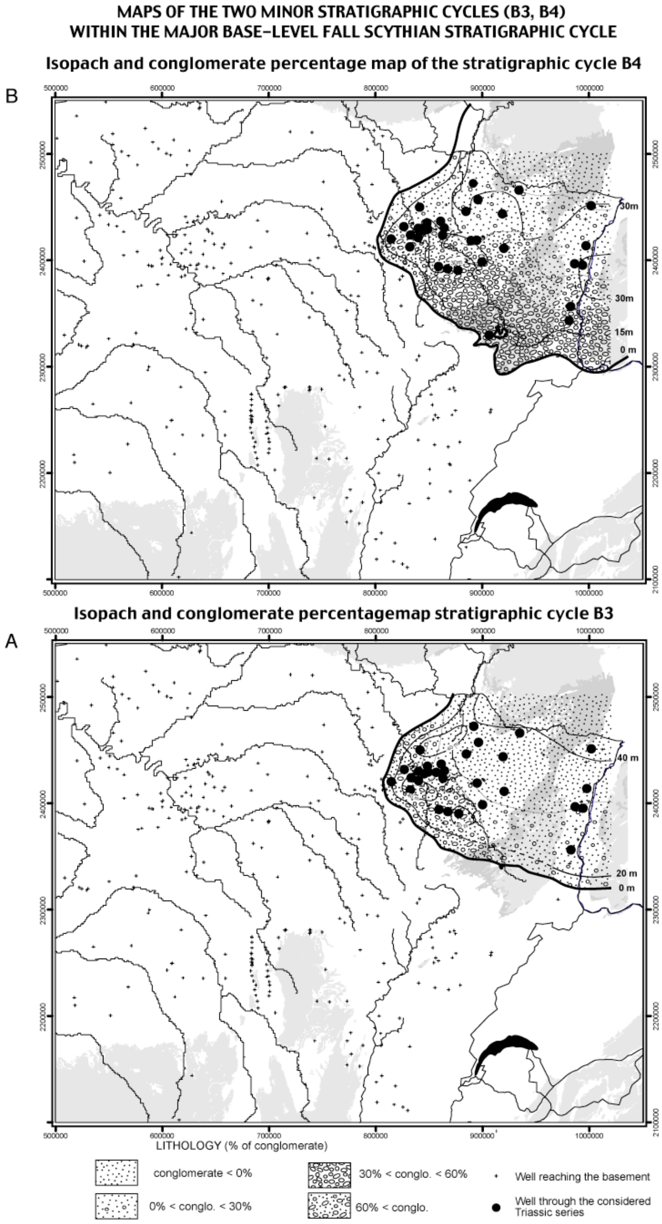



**Figure II.6**: Isopach maps with superimposed lithology (% of conglomerate) for the B3 (A) and B4 (B) stratigraphic cycles (see Figs. II.2, II.3, II.4), constructed from well-log data and outcrops information After Bourquin et al., 2006.

The B4 cycle shows well-preserved fluvial sandstones overlain by a maximum flooding episod and then prograding conglomerates (Figs. II.3 and II.4). These conglomerates migrate basinwards and grade laterally into sandstones. In the Vosges Massif outcrops and Emberménil well, these conglomerates correspond to the 'Conglomérat principal' Formation. The lithogical map of this cycle (Fig. II.6B) shows that the conglomerates spread across the basin. The 'Conglomérat principal' Formation rarely occurs at outcrop north of the Vosges Massif, near the German Frontier, where it is eroded. In outcrop, the 'Conglomérat basal' and of the 'Conglomérat principal' display same petrographic materials, notably

Silurian and Proterozoic graphitic cherts that are derived from the Armorican Massif (Durand et al., 1994; Dabard, 2000), implying same provenance. The transition between the 'Grès vosgiens' and the 'Conglomérat principal' reflects only a progressive increasing in gravel content and then an acceleration of the prograding phase. The base of the 'Conglomérat principal' is diachronous: conglomeratic facies are younger in the western part of the basin (Cycle B4, Fig. II.4).

Geometrically, the correlations (Fig. II.3 and II.4) reveal the landward migration of the silty-clay facies (attributed to playa deposits of the Karlstal Formation) into a retrogradation trend, until the maximum flooding surface of the cycle B3, and then a progradational trend of sandstone and conglomerate deposits of the 'Conglomérat principal' Formation. This evolution characterizes a major cycle, where the period of the stratigraphic base-level rise is represented by the cycle B1 to B3 and the period of the stratigraphic base-level fall by the cycle B4 (Figs. II.3 and II.4). This cycle is located above the Permian and below the Anisian, thus it is called the Scythian cycle.

The top of cycle B4 is marked by a major discontinuity, above a sedimentary break. This episode can be correlated with the forming of the 'Zone Limite Violette' that crops out in many parts of Lorraine (Fig. II.2). The 'Zone Limite Violette' overlies the 'Conglomérat principal' Formation and contains paleosols (dolocretes and silcretes), providing evidence for very low sedimentation rates (Durand and Meyer, 1982). In north Lorraine, the 'Zone Limite Violette' and even the 'Conglomérat principal' are locally eroded. This is indicated locally by the occurrence of a conglomerate containing 'Conglomérat principal' pebbles mixed with pedogenic carbonate and cornelian pebbles reworked from the 'Zone Limite Violette'. This unit, known as 'Karneolkonglomerat' in the Palatinate (Reis and von Ammon, 1903), corresponds to the 'Conglomérat de Bitche' defined in northern Lorraine (Ménillet et al., 1989). In addition, well-log data allow to recognize locally conglomerate facies above the discontinuity (e.g. Saulcy and Johansweiller, Fig. II.2, II.4). The erosional surface corresponds to the 'Hardegsen unconformity' expressed in many parts of the Germanic basin (Durand et al., 1994).

### *II.2.2. Upper Buntsandstein cycles*

The lithostratigraphic succession comprising the Upper Buntsandstein formations ('Couches intermédiaires' and 'Grès à Voltzia') the Lower Muschelkalk ('Grès coquillier', 'Complexe de Volmunster', and 'Dolomie à Myophoria orbicularis'), and the lower part of the Middle Muschelkalk ('Couches rouges' Formation) corresponds to three minor cycles (noted B5 to B7, Fig. II.2). They belong to the lower part of the major Anisian-Carnian cycle.

The sandstone facies of the Upper Buntsandstein correspond to low sinuosity fluvial channels (Durand, 1978; Durand et al., 1994). The well-log data allow a quantification of sandstones, floodplain and/or lake deposits and sabkha lithofacies and the expression of the genetic units in these depositional environments.

The well-log analyses allow to characterize the occurrence of a new depositional area in the western part of the Paris Basin (Figs. II.3 and II.4). Its sediments seem to be contemporaneous with those located above the discontinuity in the eastern part of the basin, where the three cycles can be correlated.

In the Lorraine outcrop area and in the Emberménil borehole, the two first cycles above the discontinuity (B5, B6) correspond to the ‘Couches intermédiaires’ Formation (Fig. II.2). They show an evolution from sandstone to clay facies (Figs. II.3 and II.4) attributed, by comparison with outcrops data, to low sinuosity fluvial channel sandstones to well-developed lake or floodplain fine deposits (Durand, 1978; Durand and Meyer, 1982). The facies map of these cycles (Fig. II.7A) shows the distribution of the sandstone and clay deposits. This distribution could express the location and orientation of the low sinuosity river and floodplain environments during the considered period.

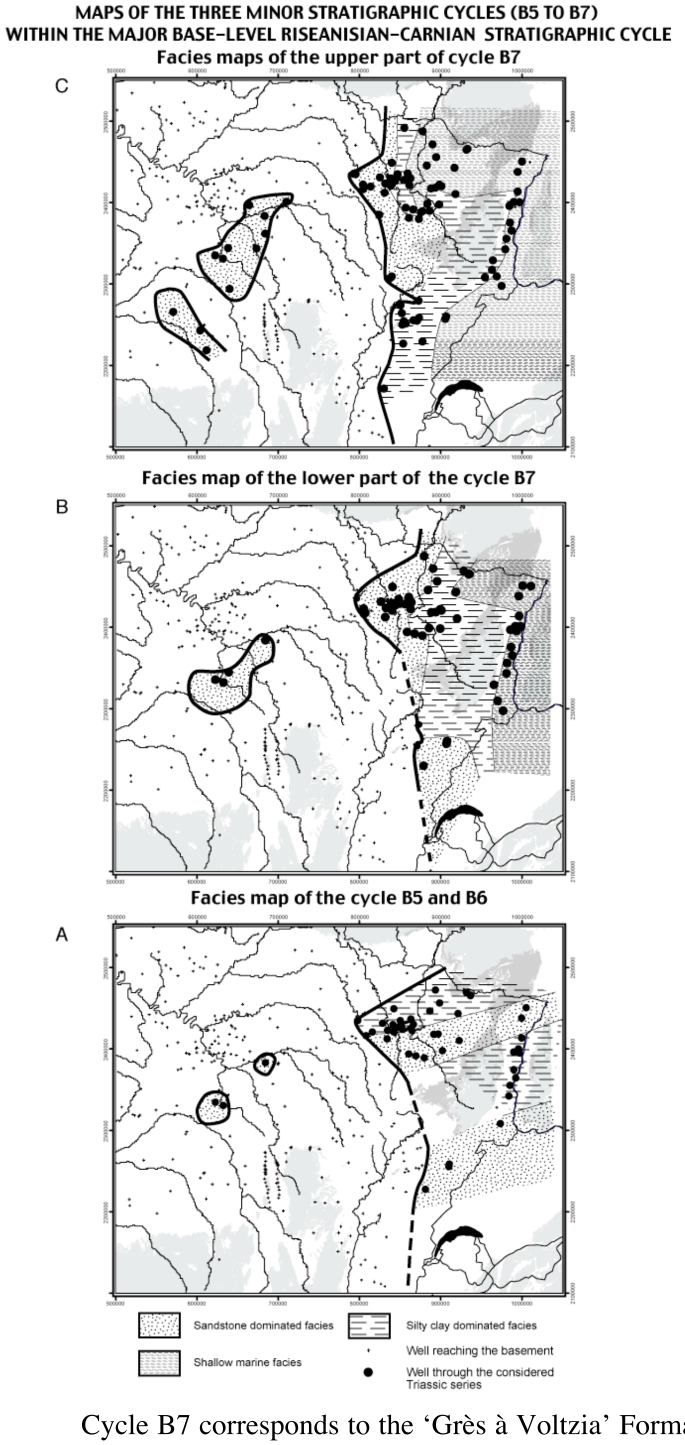



**Figure II.7**: Paleoenvironmental maps of the Upper Buntsandstein stratigraphic cycles, drawn up from well-log data and outcrop information (geological maps, scale 1/50 000, and Durand, 1978): (A) Paleoenvionmental map of the B5 and B6 minor stratigraphic cycles (“Couches intermédiaires” Formation at Emberménil well see Figs. II.2, II.3, II.4), (B) Paleoenvionmental map of the lower part of the B7 minor stratigraphic cycle (“Grès à Voltzia” Formation at Emberménil well, see Figs. II.2, II.3, II.4), and (C) Paleoenvionmental map of the upper part of the B7 minor stratigraphic cycle (“Grès coquillés” to “Couches rouges” formations at Emberménil well, Figs. II.2, II.3, II.4). After Bourquin et al., 2006.

Cycle B7 corresponds to the ‘Grès à Voltzia’ Formation up to ‘Couches rouges’ Formation of Lorraine outcrops and Emberménil well (Fig. II.2). This cycle shows a different expression in the eastern and western parts of the basin. Indeed, the correlations demonstrate that the Upper Buntsandstein formations are diachronous (Figs. II.2 and II.8), as previously established by biostratigraphic data across the outcrop area

(Durand and Jurain, 1969; Gall, 1971). For example, the ‘Grès à Voltzia’ are located in the lower part of cycle B7 in the Johansweiller well, but in the upper part of this cycle farther eastwards (Fig. II.8). Moreover, these correlations point out the lateral evolution from dolomitic and anhydritic clays, attributed to shallow marine and sabkha facies, in the eastern edge of the studied area (Gall, 1971; Durand, 1978; Courel et al., 1980, Durand et al., 1994), to sandstones in the west. Geometrically, the transect reveals the landward migration - *i.e* to the west - of dolomitic clay facies (marine deposits) in a major retrogradational trend (Fig. II.3). The upper part of the cycle B7 is characterized by first occurrence of anhydritic deposits (landward equivalent of dolomitic facies observed in the Soultz-sous-Forêts well) overlying previous marine facies in a retrogradation trend (Fig. 4). Two detailed facies maps are drawn up for this cycle, one in its lower part, which correspond to the ‘Grès à Voltzia’ Formation of Lorraine outcrops and Emberménil well (Figs. II.2 and II.7), and the other in its upper part which correspond to the Lower Muschelkalk formations and ‘Couches rouges’ Formation of Lorraine outcrops and Emberménil well. These two maps show the westward migration of the paleoenvironments and the geographic distribution of the two facies of the ‘Grès à Voltzia’ (Grès à Meules’: sandstone facies, Fig. 7B, and ‘Grès argileux’: silty clay facies, Fig. II.7B). The fluvial systems are localized mainly along the basin border (previous basement area) and evolved basinwards into shallow marine deposits (Fig. II.7B, C).

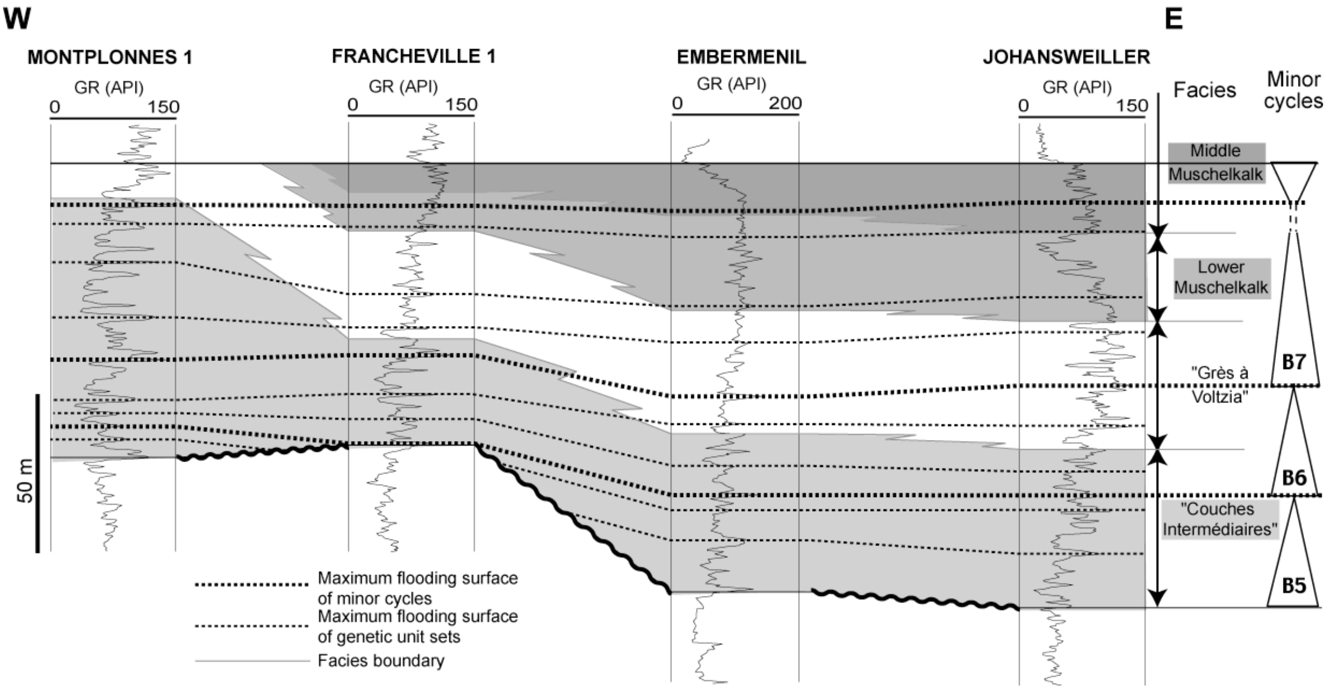



**Figure II.8**: E-W correlations of the Upper Buntsandstein stratigraphic cycles showing the diachronous nature of the formations. See location Fig. I.1B. After Bourquin et al., 2006.

### II.3. – Comparison with other parts of the German Basin

The comparison with the central Germanic Basin cycles (Fig. II.9) is carried out by correlating the Soultz-sous-Forêts and Kraichgau 1002 wells and then the combined well-logs for Bockenem 1 and Bockenem A100 (Fig. 3 of Aigner and Bachmann, 1992).

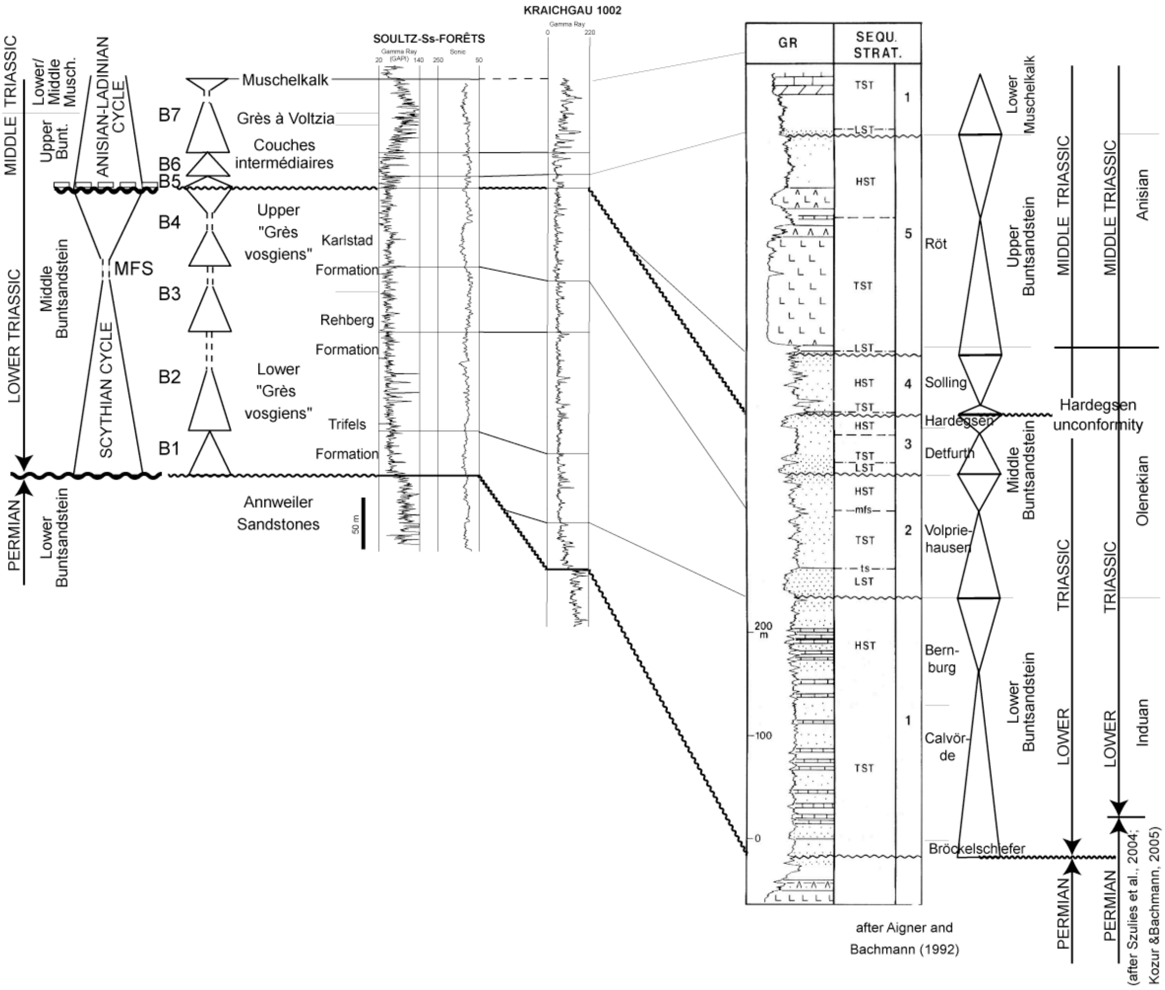



**Figure II.9:** Correlation between the Rhine Graben (Soultz-sous-Forêts well) and the Palatinate (Kraichgau 1002 well), and comparison with stratigraphic cycles defined in the central German Basin (Bockenem, 50 km SE of Hannover, from Aigner and Bachmann, 1992). See Figs. I.1A and B for location. After Bourquin et al., 2006.

The correlations with the Kraichgau well, located between the Black Forest and the Odenwald, allow us to identify the Middle Buntsandstein cycles defined in the Paris Basin. However, an additional stratigraphic cycle is present at the base of the Lower Triassic successions in this part of the Germanic Basin. This cycle is attributed to the Induan by magnetostratigraphy (Junghans et al., 2002).

A comparison with the combined Bockenem wells (Aigner and Bachmann, 1992) demonstrates that. sequence 1, as defined in the Germanic Basin (Calvörde and Bernburg formations), would appear to have no equivalent in the Paris Basin where only erosion and/or sediment transport occur at that time. The cycles B1, B2 and B3, corresponding to the lower part of the major cycle defined in the Paris Basin, could be equivalent to sequence 2 (Volpriehausen Formation), and cycle B4 to sequence 3 (upper part of Volpriehausen, Detfurth and Hardegsen formations). The individual sequences observed in the Germanic Basin are characterized by an evolution from fluvial sandstones to playa-lake deposits. The maximum flooding episode of the major stratigraphic cycle defined in the Paris Basin appears equivalent to the mfs of sequence 2 (*i.e.* Volpriehausen), where more or less marine fauna is present in the central part of the Germanic Basin (Richter-Bernburg, 1974, Roman, 2004). In Lorraine, the top of the cycle B4 is marked by a major sedimentary break period of by-pass with first development of paleosols (*i.e.* ‘Zone limite violette’, Müller, 1954; Ortlam, 1967; Gall et al., 1977). This episode could be equivalent of Hardegsen Formation, where the evidence of biological activity (ichnites, rhizolites, palynomorphs) not allows a correlation with the arid condition of the ‘Conglomérat principal’ Formation. Similary, the discontinuity observed in the Paris Basin corresponds to the Hardegsen unconformity, representing one of the most pronounced extensional tectonic event observed in the German Triassic (Trusheim, 1961, 1963; Wolburg, 1968; Röhling, 1991).

In the German Basin, the base of the Solling Formation corresponds to the erosional episode of the Hardegsen unconformity, during which 100 m of Middle Buntsandstein deposits could be locally eroded (Aigner and Bachmann, 1992). Moreover Geluk (1998) shows that the base of the Solling Formation becomes progressively younger to the west, accompanied by a decrease in thickness. In this study, this formation appears to be missing due to non-deposition or erosion. The Solling sandstones preserved in the basin could be equivalent to an episode of sediment by-pass at the basin margin.

The Röt Formation, corresponding to evaporitic marine and sabkha deposits, represents the first occurrence of halite deposition in the Germanic Basin. It could be equivalent to the B5 cycle. The cycles B6 and B7 could be equivalent to the first cycle of the Muschelkalk in the central Germanic Basin.

### II.4. – Conclusion and perspectives

The early Triassic can be separated into two phases. The first phase, during the Scythian, is characterized by braided fluvial systems evolving laterally into lake deposits toward the central part of the Germanic Basin. At this time, the basin is a huge basin depression with only few marine connections in the eastern part. The stratigraphic cycles reflect relative lake-level fluctuation that could be attributed to sediment supply and/or lake level variation in an arid context. The second phase occurs after a major sedimentary break (planation surface and pedogenesis) followed by the formation of the Hardegsen unconformity. This surface is tectonically deformed, leading to the creation of a new sedimentation area to the west of the basin. Above this unconformity, the fluvial sedimentation, attributed to the Anisian, shows an enhanced development of floodplains (with preservation of paleosol) associated with lacustrine environment. The fluvial systems are connected with a shallow sea in communication with the Tethys Ocean. In this context, the stratigraphic cycles are induced by variations in relative sea level and/or sediment supply. The fluvial deposits are preserved in an exoreic basin.

In the dry climatic regime of the Lower Triassic (van der Zwan and Spaak, 1992), the first cycles could be attributed to lake and sediment supply variations in an arid environment. During the Olenekian, the river catchment areas are mainly located in the present-day Armorican Massif, and the paleocurrents are generally oriented towards the NNE (Fig. II.10). The facies association are essentially composed of stacked channel-fill facies with very few flood plain deposits (< 3%) and without paleosols. Channels fills are sometimes associated with aeolian deposits. In more distal areas of the Germanic Basin, the sedimentation corresponds to ephemeral playa lakes or aeolian deposits (Clemmensen, 1979, Clemmensen and Tirsgaard 1990; Aigner and Bachman, 1992; Ulicny, 2004). In this context, two hypotheses could explain the preservation of fluvial systems. According to one hypothesis, the siliciclastic sediment supply from the Hercynian- (Variscan) mountain was constant, and thus the cycles result solely from lake level fluctuations.

The lake levels could be controlled by monsoonal activity, under the influence of sea-level fluctuations (van der Zwan and Spaak, 1992). Alternatively, the basin was situated in an arid environment and the variation of the sediment supply was controlled by precipitation in the mountain ranges. To investigate the relationships between sedimentation and climate, studies are in progress to simulate Early Triassic climates. Moreover, sedimentological studies on cores and outcrops are being carried out to quantify the ephemeral character of the fluvial system and quantify the occurrence of aeolian deposits.

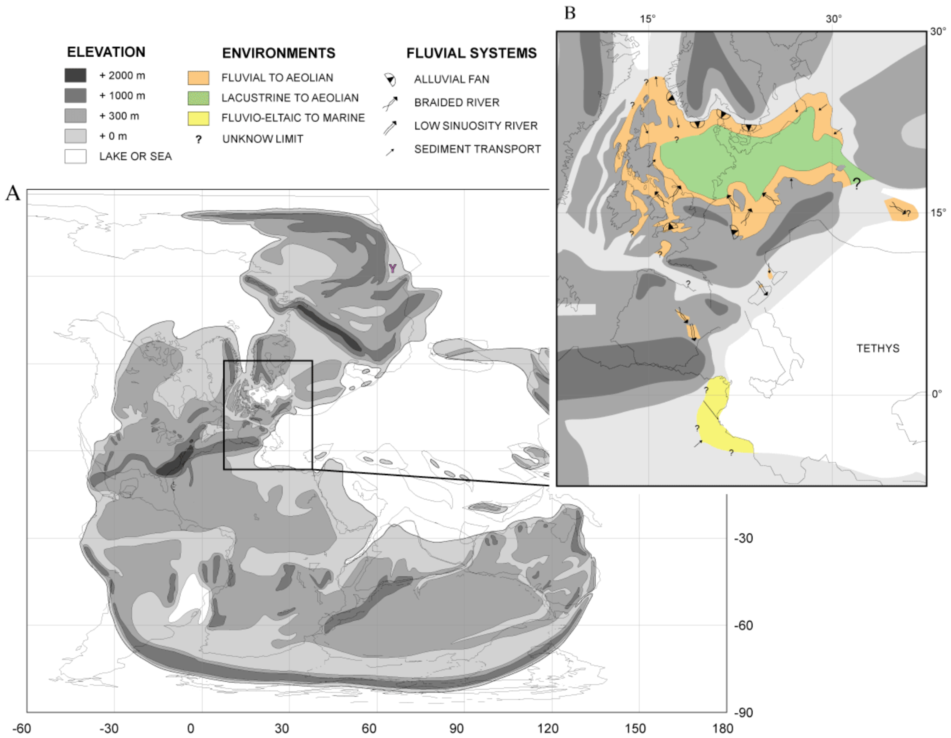



**Figure II.10:** Palaeogeographic maps for Scythian (245 Ma). (A) Global paleogeographic map representing a synthesis of different reconstructions, (B) detailed palaeogeographic map of the West-Tethys domain. After Péron et al., 2005.

In other respects, recent studies from paleoenvironmental reconstructions allow us to simulate climate conditions during the Olenekian period (Péron *et al.,* 2005). The present study is focused on Western Europe, where sedimentological and stratigraphic data can be used to check the results of climate simulation against geological data (Fig. II.11, II.12). The main result is that climatic conditions in the sedimentary basins were very arid, while the sediment and water supply came from the adjacent relief (Fig. II.10). Although these arid conditions prevailed at the European scale, seasonal changes are inferred in North Africa, showing alternating periods of aridity and precipitation. In this context, we can readily explain the presence of aeolian features (dunes or ventifacts) at a large scale.

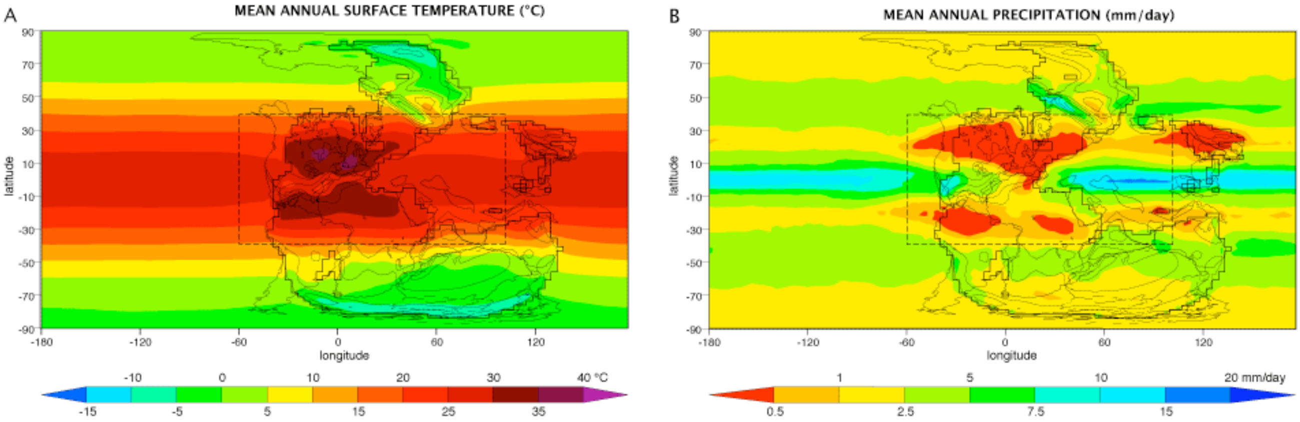



**Figure II.11:** Climate simulations for the Early Triassic (Olenekian), assuming low relief of the mountain range separating the continents of Laurussia and Gondwana. After Péron et al., 2005.

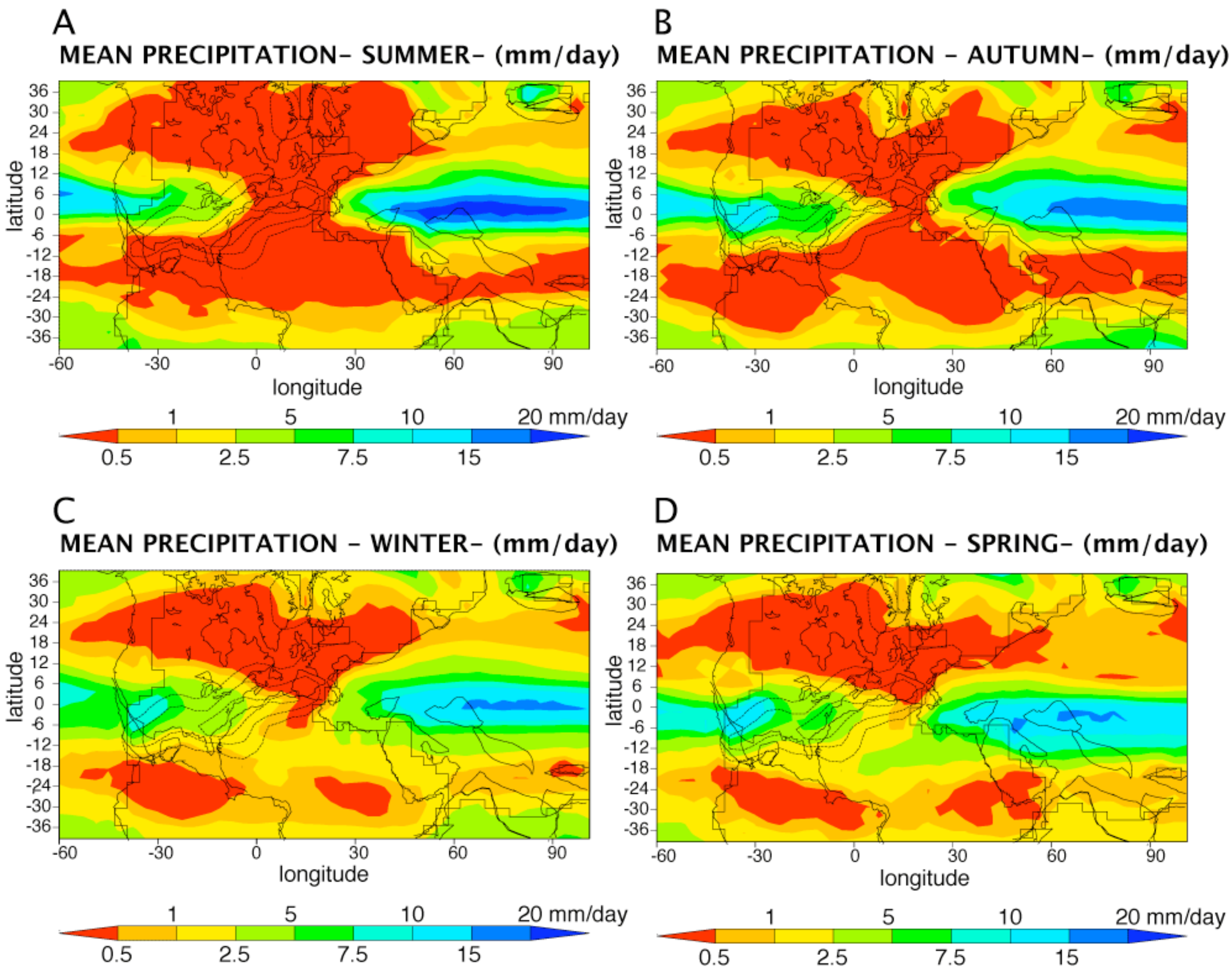



**Figure II.12:** Detail of West-Tethys climate simulations during the Early Triassic (Olenekian), assuming a low-relief scenario and for each season: (A) summer, (B) autumn, (C) winter (austral summer), and (D) spring (austral autumn). See figure II.11 for the location. After Péron et al., 2005.

Moreover the lack of typically Early Triassic fossils can be explained not only by slow recovery after the Permian-Triassic biologic crisis (López-Gómez *et al.*, 2005), but also by a true stratigraphic break during the Early Triassic, *i.e.* Induan, and/or by climatic conditions that were unfavourable for the development of flora and fauna during the lower Olenekian, *i.e.*‘desert’ environments (Bourquin et al., in press). The early

Triassic arid episode could have a global origin as suggested by recent studies on early Triassic ammonoids (Brayard *et al.*, 2006). Furthermore, it should be noticed that even in South Africa, last research provides evidence of a vegetated landscape during the earliest Triassic, and conversely of an aphytic interval from that time up to the Middle Triassic (Gastaldo *et al.,* 2005).

## III. The Muschelkalk

### III.1. -Geological setting

The French Muschelkalk is divided in three groups: the Lower, Middle and Upper Muschelkalk (Table 1 and Fig. I.1).

The Lower Muschelkalk commences with deposits with increasingly marine influence: 'Grès coquillier', 'Complexe de Volmunster', 'Dolomie à Myophora orbicularis' formations, passing then into ~~the~~ evaporitic facies.

The Middle Muschelkalk records for the first time evaporite sedimentation in the Paris Basin (Ricour, 1962): 'Couches rouges', 'Couches grises' and 'Couches blanches' formations. These three formations displays the evolution from clays, with sandstone, gypseous and dolomitic thin beds, to salt and anhydritic beds with clay layers, and to dolomitic limestones with some gypsum or anhydrite. These facies are attributed on outcrops to Upper Anisian (Adloff et al., 1982).

The Upper Muschelkalk is constituted of the 'Calcaire à entroques', Calcaire à cératites' and 'Calcaire à térébratules' formations that represent the marine deposits of the Ladinian. The vertical evolution from 'Couches intermédiaires' to these marine deposits characterizes a general backstepping trend, in which the maximum flooding surface (mfs) is located at the top of the 'Calcaires à cératites' Formation dated as Ladinian (Duringer and Hagdorn, 1987, Duringer and Vecsei, 1998; Vecsei and Duringer, 2003).

### III.2. - High resolution sequence stratigraphy from well-log analysis

The 'Couches rouges' Formation end the cycle B7 defined previously (Fig. II.2, II.7C).

The evolution from 'Couches grises' to 'Calcaires à cératites' shows a general evolution to more marine environment from coastal plain to mixed marine platform. These formations evolve laterally westwards to fluvial deposits of the 'Grès de Donnemarie'. The maximum flooding surface of the top of the 'Calcaires à Cératites' is an equivalent to the 'cycloïdes-Bank' in the German Basin. This characterized the maximum flooding surface of the second sequence defined in the Muschelkalk: Middle and Upper Muschelkalk (Aigner and Bachmann, 1992). The well-log correlations (Bourquin et al., 1995) allow to show the progressive onlap of the Muschelkalk on the basement and the westward transition between marine calcareous and fluvial deposits (Fig. III.1). The constant thickness of the correlation attests no tectonic event during this period.

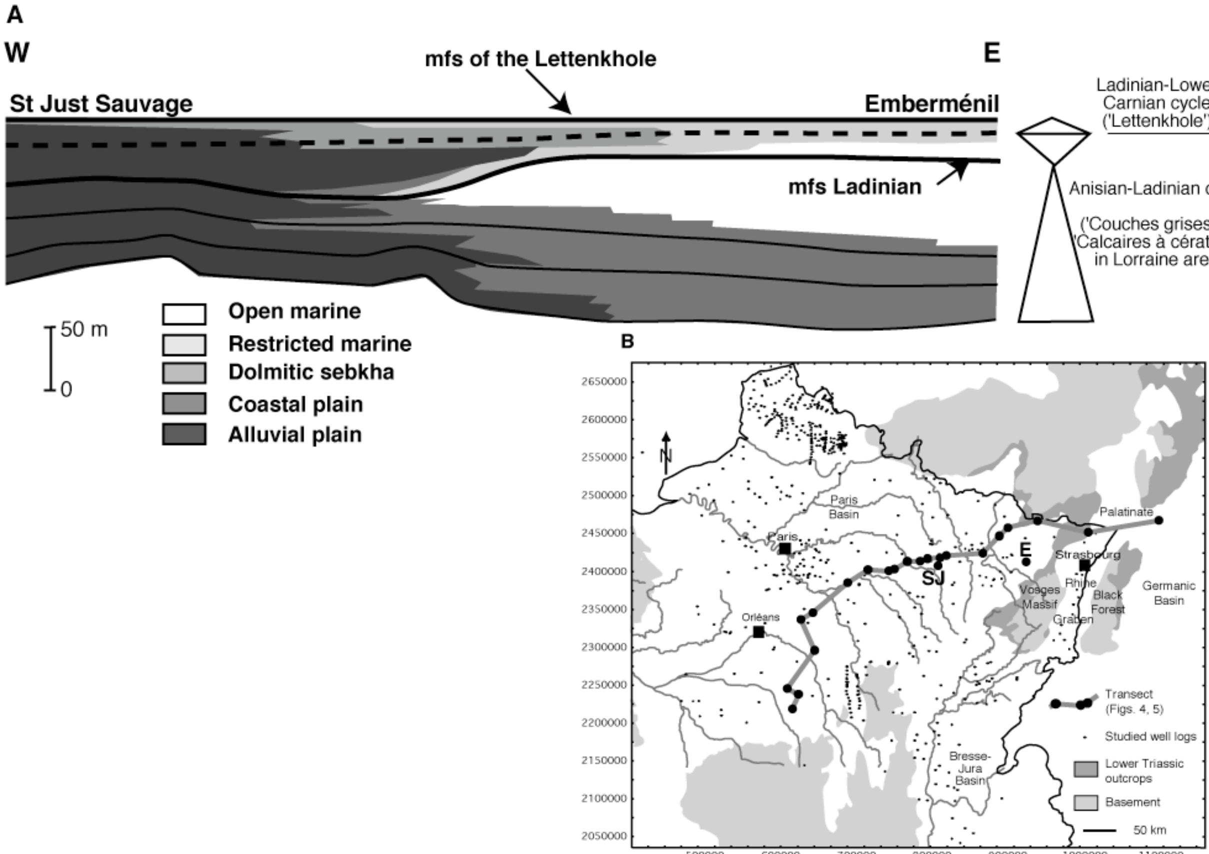



**Figure III.1: (A)** E-W Muschelkalk section between Emberménil and Saint Just Sauvage: depositional sequence geometries-relationship between time-lines and facies. (B) Wells location. After Bourquin et al., 1995, modified.

In the western and northern part of the Paris Basin (Fig. III.2), we observed from subsurface data (well-log and core) that the lower part of the Lettenkhole consists of mixed terrigenous-evaporite sediments (playa floodplain and channel deposits) which thicken west of the Aire Fault (Fig. III.2a) and to the north (Fig. III.2b) (Bourquin and Guillocheau, 1993, 1996). There is no evidence of incised valleys like those described in the German Basin (‘Hauptsandstein’ Formation, Aigner and Bachmann, 1992). In the eastern part, the evolution from the mfs to the ‘Calcaire à térébratule’ and to the flood plain deposits of the Middle Lettenkohle attests a progradation phase that ends this cycle.

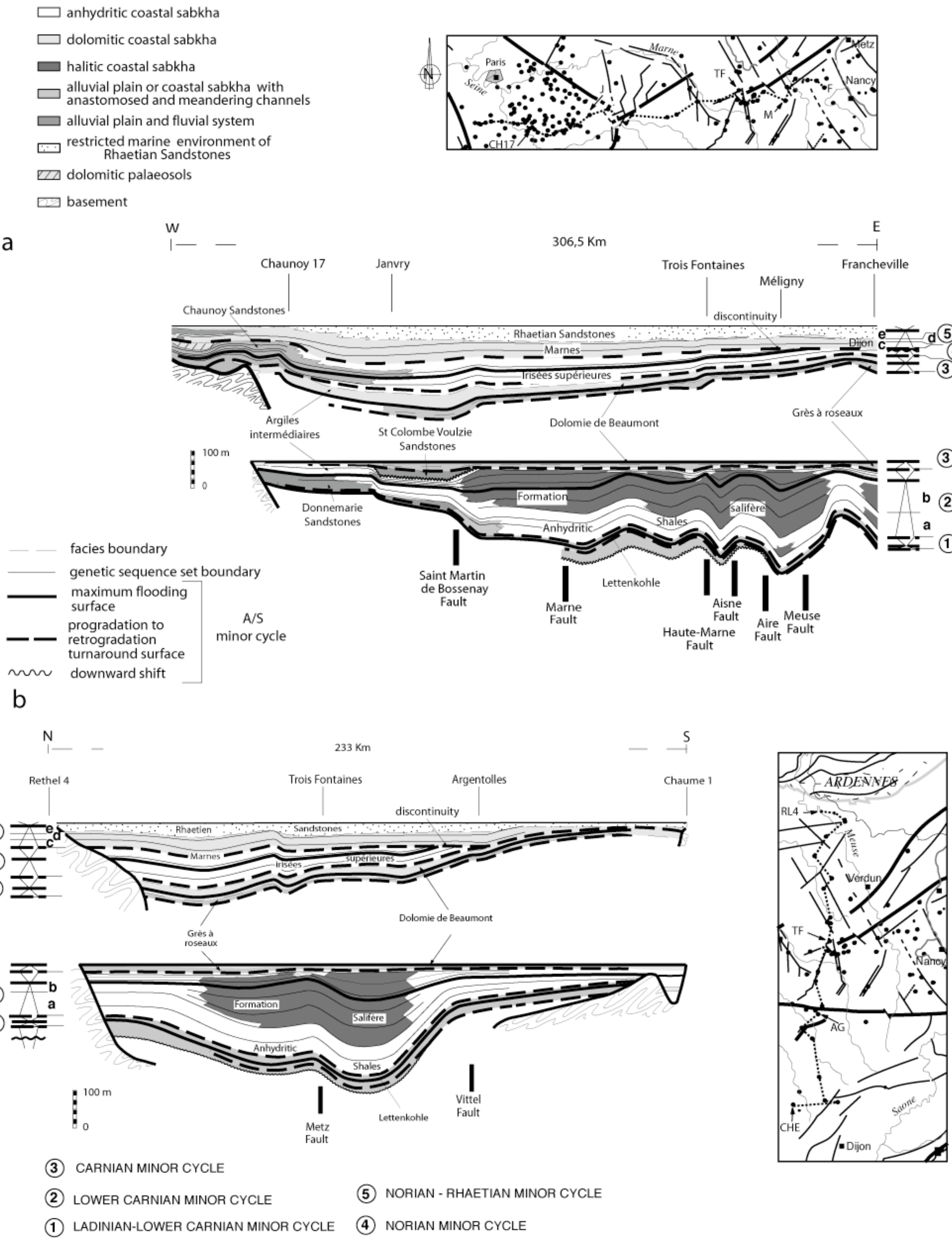



**Figure III.2:** (a) Keuper east-west stratigraphic cycle geometries, between Nancy and south-west Paris FRV: Francheville, TF: Trois Fontaines, JAY: Janvry, CH17: Chaunoy 17. (b) Keuper north-south stratigraphic cycles geometries, between the Ardennes and Burgundy. VD: Vaudeville, LZV: Lezeville, LDM: Landomont, SMB17: Saint Martin de Bossenay 17, FDB: Fontenay de Bossery, EST: Estouy. After Bourquin and Guillocheau, 1996, modified in Bourquin et al., 2002.

# IV. The Keuper

## IV.1. - Geological setting

Classically, two areas of sedimentation have been distinguished in the Keuper of the Paris Basin. These are an eastern area consisting essentially of halitic or anhydritic coastal sabkha deposits and a western area dominated by fluvial deposits (Dubois and Umbach, 1974; Courel et al., 1980; Matray et al., 1989). The Saint-Martin de Bossenay fault divides these two areas (Bourquin and Guillocheau, 1993, Fig. III.2). The Norian as never been dated in the eastern Paris Basin.

### *IV.1.1. - Lettenkhole*

In the eastern part of the Paris Basin, the first facies attributed to the Keuper are characterized by dolomites and clays of the Lettenkhole. The age of this unit is well established in the eastern part of the Paris Basin (Fig. I.1): the Middle Lettenkohle is Upper Ladinan (Kozur, 1972; Adloff et al., 1984) and the 'Dolomie limite' is Lower Carnian (Kozur, 1972). These strata are equivalent to the Lettenkeuper deposits of the German Basin (Gall et al., 1977). The Lettenkohle, which crops out in the eastern part of the Paris Basin, is composed of dolomitic-claystones and dolomites overlain by an anhydrite bed. It was deposited in a restricted marine environment (Courel et al., 1980; Duringer and Doubinger, 1985). The upper part of the Lettenkohle 'stage' is characterized by lagoonal-marine facies (Ainardi, 1988), followed by more marine dolomitic claystones which accumulated during maximum water depth.

### *IV.1.2. - Marnes irisées*

The 'Marnes irisées' Group is divided in three parts: the 'Marnes irisées inférieures', 'Marnes irisées moyennes' and the 'Marnes irisées supérieures' (Table 1 and Fig. I.1).

In the east of the Paris Basin, the 'Marnes irisées inférieures' are made up of evaporite coastal sabkha deposits (Fig. I.1): the 'Couches à pseudomorphoses' (anhydritic shales), 'Formation salifère' (halite and shale) and 'Couches à esthéries.' The base of the 'Formation salifère' in Lorraine is dated as Lower Carnian (Kozur, 1972; Geisler et al., 1978). These evaporite series occurred at remarkably similar times throughout the Triassic basins of western Europe, where halite deposits may be several hundred metres thick. This major Triassic evaporite 'crisis' corresponds to the 'Unterer-Gipskeuper' (Grabfeld Formation) in the Germany.

The 'Marnes irisées moyennes' are composed of three formations: the 'Grès à roseaux', the 'Argiles bariolées intermédiaires' and the 'Dolomie de Beaumont' formations (Table 1 and Fig. I.1).

In the Germanic Basin, evaporite sedimentation was suddenly interrupted by the spread of fluvial deposits forming the most consistent lithostratigraphic marker of the entire basin: the 'Schilfsandstein' (Dittrich, 1989) and 'Grès à roseaux' of northeast France (Fig. I.1). This unit is dated as Middle Carnian (Julian) (Kannegieser and Kozur, 1972; Kozur, 1993) and must have been deposited during a relatively short time (Hahn, 1984). Correlative units have been identified in several other basins: 'Arden Sandstone' in Great

Britain (Warrington et al., 1980), ‘Areniscas de Manuel’ of the Valencia Basin in Spain (Orti-Cabo, 1982), ‘Grès à *Equisetum mytharum*’ of the Briançonnais. Simms and Ruffel (1990), assumed such consistency represents a climatic event of global scale providing, in the absence of biostratigraphic data, a valuable chronostratigraphic marker. The ‘Grès à Roseaux’ formation is characterized by alluvial plain deposits with anastomosed and meandering channels (Palain, 1966; Courel et al., 1980). The ‘Grès à roseaux’ Fm grades vertically into the clayey coastal sabkha deposits of the ‘Argiles bariolées intermédiaires’ and then into the lacustrine deposits of the ‘Dolomie de Beaumont’ within some marine influence (tempestites).

In the east of the Paris Basin, the base of the ‘Marnes irisées supérieures’ consists of anhydritic red clays deposited in a coastal-sabkha environment: ‘Argiles de Chanville’ Formation. They are overlain by variegated dolomite-clay, playa deposits: ‘Argiles bariolées dolomitiques’ Formation (Table 1 and Fig. I.1).

#### *IV.1.3. - Rhaetian*

The Rhaetian are characterized by restricted marine sandstone deposits of the ‘Grès rhétiens' Formation which displays some limited open marine influences. The occurrence of marine littoral fauna (pelecypods and gastropods) is attributed to the Rhaetian transgression (Al Khatib, 1976; Shuurmann, 1977, Gunatilaka, 1989); intercalations of black shales yield in many places marine microfossils (Rauscher et al., 1995). The sandstones are overlain by the continental deposits of the red ‘Argiles de Levallois’ (Al Khatib, 1976; Roche, 1994).

### IV.2. - High resolution sequence stratigraphy from well-log analysis

By high-resolution sequence stratigraphy based on well-logs and core data from 300 wells across the basin, the correlation between basin-centre evaporites with basin-margin clastics allow to precise the evolution of the basin (Bourquin and Guillocheau, 1993; 1996) correlated. Five minor stratigraphic cycles in the Keuper, each having an average duration of 2-10 Ma (Fig. III.2; IV.1), have been defined:

(1) the Lettenkohle minor cycle or Ladinian-lower Carnian Cycle,
(2) the ‘Marnes irisées inférieures’ minor cycle or Lower Carnian Cycle,
(3) the ‘Grès à roseaux’ - ‘Dolomie de Beaumont’ - base of the ‘Marnes irisées supérieures’ minor cycle or Carnian Cycle,
(4) the lower ‘Marnes irisées supérieures’ minor cycle or Norian Cycle,
(5) separated by the Eo-Cimmerian unconformity from
(5) the upper ‘Marnes irisées supérieures’ - Rhaetian minor cycle or Norian-Rhaetian Cycle.

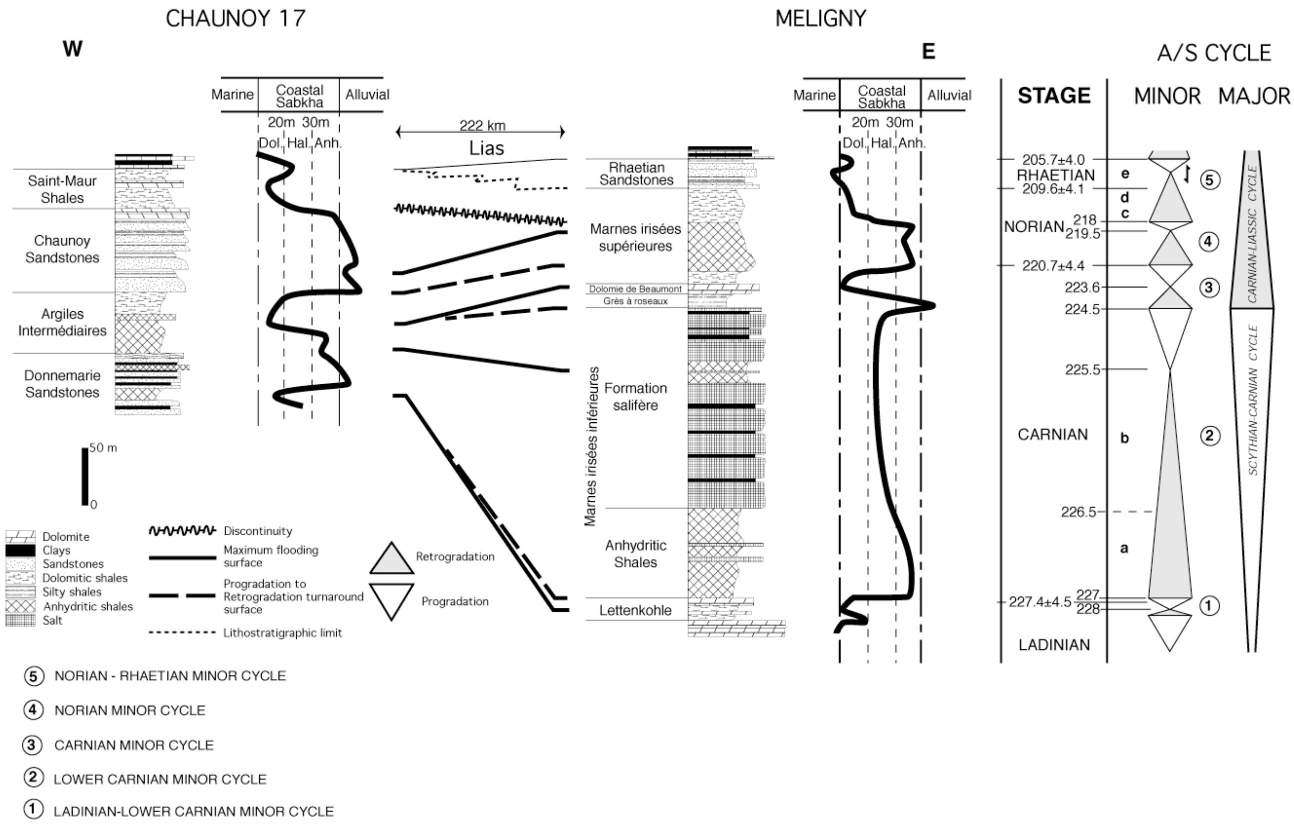



**Figure IV.1**: Lithostratigraphy, sedimentary environment variations and rank of different A/S stratigraphic cycles in two wells characteristic of the eastern and western Paris Basin (after, Bourquin and Guillocheau, 1996, modified). See Fig. IV.2 for location. After Bourquin and Guillocheau, 1996.

Cycles (1) and (2) belong to the progradational hemi-cycle of the Scythian-Carnian major cycle, while cycles (3), (4) and (5) belong to the retrogradational hemi-cycle of the Carnian-Liassic major cycle (Figs. 1b and 2). These cycles are summarised in two sections: one from East to West (Fig. III.2a) and the other from North to South (Fig. II.2b). In another study, detailed isopach maps of each of the five minor cycles are used to analyse the 3D evolution of the basin during this period (Bourquin et al., 1997). These maps show that local tectonic activity has influenced the preservation of the evaporitic and fluvial deposits. The major base-level cycles record variations in the rate of subsidence in time and space. The maximum rate of subsidence for the Scythian-Carnian cycle occurred in the east of the Paris Basin. During the Carnian-Liassic cycle, the areas of greatest subsidence shifted northwestwards. The shift marked the appearance of an independent Paris Basin which was no longer simply the western margin of the German Basin. This shift can be ascribed to large-scale wavelength tectonic deformation and produced an intra-'Marnes irisées supérieures' truncation.

### *4.2.1. Lettenkohle minor cycle or Ladinian - lower Carnian Cycle*

The Lettenkohle, which crops out in the eastern part of the Paris Basin, occur throughout the east and grade laterally into siliciclastic sediments in the extreme northeast only (Fig. 7). The Lettenkohle Formation grades westwards into the fluvial sediments of the Donnemarie Sandstones, to the west of the Saint-Martin-de-Bossenay Fault (Figs. III.2, IV.1). Within these strata, are bioturbated claystones with occasional dolomitic or anhydritic nodules, which record short term transgressions to the west. These are the most marine facies of this area and are correlated with the maximum flooding deposits of the Lettenkohle.

#### *4.2.2.'Marnes irisées inférieures' minor cycle or Lower Carnian Cycle*

In the east of the basin, this cycle is made up of evaporitic coastal sabkha deposits. The 'Marnes irisées inférieures' minor cycle starts with the anhydritic coastal sabkha deposits of the 'Couches à pseudomorphoses' (Anhydritic Shales Formation, Bourquin and Guillocheau, 1996). These grade vertically into the halitic coastal sabkha environments of the 'Formation salifère' (Figs. III.2 and IV.1). The upper boundary of the Anhydritic Shales Formation, defined in the east of the basin, is a diachronous facies boundary between anhydritic and halitic coastal sabkha deposits of the 'Formation salifère' (Fig. III.2a). The halitic coastal sabkha deposits grade laterally into an anhydritic coastal sabkha environment. The evaporite deposits grade westwards into the fluvial deposits of the Donnemarie Sandstones which are overlain by anhydritic coastal sabkha deposits of the 'Argiles intermédiaires' Formation. The coastal evaporite deposits migrate westwards, or landwards, while the Donnemarie Sandstone fluvial sediments step landwards in a transgressive pattern (Fig. III.3a). Vertical aggradation predominates towards the top of the salt formation, with lateral transitions into anhydritic-shale coastal sabkha facies.

During this cycle, faulting greatly influenced evaporite sedimentation and cycle geometries by creating space where halite could accumulate. The N-S section (Fig. III.2b) and the maps (Fig. IV.2) show that the salt series were abruptly limited by the E-W Vittel Fault, inherited from the Hercynian, to the south and by the Ardennes, or unpublished E-W fault, to the north where they graded into anhydritic environments. The reactivation of E-W faults, inherited from the Hercynian, controlled the extent of halite to the north and south by creating a 'corridor' where subsidence was greater. The NE-SW and NW-SE faults controlled salt deposits within this corridor. The westward shift of the areas of subsidence was associated with the migration of faulting to the west, which enhanced the migration of salt series bounded by the Saint-Martin-de-Bossenay Fault.

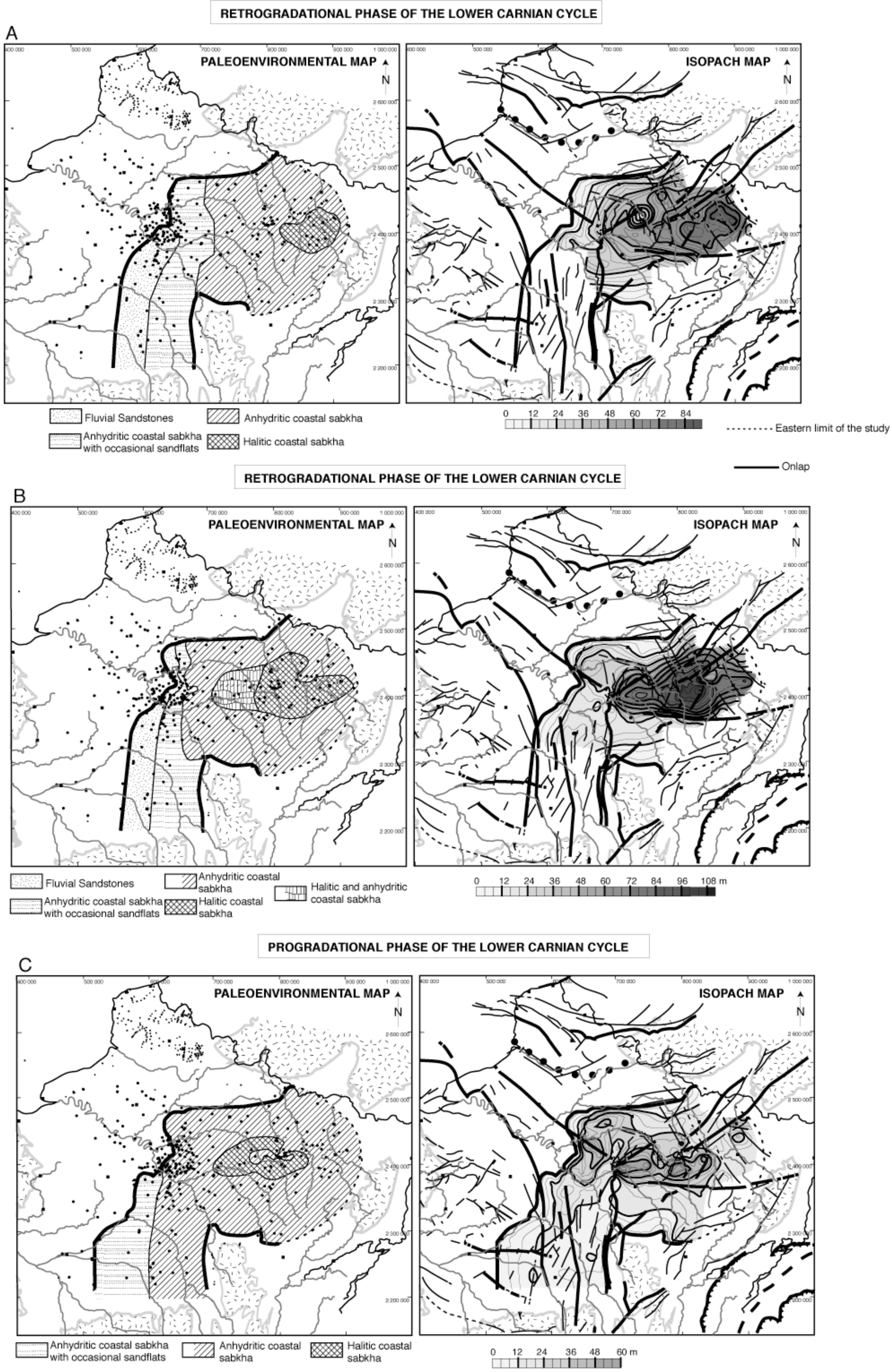



**Figure IV.2**: (A) Maps of the retrogradational phase of the Lower Carnian cycle, from base to top of the Anhydritic Shales Formation, defined in the eastern part of the basin (denoted a, Fig. III.2). (B) Maps of the retrogradational phase of the Lower Carnian cycle, from the base of the "Formation salifère", defined in the East of the basin, to the maximum flooding surface within the "Formation salifère". (denoted b, Fig. III.2). (C) Maps of progradational phase of the Lower Carnian cycle from the maximum flooding surface within the "Formation salifère" to the top of the "Formation salifère". See Figs. III.2 and IV.1 for key After Bourquin et al., 2002.

A non-erosional valley-shaped structure was formed by local flexure where the Saint-Martin-de-Bossenay and Bray Faults converged. This valley was filled by lenticular fluvial sediments (Sainte-Colombe-Voulzie Sandstones, Figs. III.2) with a basal onlap. The Sainte-Colombe-Voulzie Sandstones are part of this base-level fall cycle (Bourquin and Guillocheau, 1996). A separate map of these sandstone deposits (Fig. IV.3) has been made to show their location.

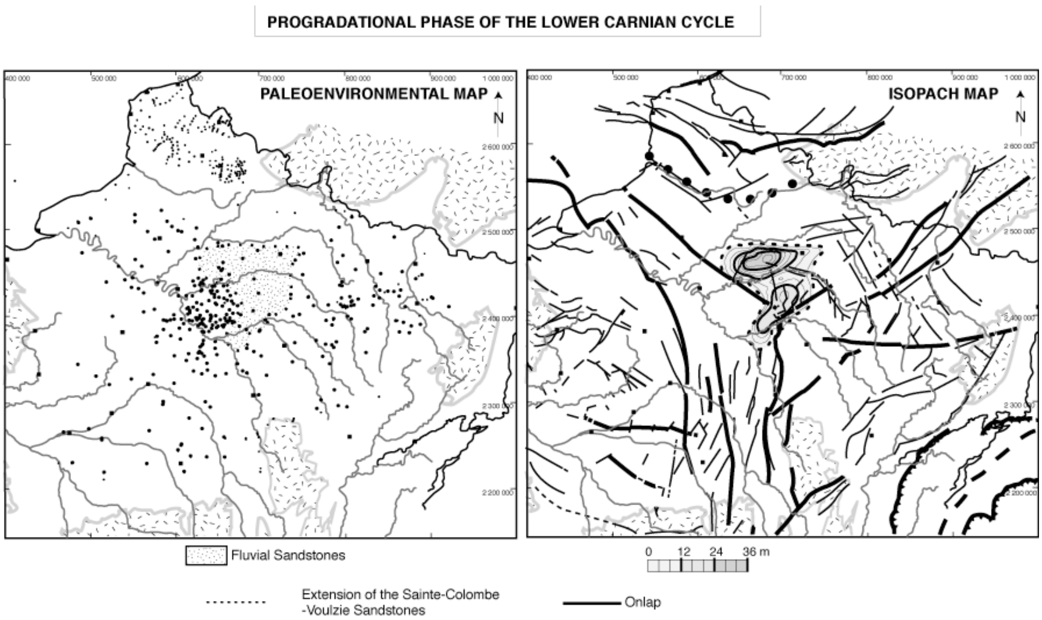



**Figure IV.3**: Maps of the Sainte-Colombe-Voulzie Sandstones (progradational phase of the Lower Carnian cycle) showing the location of this sandstone formation. See Figs. III.2 and IV.1 for key. After Bourquin et al., 2002.

### *4.2.3. 'Grès à roseaux' - 'Dolomie de Beaumont' - base of the 'Marnes irisées supérieures' minor cycle or Carnian Cycle*

This cycle started with the alluvial plain deposits (Palain, 1966; Courel et al., 1980), which accumulated during a period of base-level rise (Bourquin and Guillocheau, 1993; Bourquin and Guillocheau, 1996, Figs. I.1, IV.1). Southwest of the Bray Fault these deposits grade into the anhydritic coastal sabkha of the 'Argiles intermédiaires' Formation (Figs. III.2). The maximum accumulation of the 'Grès à roseaux' is located in the areas of greatest subsidence bounded by faults: one in the northwestern part (north of the Bray Fault), as for the Sainte-Colombe-Voulzie Sandstone deposits (Fig. IV.3) and one east of basin (Fig. IV.4A).

The 'Grès à roseaux' grade vertically into the lake deposits with marine influence of the 'Dolomie de Beaumont' (Fig. III.2, IV.1). The base-level fall is represented by dolomitic coastal sabkha deposits, which occurred throughout the eastern part of the basin. Further west, the anhydritic coastal sabkha sediments, which top dolomite deposits, are thicker (Fig. IV.4B). Still further west, the base-level fall ended with the basal part of the fluvial Chaunoy Sandstones. During the base-level fall (Fig. IV.4B), the depocentres were located in the west of the basin, and the areas of greatest subsidence north of the Bray Fault.

From this time (Fig. III.2), the areas of greatest subsidence were located in the northwest of the basin and resulted from a westward shift of the Paris Basin depocenter which began with the Sainte-Colombe-Voulzie deposits. There was a marked decline in fault activity in the east.

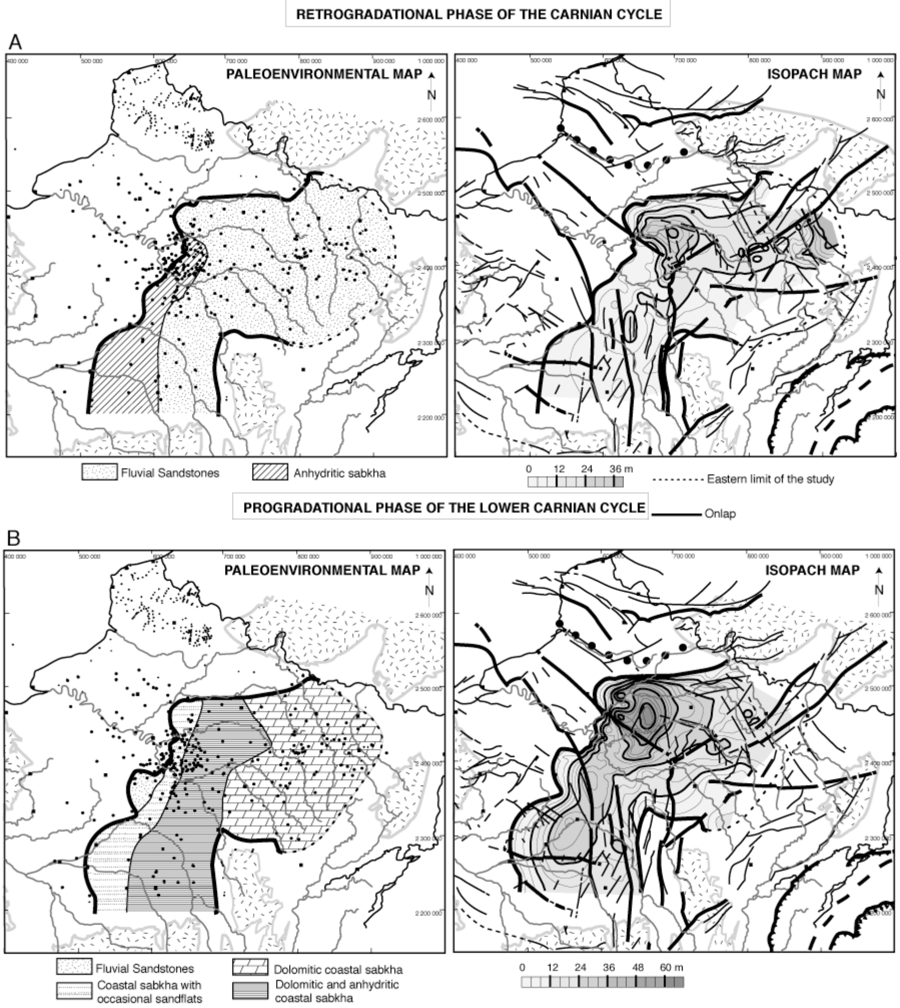



**Figure IV.4**: (A) Maps of retrogradational phase of the Carnian cycle. (B) Maps of progradational phase of the Carnian cycle. See Figs. III.2 and IV.1 for key. After Bourquin et al., 2002.

#### *4.2.4. Lower 'Marnes irisées supérieures' minor cycle or Norian Cycle*

In the east and centre of the Paris Basin, the base of the 'Marnes irisées supérieures' consists of anhydritic coastal sabkha deposits (called 'Argiles de Chanville' on outcrops). Landward, in the extreme western part of the basin, the deposits consist of alluvial fan deposits of Chaunoy Sandstones (Figs. I.1 and IV.1) exhibiting dolomitic palaeosols which are mainly well developed at the top (Bourquin et al., 1993, 1998). The alluvial fan axis is oriented WSW-ENE and the terrigenous sediments were introduced from the WSW. To the east, these alluvial fan deposits pass progressively at their base into fan delta deposits in a lacustrine environment, and are overlain by a braided fluvial system.

This minor cycle is characterized in the west by a base-level rise in the Chaunoy Sandstones. The maximum of the base-level rise is characterized by extensive flooding of the alluvial fan by lacustrine sediments. It is overlain by braided channel deposits or fluvio-lacustrine deposits. To the east, the base-level rise is recorded within the anhydritic coastal sabkha sediments (Figs. III.2, IV.2). The base-level fall trend, characterized in the central part of the basin by numerous well developped anhydritic strata, ends with an erosional discontinuity.

In the northwest of the basin, the reactivation of the Bray Fault and the Villers Fault, inherited from the Hercynian, influenced the fluvial deposits by creating tilted blocks where large quantities of sediments accumulated (Fig. IV.5). South of the Bray Fault, the areas of highest fluvial deposit accumulation were bounded by N-S faults. Eastwards, the depositional environment consisted of anhydritic coastal sabkha, and the areas of high subsidence were located in the north.

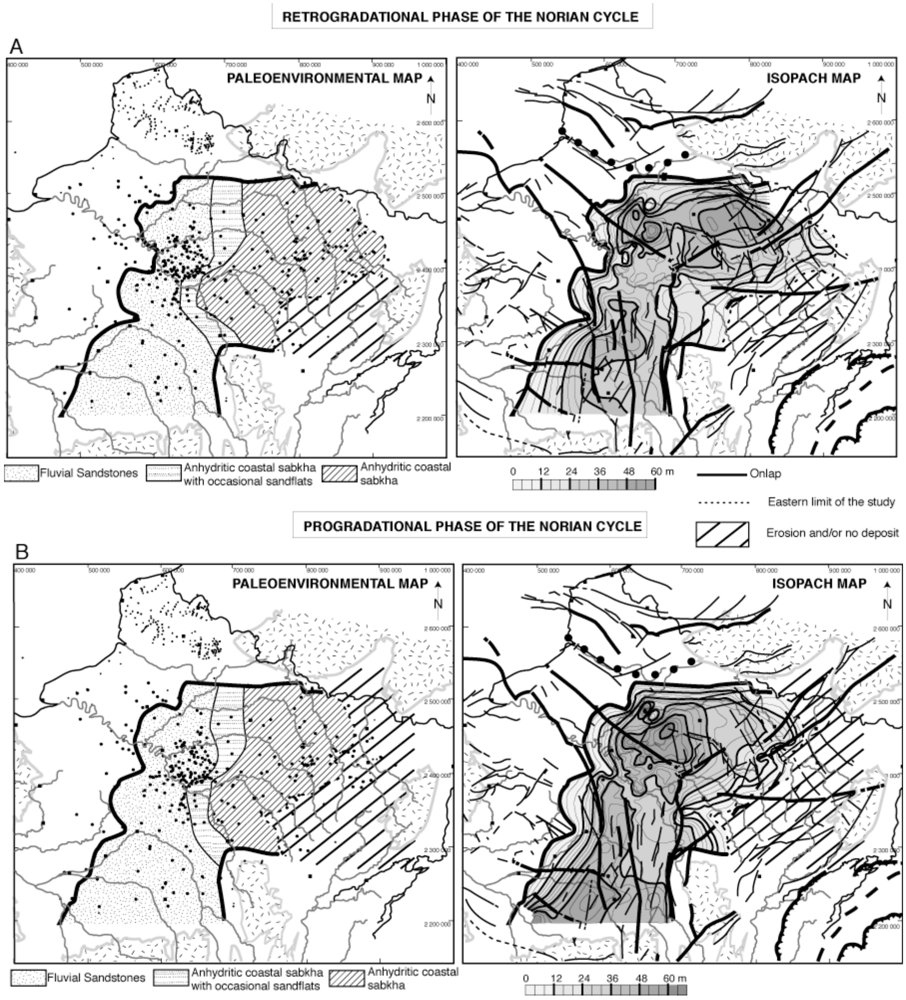



**Figure IV.5**: (A) Maps of retrogradational phase of the Norian cycle. (B) Maps of progradational phase of the Norian cycle. See Figs. III.2 and IV.1 for key. After Bourquin et al., 2002.

### *4.2.5. Eo-Cimmerian unconformity*

A stratigraphic discontinuity is observed within the 'Marnes irisées supérieures' in the Paris Basin (Bourquin and Guillocheau, 1993; Bourquin and Guillocheau, 1996). In the east and southeast of the basin (Figs. III.2, IV.1), this discontinuity is an angular unconformity within the coastal evaporites of the 'Marnes irisées supérieures'. It separates the underlying anhydritic from the overlying dolomitic coastal playa strata. In the eastern part of the basin, erosion associated with this unconformity has removed much or all of the underlying minor base-level cycle deposits (Figs. III.2, IV.1). Because of this truncation, no deposits were preserved to the southeast during the base-level rise (Fig. IV.5A) or to the east during the base-level fall (Fig. IV.5B).

### *4.2.6. Upper 'Marnes irisées supérieures' - Rhaetian minor cycle or Norian-Rhaetian Cycle*

This cycle started in the east with dolomitic playa deposits grading upwards into the restricted marine deposits of the Rhaetian Sandstones which display some limited open marine influences within a transgressive trend (Fig. III.2, IV.1). The base-level fall is recorded in the upper part of the Rhaetian, characterized by the continental deposits of the 'Argiles de Levallois'. Because of the intra-'Marnes irisées supérieures' stratigraphic discontinuity, this minor cycle lies directly upon the 'Grès à roseaux' - 'Dolomie de Beaumont' minor cycle in the east (Fig. IV.1). Further west, the dolomitic coastal sabkha deposits grade laterally into alluvial plain sediments with fluvio-lacustrine sandstones ('Grès d'Egrenay', 'Grès de Boissy', 'Grès d'Etrechy') where no classical Rhaetian facies are recognized (Fig. IV.6).

E-W correlations show that the 'Rhaetian' boundary is a diachronous facies boundary between a coastal sabkha and a restricted marine environment within a base-level rise (Bourquin and Guillocheau, 1993; Bourquin and Guillocheau, 1996, Figs. III.2). In the southeast of the basin, the Rhaetian Sandstones may have eroded the 'Marnes irisées supérieures' deposits locally.

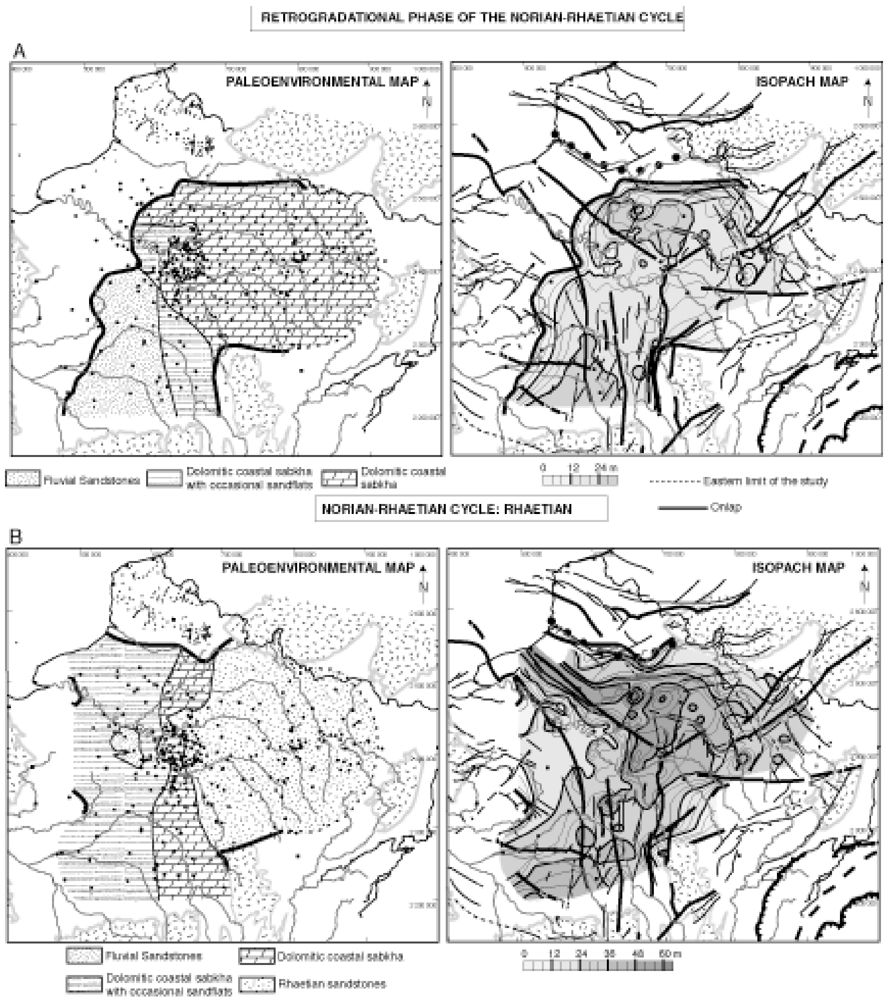



**Figure IV.6**: (A) Maps of retrogradational phase of the Norian-Rhaetian cycle (denoted d, Fig. III.2). (B) Maps of the base of the Rhaetian sandstones for the wells located in the eastern part of the basin to the top of the Triassic (end of retrogradational phase and progradational phase of the Norian-Rhaetian cycle (denoted e, Fig. III.2). See Figs. III.2 and IV.1 for key. After Bourquin et al., 2002.

### IV.3. -Comparison with the German Basin

The coastal onlap curve of the German Keuper (Aigner and Bachmann, 1992) exhibits many similarities with the sequence evolution of the Paris Basin (Fig. IV.7). But the Triassic succession is more complete in the German Basin and more cycles are observed within the Ladinian and the Norian-Rhaetian. The Lettenkohle contains only one minor base-level cycle in the Paris Basin, whereas the equivalent Lettenkeuper lithostratigraphic unit contains two cycles in the German Basin. Aigner and Bachmann assume that the 'Schilfsandstein' deposits represente a lowstand systems tract and record a base-level fall period. Then, the 'Saint-Colombe-Voulzie Sandstones' alone could be equivalent of the 'Schilfsandstein' and the 'Grès à roseaux,' marking the base level rise in the Paris Basin, could be the lateral equivalent of the 'Dunkle Mergel' or eventually of the upper part of the 'Schilfsandstein'. The maximum flooding within the 'Dolomie de Beaumont' is an equivalent of the 'Hauptsteinmergel' (Aigner and Bachmann, 1992). No biostratigraphic data exist above the 'Grès à roseaux,' and the intra-'Marnes irisées supérieures' truncation in the Paris Basin disturbs the sequence record. Consequently it is difficult to be certain of the correlations of two minor base-level cycles in the Paris Basin with the three cycles in the German Basin. The major difference between these two basins during the Keuper deposition is that the 'Marnes irisées inférieures' minor cycle (retrogradation and progradation) does not have the same expression in the German Basin: the equivalent of the 'Unterer Gipskeuper' will be preserved in a progradational phase.

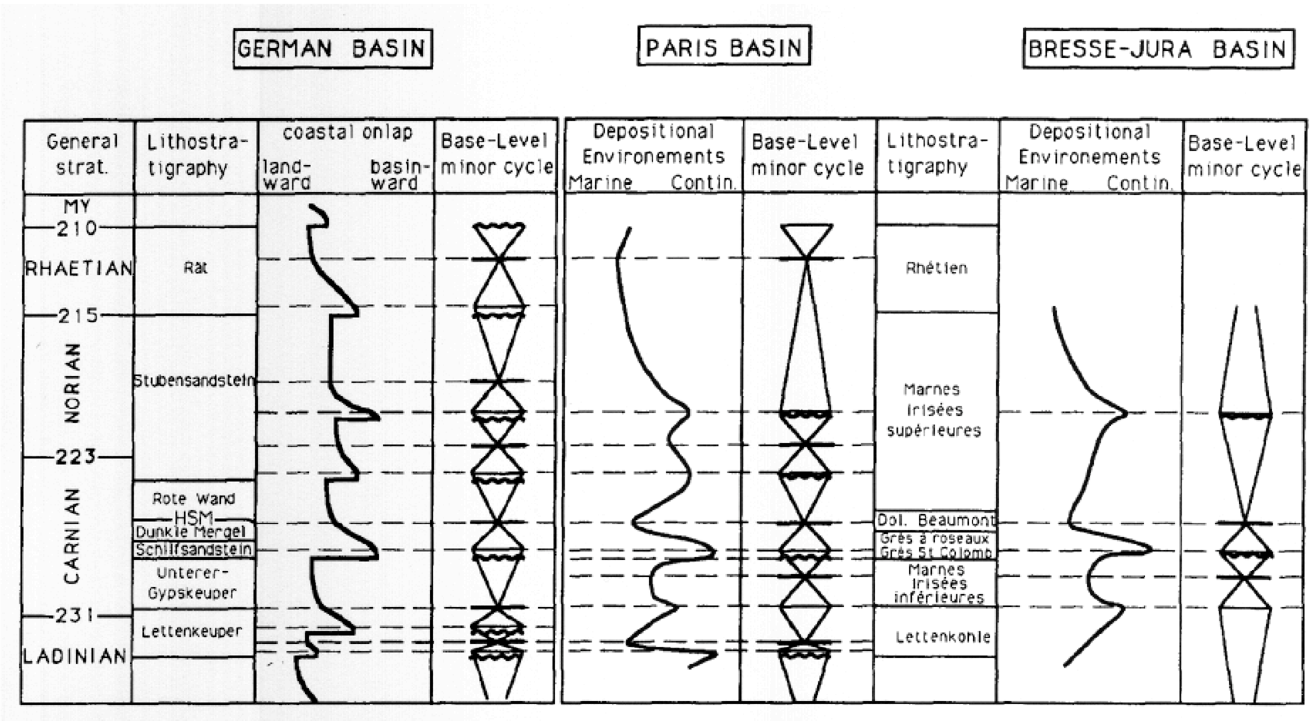



**Figure IV.7**: (A) Comparison of the stratigraphic records between German Basin (Aigner and Bachmann, 1992), Bresse-Jura Basin (Dromart et al., 1994, modified after oral communication) and Paris Basin. HSM: Hauptsteinmergel After Bourquin and Guillocheau., 1996.

In the Paris basin we observed an intra-Norian discontinuity (intra-'Marnes irisées supérieures' Formation, Figs. 2 and 3). This discontinuity has been also recognized in the Bresse-Jura Basin (Dromart et al., 1994), in the German Basin (erosional truncation of the Stubensandstein), in the Barent Sea, in the

Dolomites (Aigner and Bachmann, 1992), and in the Netherlands (Geluk, 1998). This discontinuity could be attributed to the Eo-Cimmerian unconformity that occurred during the Early-Cimmerian phase, expression of a pronounced extensional tectonic event related to the disintegration of Pangea with numerous short pulses (Wolburg, 1969; Ziegler, 1990; Kockel, 1995). Moreover, the quantification of the Eo-Cimmerian movements in NW-Germany, by Frisch and Kockel (1999) suggest that the end of the extension is coeval with the Norian unconformity (Steinmergelkeuper unconformity, Arp et al., 2005) and not of the early Rhaetian unconformity. In the Paris Basin, the Rhaetian-unconformity is only observed on outcrops in the eastern part of the Paris Basin. This Eo-Cimmerian disconformity can be interpreted as a change of the intraplate stress in response to the early closing phases of the Black Sea back-arc Basin (Ziegler, 1990).

# Day 1 — Tuesday, 03.10 2006

## Stop 1.1 - Haut-Barr Middle Buntsandstein ('Grès vosgien' and 'Conglomérat principal' Fms)

**Figure 1**: Haut-Barr outcrops (see p. 7 for location): Middle Buntsandstein ('Grès vosgien' and 'Conglomérat principal' Fms) located south (noted A Fig. 2)

### Facies association: Braided rivers

The fluvial sandstone facies association the most commonly observed in the 'Grès vosgiens' Formation (Fig. I.1), is characterized by a vertical arrangement, 2 to 5 m thick and with lateral extent in excess of about ten metres, of mainly through cross-bedded sandstones (dm to m scale) passing upwards to planar cross-stratification (Fig. 1 and 2). These sandstones are composed of sub to well rounded grains of quartz (80 to 95 %) and feldspar, more ore less coarse (locally very coarse at the bottomset). In places the vertical passage up into migrating current ripples (facies Sr) marks the end of channel infilling. These channel deposits are characterized by bed-load dominated sediments and the migration of 3D, and more rarely 2D, dunes and barforms. Unimodal paleocurrent indicators, oriented to the NNE, suggest the channels display a low sinuosity. Within these deposits, clay facies can be observed as discontinuous cm to dm-thick layers, with frequent mud-cracks that, laterally, either grade into intraformational breccias or are totally eroded by sandstones. They are interpreted as deposition from settling in topographic hollows, located at the bottomset, after the cessation of migration of fluvial barforms, during periods of either low water level or aridity. The floodplain deposits associated with these channel deposits are characterized by laminated silstones, or fine sandstones, along with red mudstones. These deposits are thinly layered (a few cm to up to 40 cm in thickness), and very sandy, with some weak bioturbations in places. They are composed of interbedded fluvial overbank, aeolian, and flooded interdune deposits (overbank-interdunes). This facies association, characteristic of arid environments, replaces classic floodplain facies (Langford & Chan, 1989). The occurrence of 3D dunes and barforms, as well as the unimodal paleocurrents and scarcity of floodplain deposits, indicate braided channels. The lack of root traces, and the occurrence of aeolian deposits associated within the floodplain provide evidence of an arid climate. Moreover, the channels underwent periods of cessation in their activity that could indicate the ephemeral character of some watercourses. During flood periods, the formation of ponds allowed the ephemeral development of subaqueous life (bioturbated facies).

The fluvial conglomerate facies association of the 'Conglomerat principal' Formation shows vertical arrangements of trough cross-bedded, and rarely planar cross-bedded, gravel to coarse sandstone lenses (dm to m scale) that does not exceed 3 m in thickness. This facies contain abundant very rounded gravels, sometimes of dm size, of extremely mature (exclusively siliceous) composition: quartz, quartzite, lydite. Paleocurrent measurements indicate unimodal directions, oriented to the NNE, that characterize low sinuosity channels. These channel deposits seem to be not markedly different from those described below. However, the lack of channel-fill ends (facies Sr), as well as the predominance of conglomeratic facies, suggest a period of transit and/or granulometric segregation. At outcrop, this formation has a maximum thickness of 20 m, and shows a great lateral extent towards the eastern (Durand, 1974; Bourquin *et al.*, 2006).

The arid climate prevailing in the sedimentation area is demonstrated by the presence of many wind-worn pebbles and cobbles (ventifacts), not only concentrated in the conglomeratic layers, but also scattered here and there throughout the 'Grès vosgiens' Formation. (Durand *et al.*, 1994).

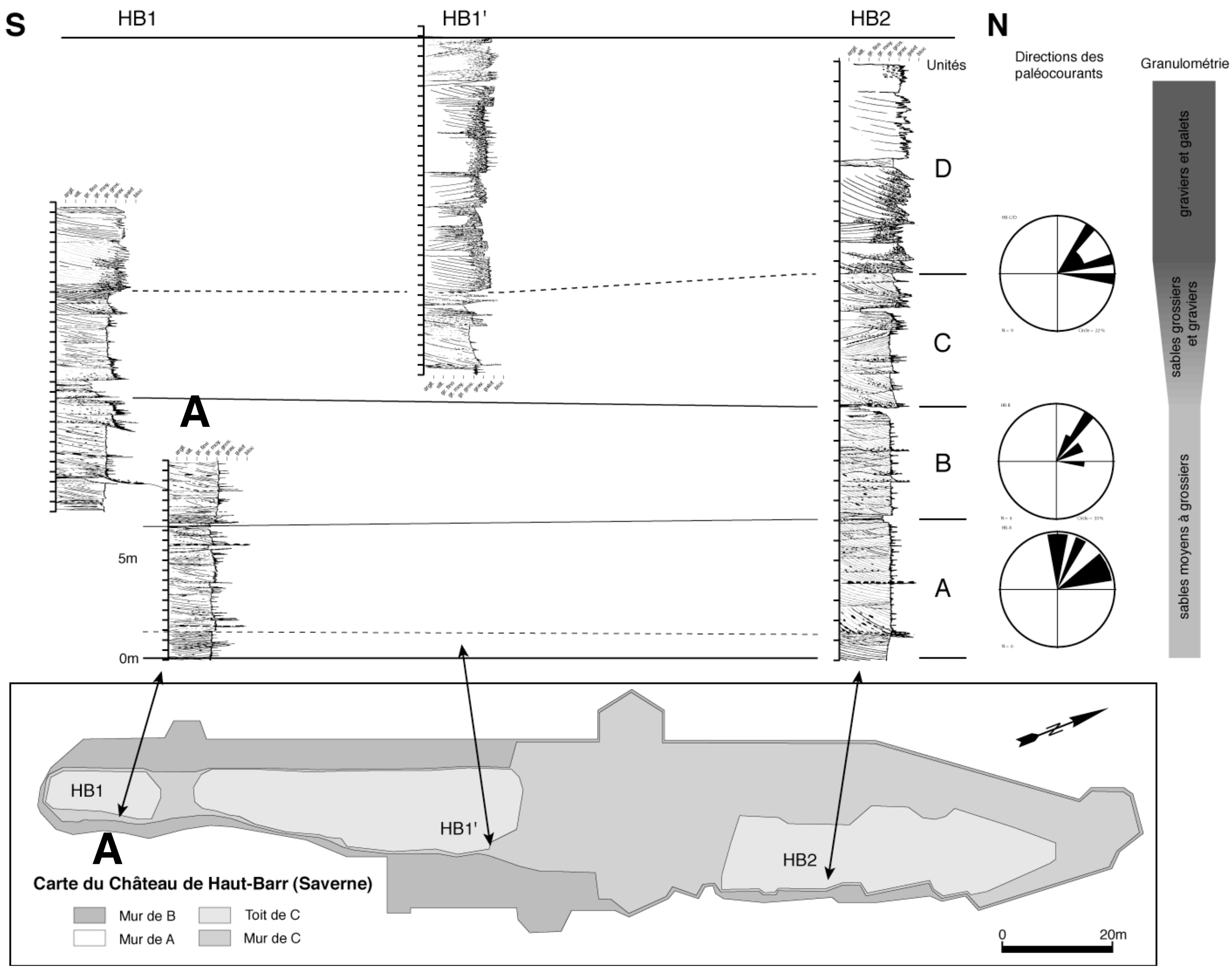



**Figure 2**: Sedimentological log of 'Grès vosgien' and 'Conglomérat prinicpal' of the Haut Barr outcrop (after Guillocheau et al., 2002a)

## Landscape reconstruction for the early Triassic (Middle Buntsandstein)

The facies descriptions allow us to characterize these deposits as resulting from braided rivers within an arid alluvial plain without vegetation (Fig. 3). The fluvial channels seem to be very wide, and they are divided during low-water stages into numerous distributaries separated by temporary islands with aeolian deposits (See Stops 1.4, 4.6) and ephemeral ponds that allowed only a very limited development of subaquatic life. Moreover, many distributaries display periods of inactivity that reflect their ephemeral character. The 'Conglomérat principal' Formation does not exceed a thickness of 20 m at outcrops in the Vosges, and shows a great extension to the east and the south. The 'Conglomérat principal' Formation rarely occurs at outcrop north of the Vosges Massif, near the German Frontier. Here, it is truncated by a major discontinuity referred to as the 'Hardegsen unconformity' (Stop 3.8, 4.3), which even cuts locally into the 'Grès vosgiens' (Bourquin *et al.*, 2006). This unconformity expresses one of the most pronounced extensional tectonic events observed in the German Triassic (Trusheim, 1961 and 1963; Wolburg, 1968; Röhling, 1991).

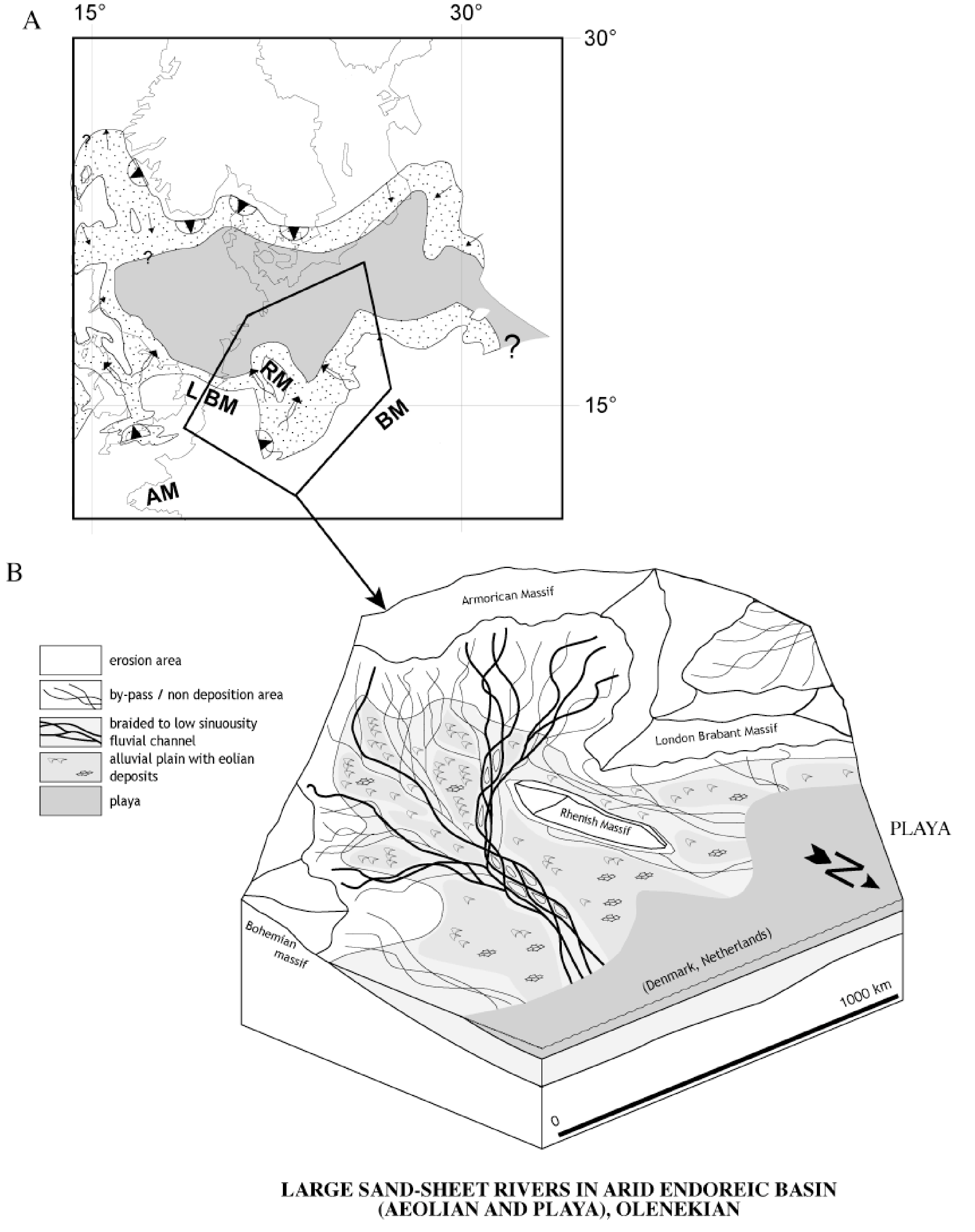



**Figure 3**: (A) Early Triassic palaeogeographic map of southern part of the German Basin with superimposed palaeoenvironments and fluvial systems. (B) Paeloenvironmental reconstruction of the western part of the Germanic Basin. After Bourquin et al., 2006.

## Stop 1.2 - Niderviller (Metzger quarry): Upper Buntsandstein ('Grès à Voltzia' Fm)

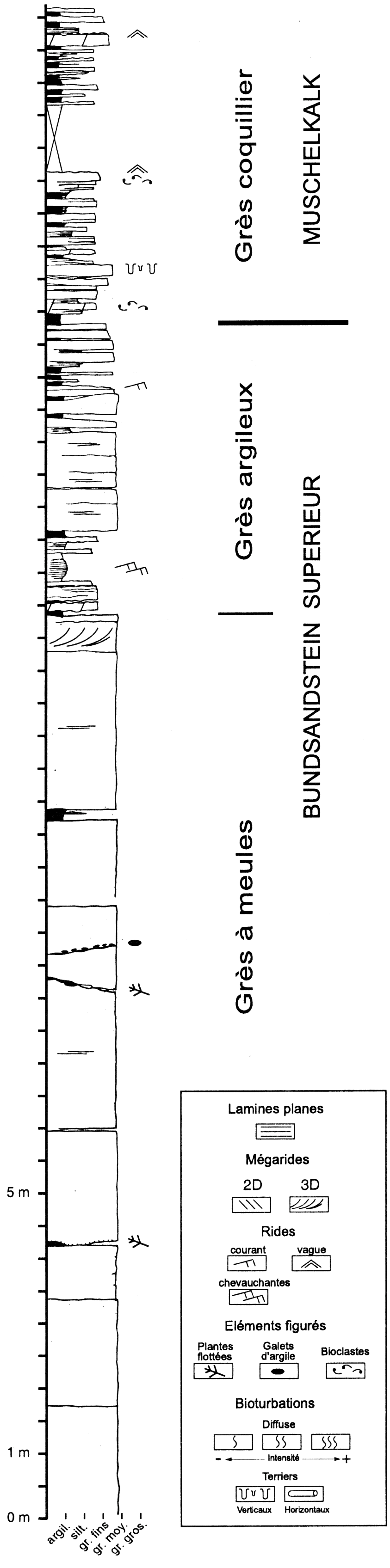



**Figure 5**: Sedimentological log of 'Grès à Voltzia' of the Adamswiller Quarry (after Guillocheau et al., 2002a)

**Figure 4**: Outcrop of the 'Grès à Voltzia' of the Niderviller quarry

**Facies association: Single-channel low sinuosity rivers**

In this quarry (see p. 7 for location, Fig. 4), we observed the two facies of the 'Grès à Voltzia' Formation: the 'Grès à meules' and the 'Grès argileux'. The facies association of the 'Grès à meules' Member (Fig. 5) is characterized by fine to very fine sandstones with high content of feldspar. They forms lenticular bodies (1,5 to 2 m thick) showing the following vertical arrangement, from base to top:

- basal lag with clay clasts which sometimes contains bivalves,
- rarely trough cross-bedding of low angle and pluri-metre long wavelength,
- parallel lamination, with primary current lineation (upper flow-regime plane beds),
- ripple cross lamination,
- decantation clays beds.

These facies association could characterize one flooding event.

The 'Grès argileux' Member is characterized by the same sandstones, but in thinner and wider lenses (overbank splays) separated by thick clay layers deposited on floodplain or in pond with some marine influence. Paleocurrent directions for these two members indicate low-sinuosity to straight channels (Durand, 1978) mainly oriented to the NE.

### Landscape reconstruction for the Anisian (Upper Buntsandstein)

In this quarry, we observed the 'Grès à Voltzia' Formation with an evolution from low sinuosity fluvial systems in the 'Grès à meules', to the fluvio-marine environment of the 'Grès argileux', with weak marine influence. Within outcrops, macrofauna and palynoflora allow the attribution of a Lower to Middle Anisian age according to location (Durand and Jurain, 1969; Gall, 1971). The 'Grès à voltzia' Formation shows an evolution from a low sinuosity fluvial system in the 'Grès à meules', with floodplain including more or less brackish ponds, to the fluvio-marine environment of the 'Grès argileux'. Except fauna, no indication of marine environment is recorded in these deposits. The marine shells, found in places within the 'Grès argileux' are related to the arrival of marine flooding in ponds by occasional break of a beach bar (Durand, 1978).

The well-log correlations (Chapter II) allow to reconstruct the paleogeography of this Triassic period (Fig. II.7). The 'Grès à Voltzia' Formation corresponds to a coastal fluvial environment with more or less marine influence according to location (Fig. 6). This formation is diachronous (Fig. II.8) and evolves either into fluvial environment (landward) or to marine deposits (basinward). Laterally, to the east, i.e. basinward, it is the lateral equivalent of lower Muschelkalk facies of the German basin (Fig. II.9).

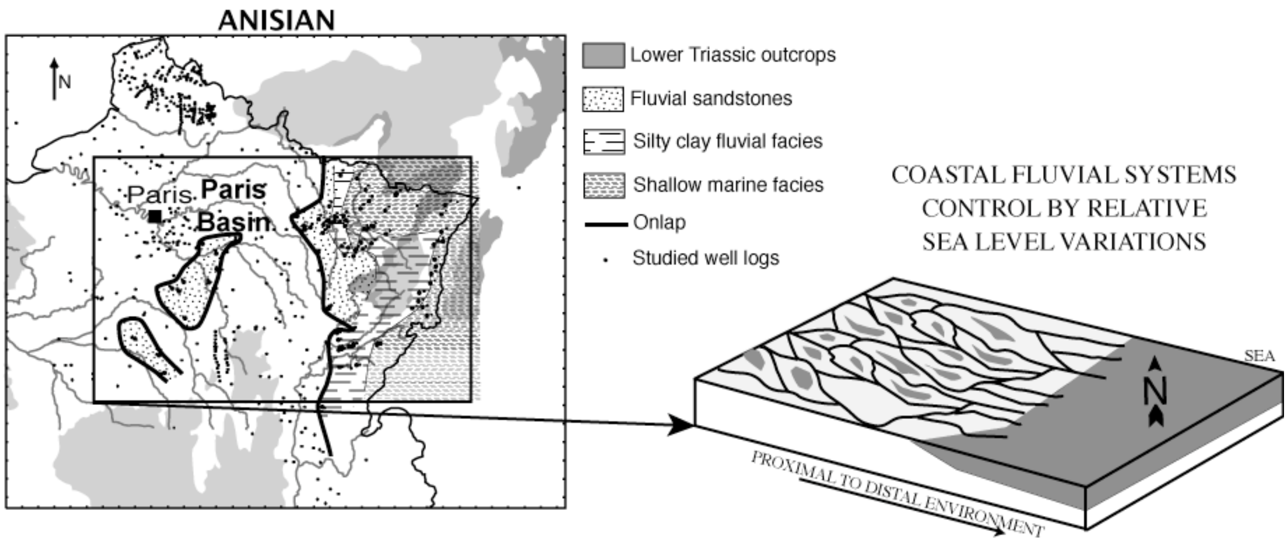



**Figure 6**: During the Anisian, the fluvial systems are connected to the Tethys sea. After Péron et al., 2005.

**Stop 1.3 - Héming (Holcim quarry): Upper Muschelkalk ('Calcaire à entroques' and 'Calcaire à cératites' Fms.**

See p. 7 for location

## Facies association and paleogeography

The 'Calcaire à entroques' characterized a nearshore (inner ramp) environment and the 'Calcaire à cératites' an upper offshore (outer ramp) environment dominated by storms (Fig. 7). Tempestites deposits are well observed, such as hummocky cross stratification, gutter casts, wave ripples cross stratification. From the Middle to Upper Muchelkalk we observe an evolution from coastal plain to mixed marine platform. The correlations between outcrops and well-log (Fig. 8) allow to show the westward lateral transition, i.e. landward, to coastal plain and alluvial plain (Fig. III.1).

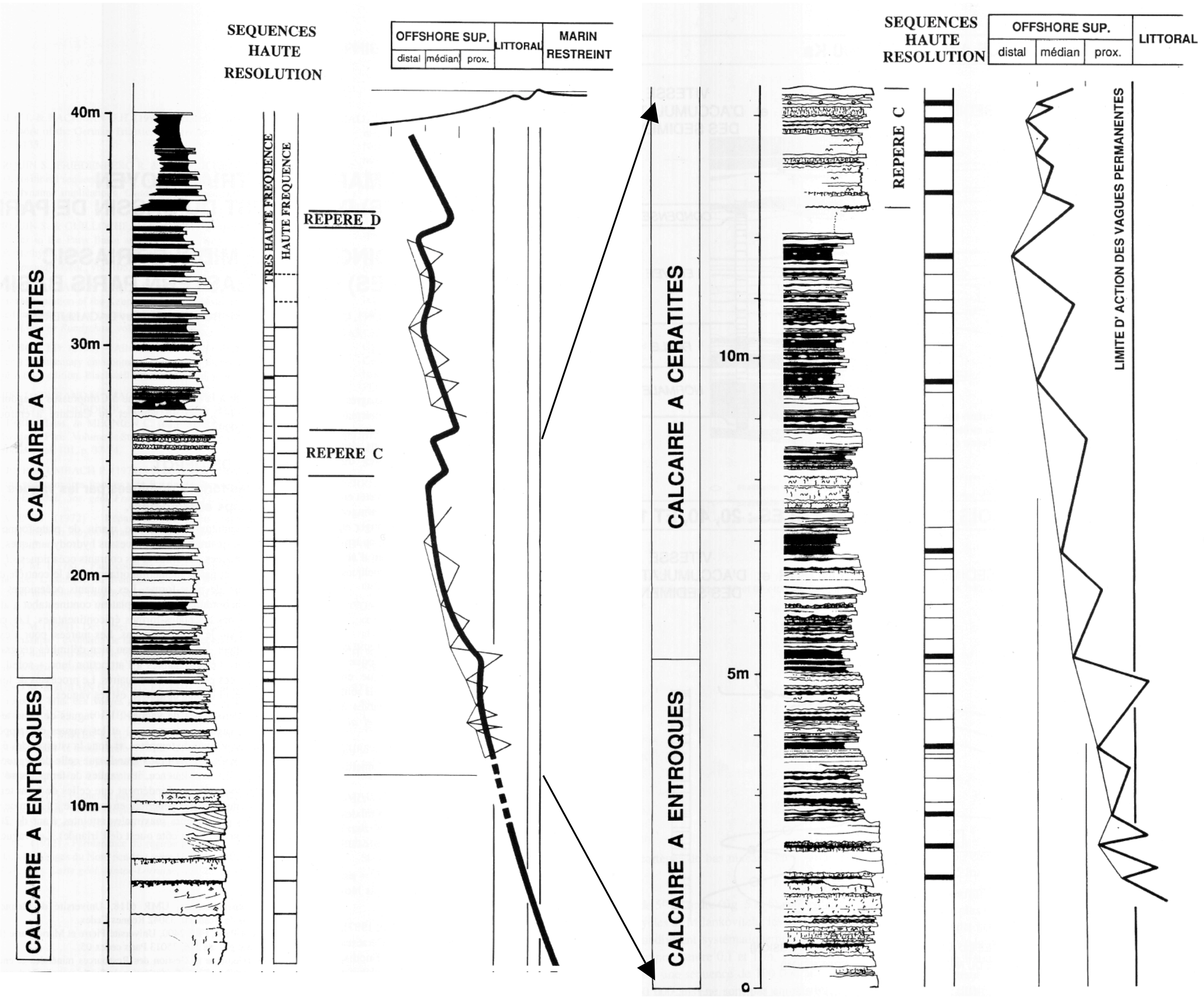



**Figure 7**: Lithostratigraphic column, sedimentary environment variations and high resolution sequence stratigraphy of the lower part of the 'Calcaires à cératites' of the Heming quarry (after Guillocheau et al., 2002b).

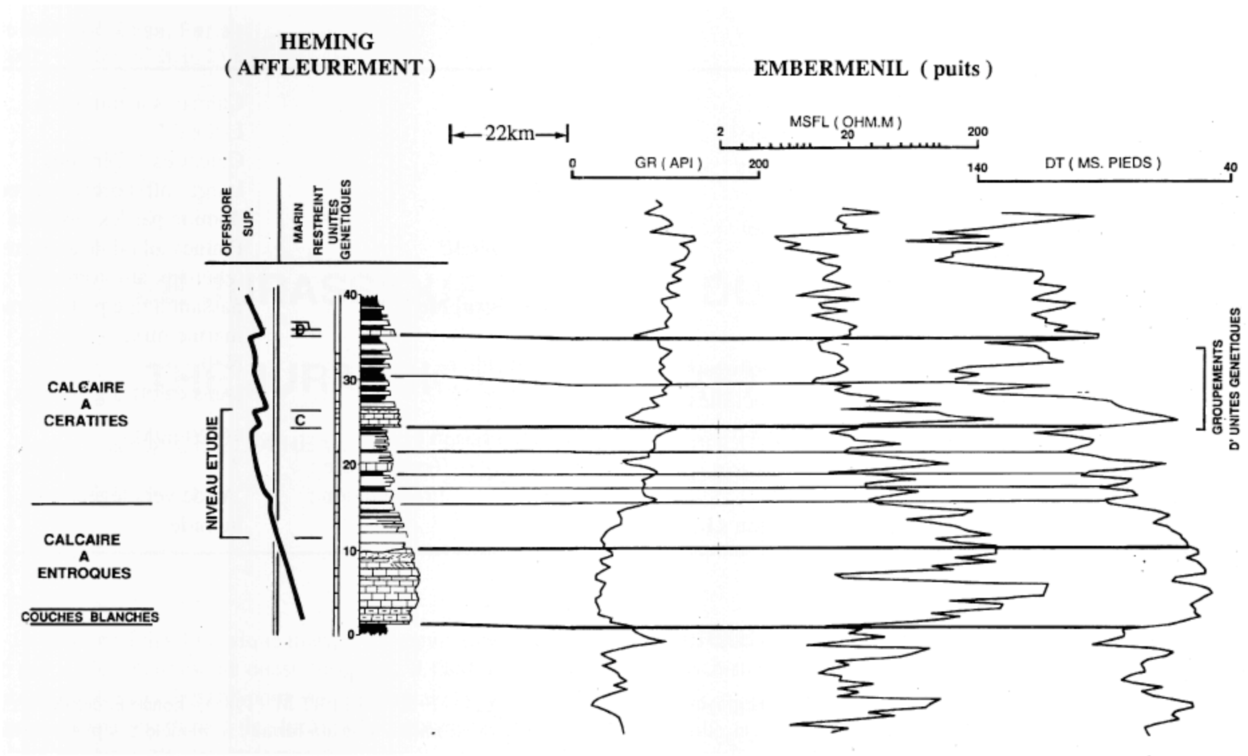



**Figure 8**: Correlations between Heming outcrops and Emberménil well-log (after Bourquin et al., 1995)

## Stop 1.4 - Raon-l'Etape (Côte de Beauregard): Middle Buntsandstein ('Conglomérat inférieur' Fm and 'Grès vosgien' Fm, with aeolian facies)

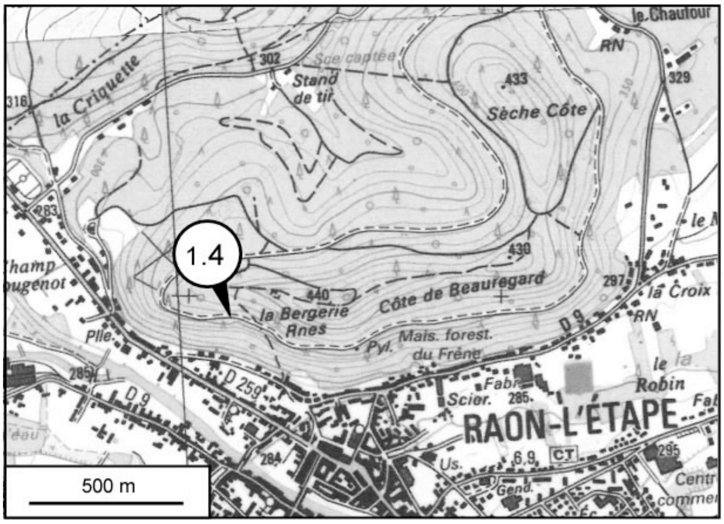



**Figure 9**: Location of the outcrop of Raon l'Etape

In this outcrop (Fig. 9), we can observe the 'Conglomérat de base' Formation, resting on the 'Grès de Senones' Fm. ('Buntsandstein inférieur'), and overlain by the 'Grès vosgien' Formation where aeolian facies are preserved.

## Facies association: braided rivers and aeolian dunes

### *Braided rivers*

The lowermost fluvial conglomerate facies association is located at the base of the Lower Triassic, characterizing the 'Conglomérat basal' Formation. This formation, well observed on well-logs, overlies the basement and is located in the western part of the basin. It is diachronous and represents the landward equivalent of the 'Grès vosgiens' Formation (Bourquin *et al.*, 2006). At outcrop, this formation displays the same fluvial facies association as described above in the 'Conglomerat principal' Formation, but with the development of trough cross-bedding and a typical abundance of the fine gravel fraction (granules), as in the 'Eck'sche Konglomerat' of Schwarzwald. Pebbles are generally less rounded, and some rhyolite, granite and gneiss add to the classical quartz, quartzites and lydites. The presence of many wind-worn gravels (ventifacts) attests an arid depositional area (Durand *et al.*, 1994).

This formation corresponds to more proximal braided-river deposits that evolves in the space (laterally, i.e. eastwards) and the time (vertically) into braided river of the 'Grès vosgiens' (Fig. 3).

### *Aeolian dunes and interdunes*

Two aeolian facies associations can be observed in the Lower Triassic succession of the western part of the Germanic Basin. Only one is exposed at this stop.

At Côte de Beauregard, the association of sandflow strata, grainfall laminations and subcritically climbing translatent strata (SCTS) is interpreted as deposit of migrating aeolian dunes, and the predominance of the latter type characterizes the basal part of a large dune (Fig. 10). Each set never exceeds 1,5 m in thickness, but can attain a length about 1 km and a width of a few hundred metres that characterizes large dunes several tens of metres thick (Clemmensen & Abrahamsen, 1983; Durand et al., 1994). The analysis of this dune system (Durand et al., 1994) allows reconstituting a linear dune (seif) trending ENE-WSW, built by seasonal winds from NE (regular) and SSE (stormy).

The second facies association is composed of a vertical pattern of fine sand, with low to very-low angle mm-scale lamination, and fine crude and irregular horizontal, mm-scale lamination, of fine well sorted sand, sometimes coarse. Within these laminations, thin horizontal layers of quartz granules can be observed. (Fig. 11b). This association is characteristic of high wind velocities and wet episodes. It could be attributed to lateral dune deposits, and represents dry interdune environments. Alternatively, such deposits could represent aeolian sand sheets within wet environments, where wind regime conditions and/or sand supply prevent the development of dunes (Kozureck & Nielson, 1986; Trewin, 1993).

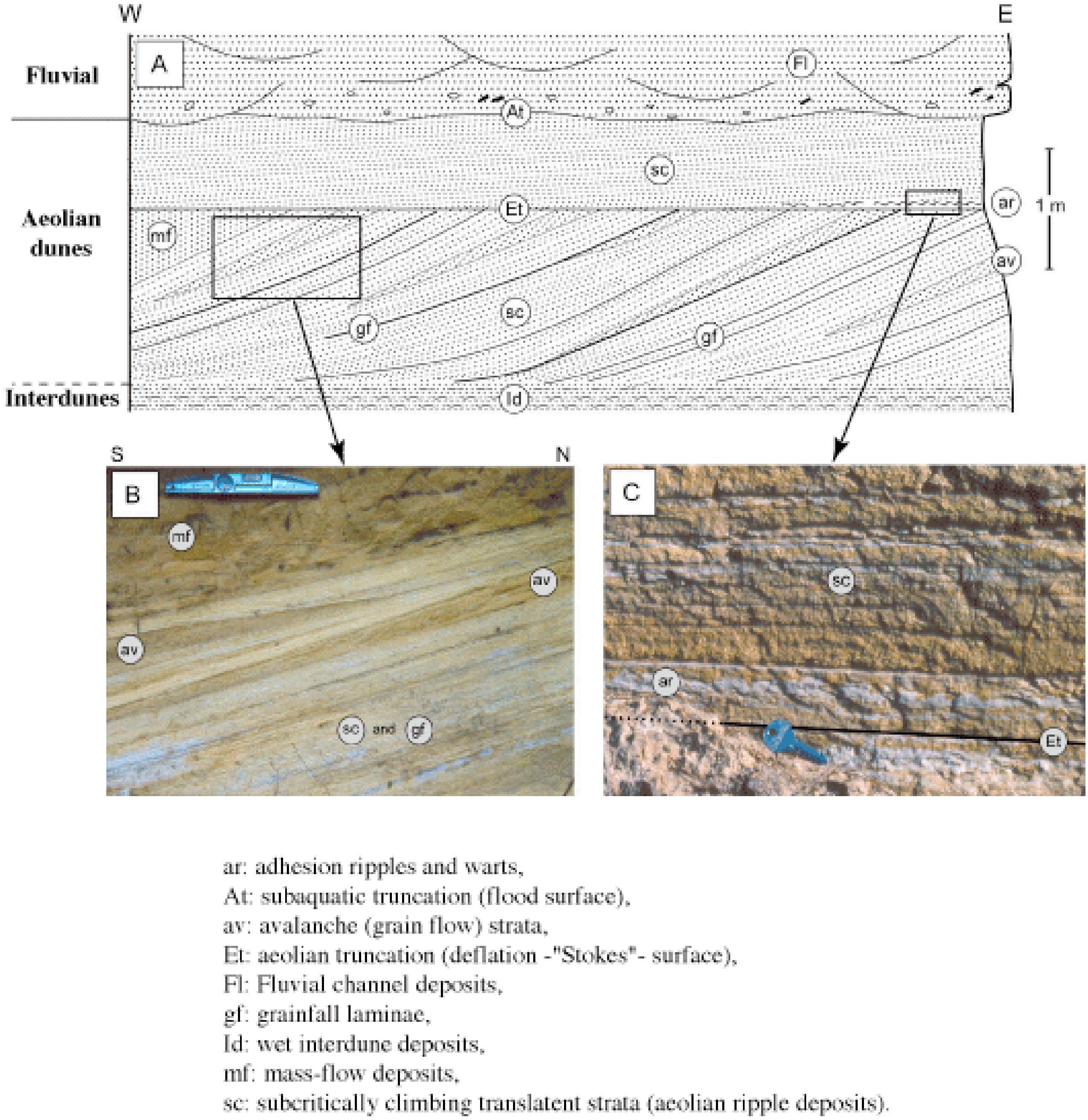



**Figure 10**: Aeolian dune facies observed within the 'Grès vosgien' Formation. (modified after Durand et al., 1994), A) General sketch of the outcrop, B) Nearly along-strike section through aeolian tabular set, C) Close-up of vertical section into the adhesion-wart level.

**Landscape reconstruction for the early Triassic (Middle Buntsandstein):** See Stop 1.1 for the landscape reconstruction and Fig. 3

**Stop 1.5 - Housseras ('Poterie lorraine' quarry): Middle Muschelkalk ('Couches rouges' Fm).**

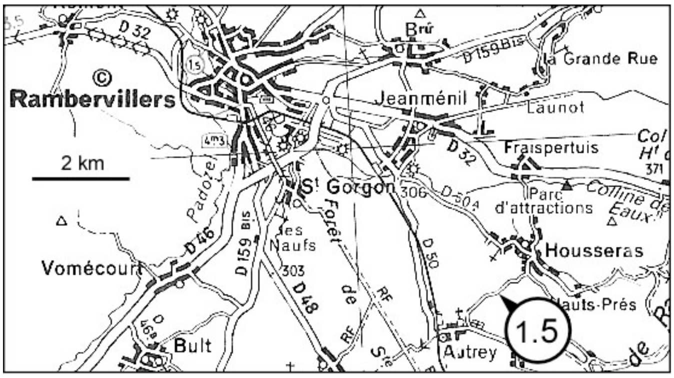



**Figure 11**: Location of the quarry of Housseras

**Figure 12**: Outcrop of the Housseras quarry

**Facies association**:

red and green clays with fine sandstone laminae, gypsiferous and dolomitic thin beds

**Depositional environment**:

coastal sebkha

For the origin of cubic hopper casts (halite 'pseudomorphs'), see Durand et al. (1989) and Hauschke (1989). In this area the Lower Muschelkalk is reduced to the 'Dolomie à Myophoria orbicularis', less than 1 metre thick.

# Day 2 — Wednesday, 04.10 2006

## Stop 2.1 - Dompaire-Racécourt (road cutting): Lower Keuper = Lettenkohle

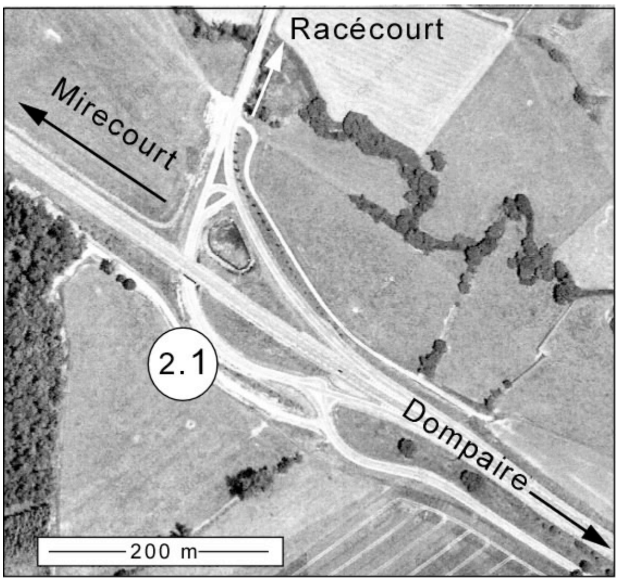



**Figure 13**: Location of the outcrop of Dompaire-Rarécourt

Very few sections of the Lettenkhole, badly exposed, can be seen en Lorraine at the moment. On this outcrop (Fig. 13) can be seen dolomite facies of its lower and upper parts, and grey to black fossiliferous shales of the Middle Lettenkhole, but bedding is partly obscured. The depositional conditions fluctuated from restricted marine to brackish environments (Fig. 14).

The age of the Lettenkohle Formation is well established in the eastern part of the basin (Fig. I.1): the Middle Lettenkohle is Upper Ladinan (Kozur, 1972; Adloff et al., 1984) and the 'Dolomie limite' is Lower Carnian (Kozur, 1972). These strata are equivalent to the Lettenkeuper deposits of the German Basin (Gall et al., 1977).

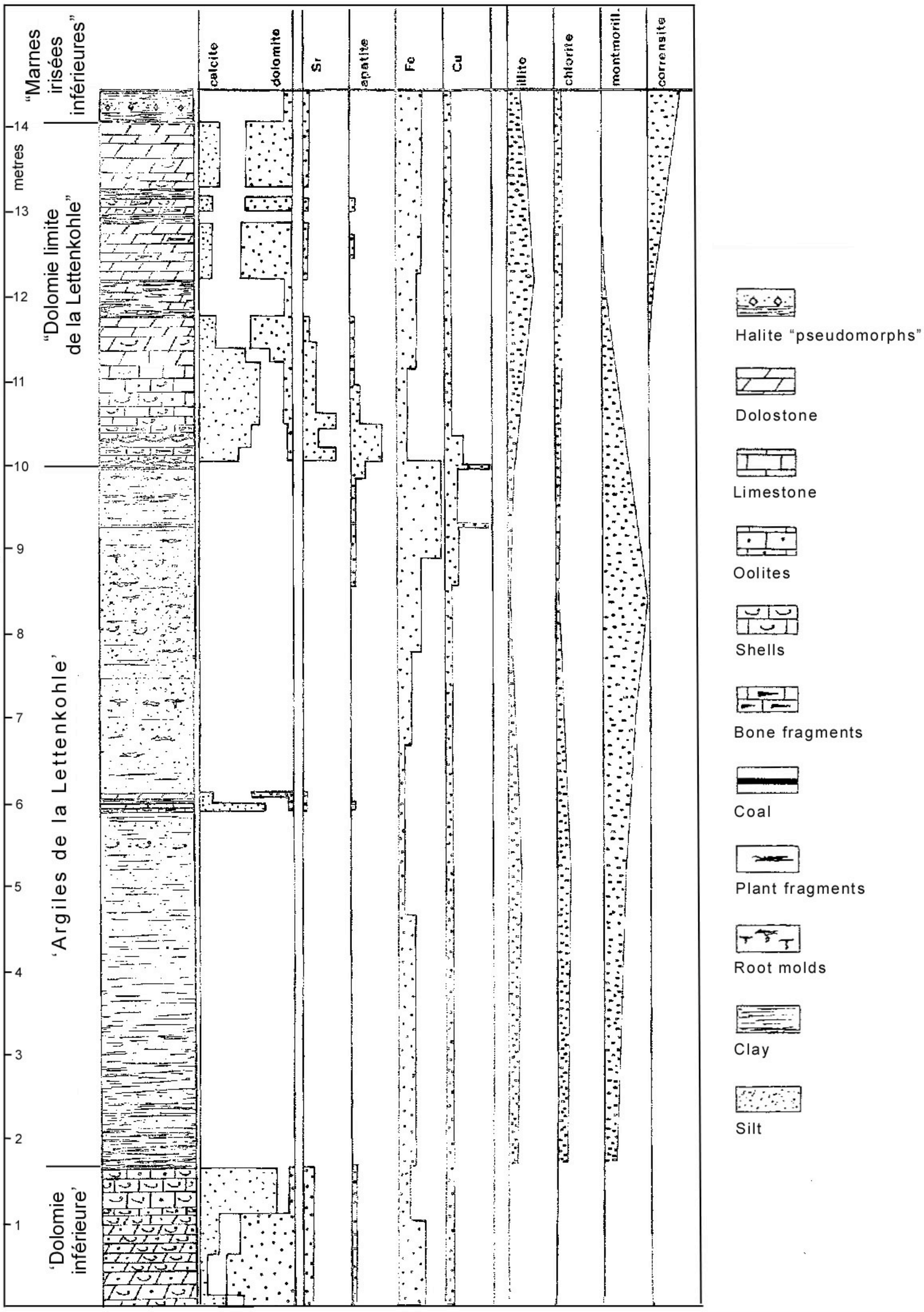



**Figure 14**: Sedimentological log of the Lettenkhole Formation in the area of Epinal (after Meyer, 1973 modified)

## Stop 2.2 - Relanges (quarry along D164 road): Middle Buntsandstein (‘Conglomérat principal’ and ‘Zone limite violette’ Fms)

At this outcrop (see p. 7 for location), the ‘Conglomerat principal' can be seen resting directly on the practically unweathered Varican basement (migmatites). It is overlain by the ‘Zone limite violette’ (ZLV) Formation (Fig. I.1, 15, 16, 17) which is characterized by the first development of Triassic palaeosols, here with development of dolomite nodules and chalcedonic crust (carnelian).

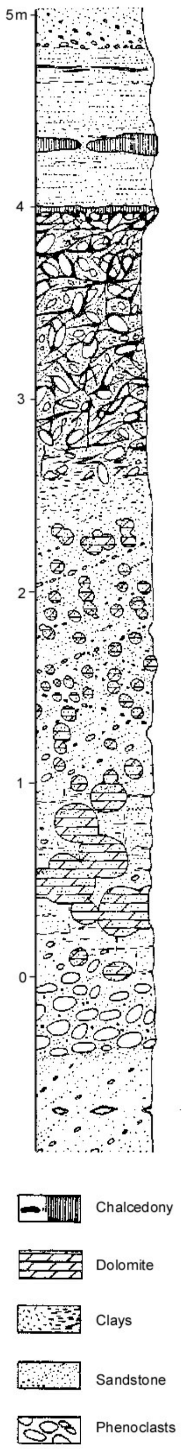



**Figure 16**: Sedimentological log of the ZLV (Durand and Meyer 1982)

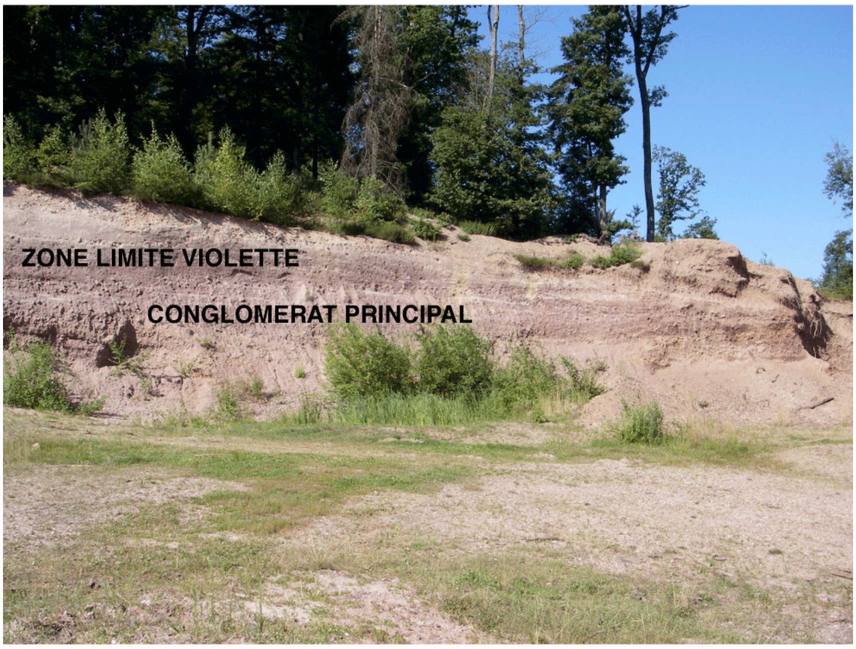



**Figure 15**: Outcrop of Redanges

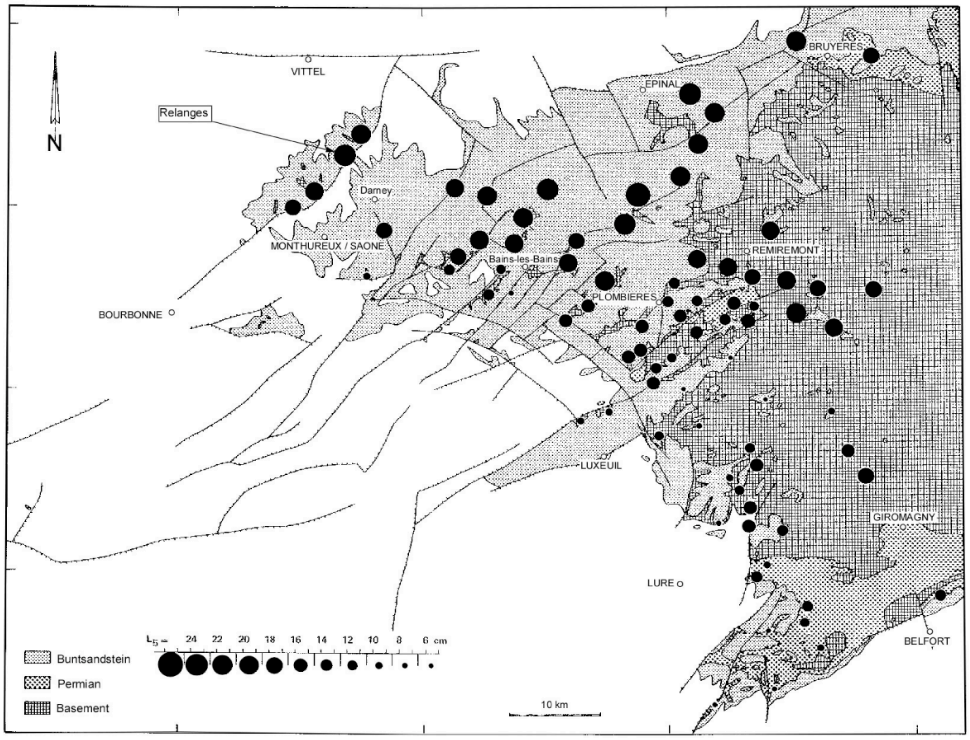



**Figure 17**: Mean lengh of the ten largest clast on outcrops of the’ Conglomérat principal’ in the souther Vosges (Durand, 1978)

## Stop 2.3 - Suriauville (road cutting): Lower Keuper (‘Dolomie de Vittel’ Fm= ‘Dolomie inférieure’ of the Lettenkohle)

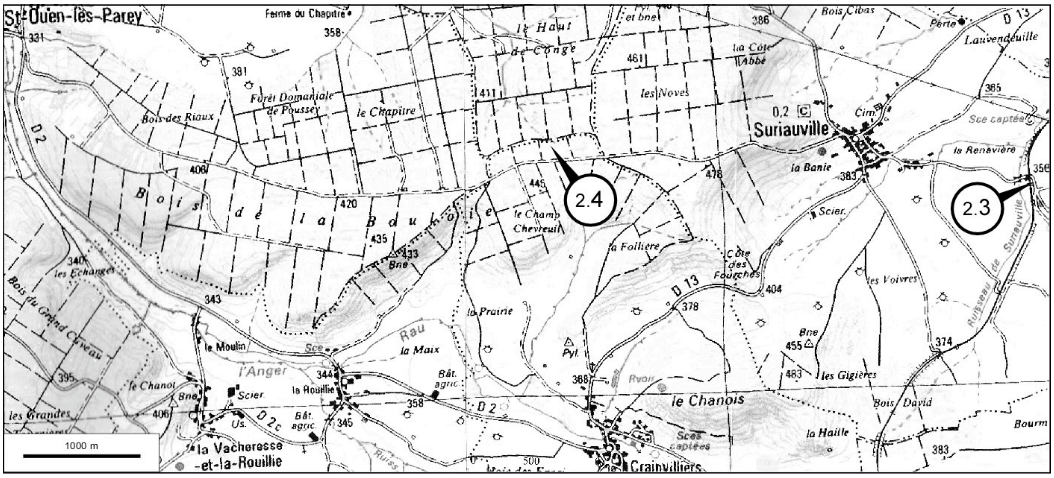



**Figure 18**: Location of the outcrop of Suriauville and Crainvilliers

This outcrop (Fig. 18) is attributed to the restricted marine environment of the ‘Dolomie inférieure’ of the Lettenkhole. In this area (south of Vittel), its lower boundary becomes difficult to place owing to a progressive dolomitization affecting finally, to the south (towards Burgundy) the whole 'Muschelkalk supérieur' (Fig. 19).

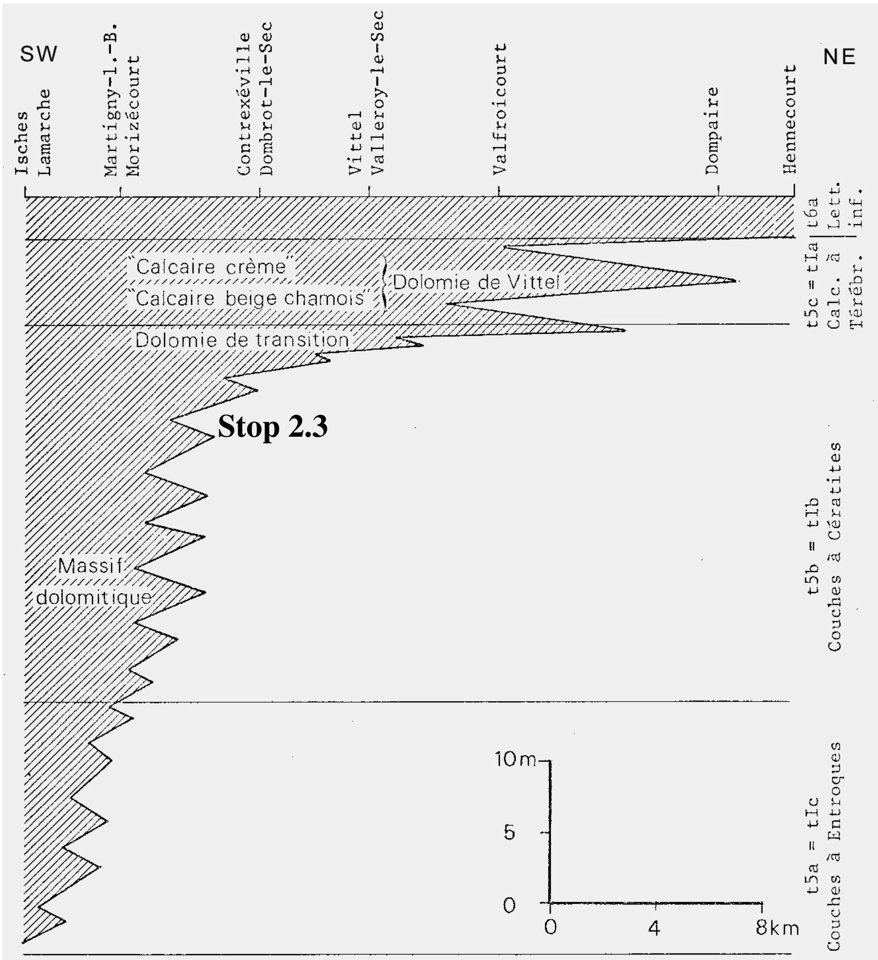



**Figure 19**: Diagramm showing the progressive dolomitization affecting finally the whole 'Muschelkalk supérieur' (Ainardi, 1976)

## Stop 2.4 - Crainvilliers (gullies in forest): Eo-Cimmerian unconformity ('Argiles bariolées dolomitiques' Fm / 'Grès à roseaux' Fm)

In this stop (Fig. 18), we show the Eo-Cimmerian unconformity (Fig. 20). The 'Argiles bariolées dolomitiques' Formation, deposited in a playa environment, overlays directly the alluvial facies of the 'Grès à roseaux' Formation (Fig. I.1). Erosional phases are recorded by the occurrence of one or two discontinuous layers (a few cm thick) of basal sedimenticlastic arenites, made up of claystone sand grains (and some coarse quartz) bounded by dolomite cement. This special facies was reworked in its turn, in the form of large intraclasts. For the interpretation of the stromatolite bed within the 'Argiles bariolées dolomitiques' Formation, see Arp et al. (2005)

The 'Argiles de Chanville' Fm were probably never deposited in this area because of the NW tilt of the basin (See Chapter and Figs. III.2, IV.1). Some confusions occur in this part of the basin, it seems that on the geological maps the dolomite beds of the 'Argiles bariolées dolomitiques' Formation have been attributed to the 'Dolomie de Beaumont'. In fact, the Eo-Cimmerian unconformity has never been observed before our well-log correlation (Bourquin and Guillocheau, 1993, 1996). Only the lack of 'Argiles de Chanville' was noted.

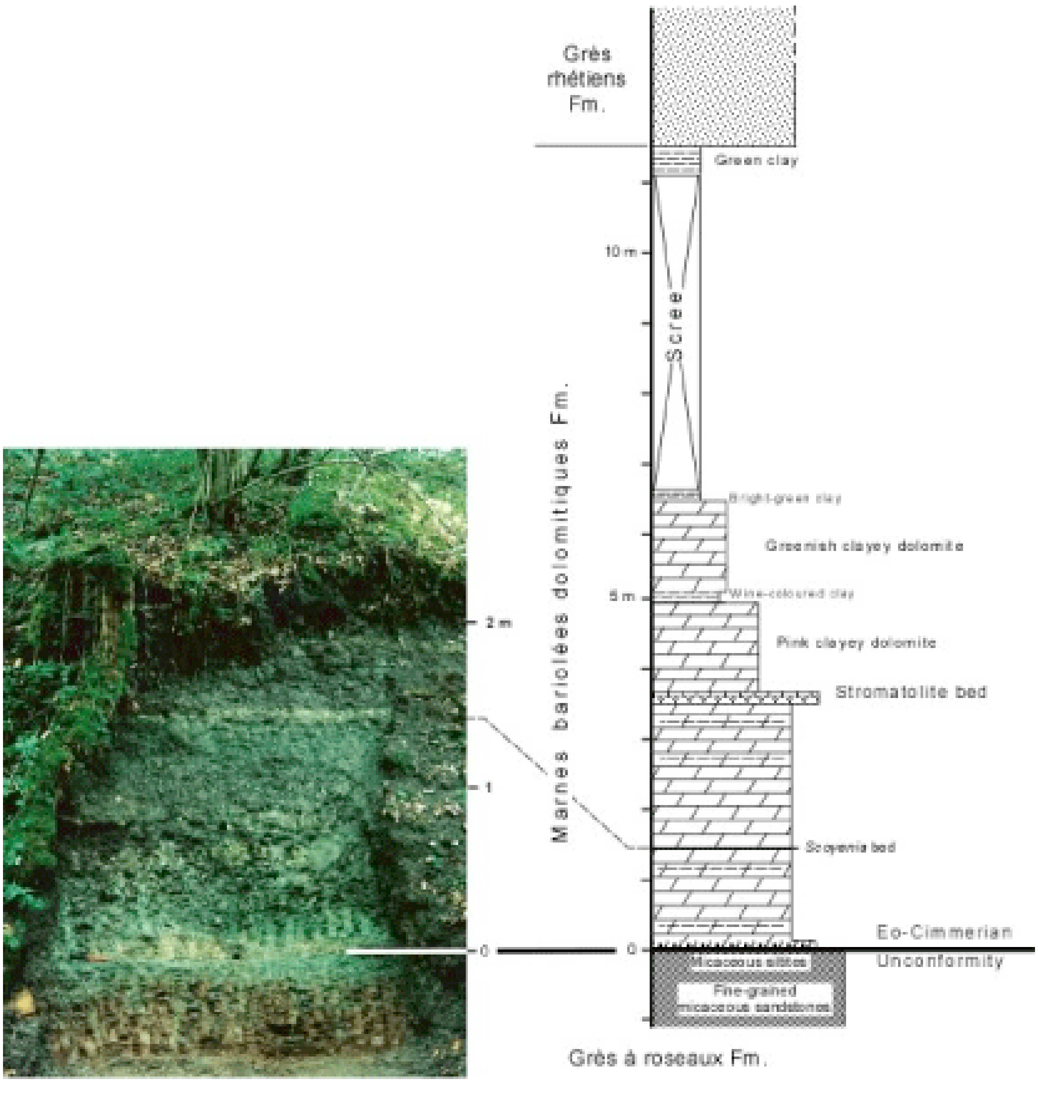



**Figure 20**: Sédimentological log of the Crainville outcrop with detail view of the Eo-Cimmerian unconformity

## Stop 2.5 - La Neuville-sous-Chatenois (old quarry): Upper Keuper ('Grès rhétiens' Fm)

This stop (Fig. 21) shows the 'Grès rhétien' deposited in restricted marine environment with some tidal influences. Near Gironcourt-sur-Vraine, 5 km to the NE, similar facies are overlain by black shales more than 1 metre thick (Fig. 22).

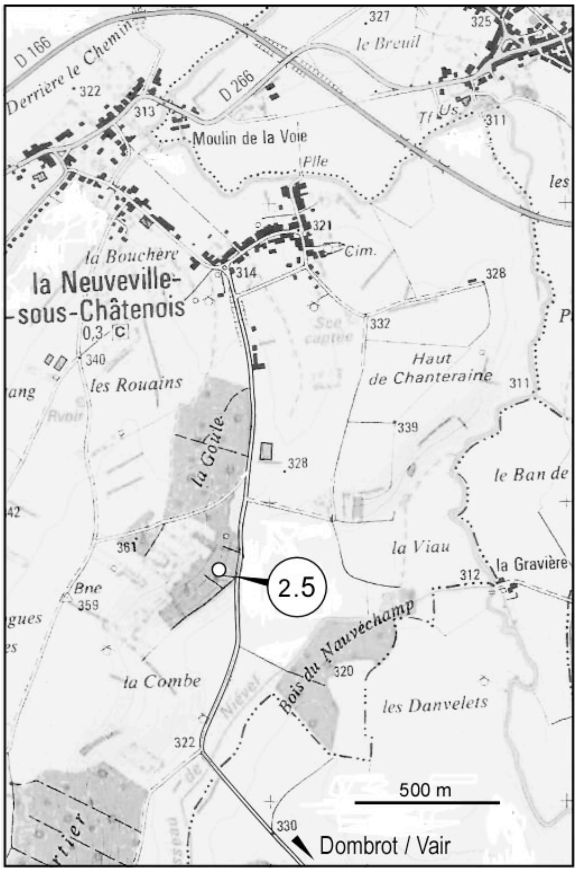



**Figure 21**: Location of the outcrop of La Neuville-sous-Chatenois


**Figure 22**: Detailed outcrop of the 'Grès vosgien' Fm located at Gironcourt/Vraine (near La Neuville-sous-Chatenois outcrop).

## Stop 2.6 - Poussay (D55 road cutting): Upper Keuper ('Argiles de Levallois' Fm and Triassic-Jurassic boundary)

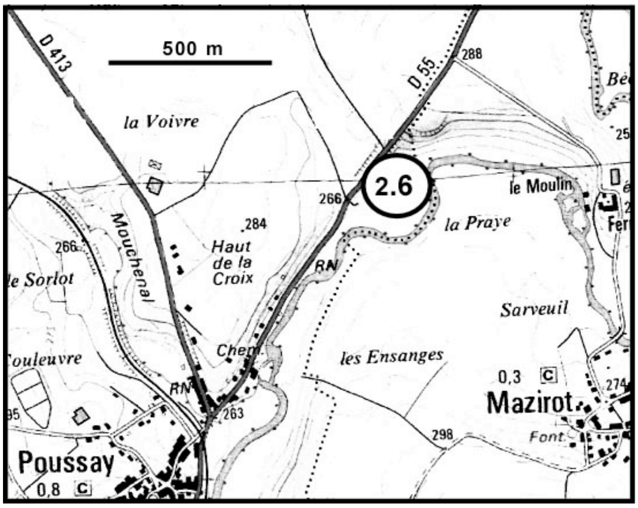



**Figure 23**: Location of the outcrop of Poussay

The 'Argiles de Levallois' Formation is made up exclusively of red clays, which yielded palynomorphs (Figs. 23, 24), and scarce conchostracans (*Eustheria minuta brodieana*) and ostracods (*Hungarella*); they are interpreted as lacustrine deposits subsequently subjected to an emerging. Here the uppermost part of the 'Grès rhétiens' Fm. is represented by black shales, similar to those found below, and the boundary between the two formations is transitional.

The first Jurassic formation (Hagemann, 1967, Hanzo et al., 1990, Rauscher et al., 1995): 'Calcaire à gryphées' (Hettangian-Sinemurian), where grey fossiliferous limestones and marls are interbedded, begins with a marly bed, 40 cm thick, devoid of macrofauna ('zone de transition'). Foraminifer study indicates that the Hettangian Stage is reduced here to about 1.5 m in thickness.

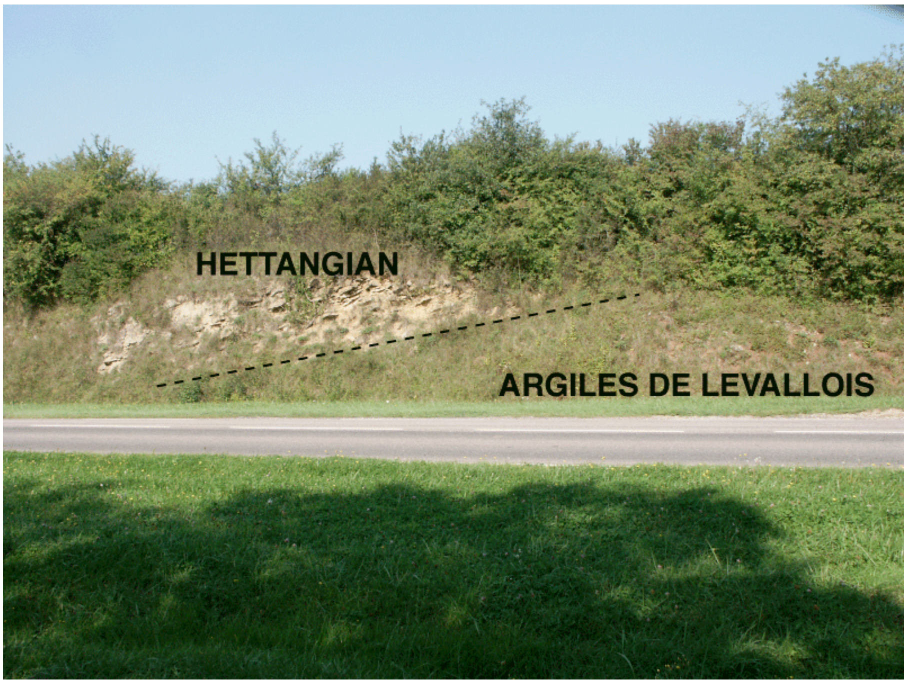



**Figure 24**: Outcrop of Poussay showing 'Argiles de levallois'Formation.

## Stop 2.7 - Florémont (N57-E23 road cuttings): Middle Keuper ('Marnes irisées moyennes' and 'Marnes irisées supérieures' Fms, with Eo-Cimmerian unconformity)

In the first part of the outcrop (noted 2.7a, Fig. 25), the three units of the 'Marnes irisées moyennes' can be sampled: 'Grès à roseaux', 'Argiles bariolées intermédiaires' and 'Dolomie de Beaumont' Fms.

At the second point (noted 2.7b, Fig. 25), the Eo-Cimmerian unconformity (Fig. III.2, IV.1) can be observed, from the other side of the main road, between the anhydrite sebkha deposits of the 'Argiles de Chanville' Fm and the dolomite playa deposits of the 'Argiles bariolées dolomitiques' Fm (Fig. 26). The basal dolomite bed of the latter is, as in many other places in south Lorraine, the only one displaying many quartz sand grains, about 1 mm in diameter and orange-to-pink coloured. They are coarser than those found in the 'Grès à roseaux'

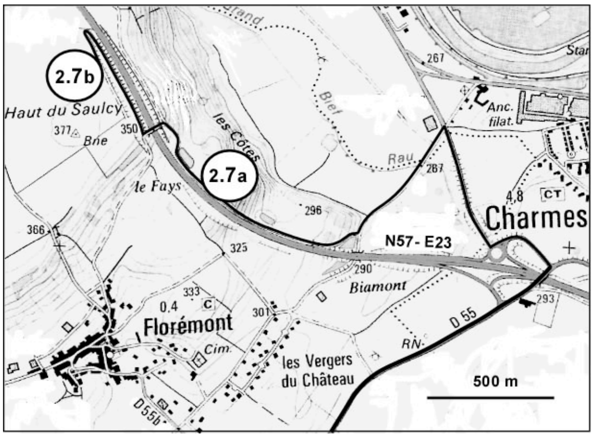



**Figure 25**: Location of the outcrop of Florémont

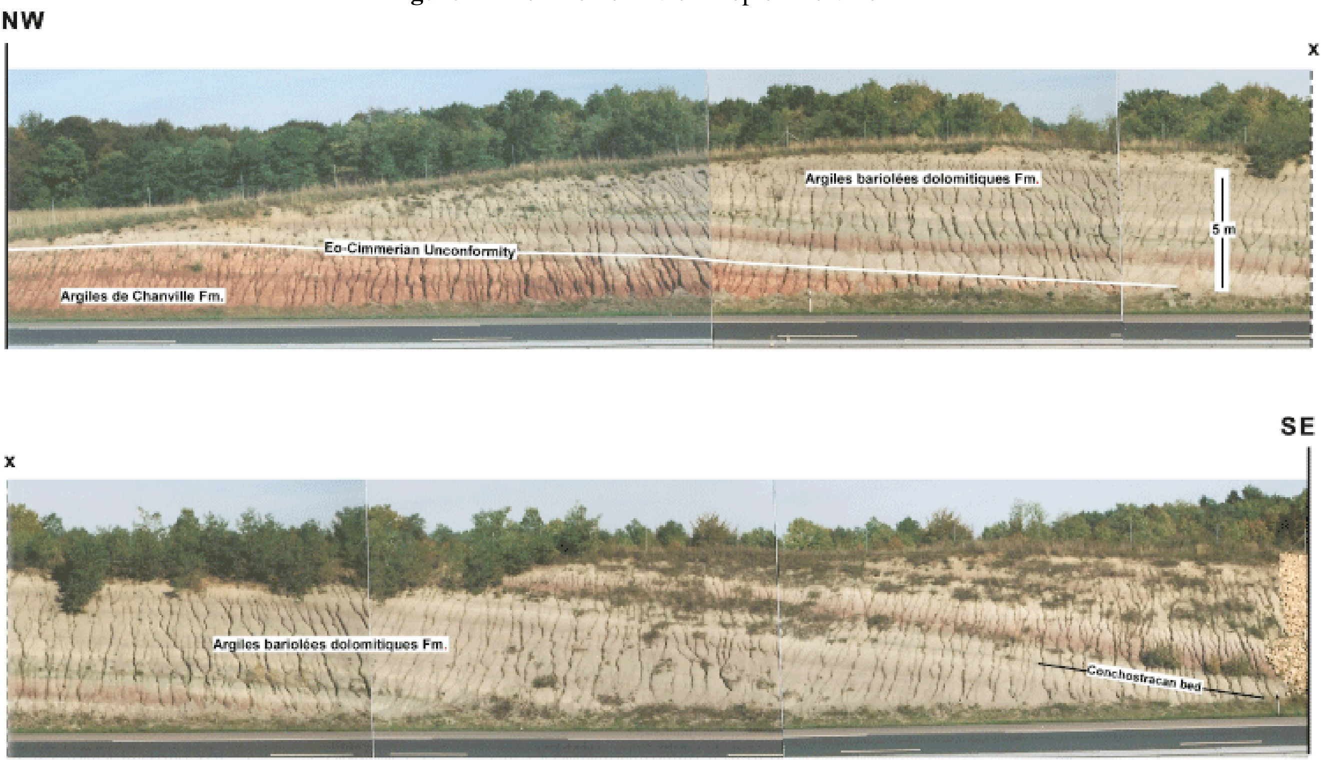



**Figure 26**: Panorama of Florémont outcrop showing the Eo-Cimmerian unconformity between the 'Argiles de Chanvilel and the 'Argiles bariolées dolomitiques' formations.

## Stop 2.8 - Xirocourt (S.R.D.E. quarry): Middle Keuper ('Dolomie de Beaumont' Fm)

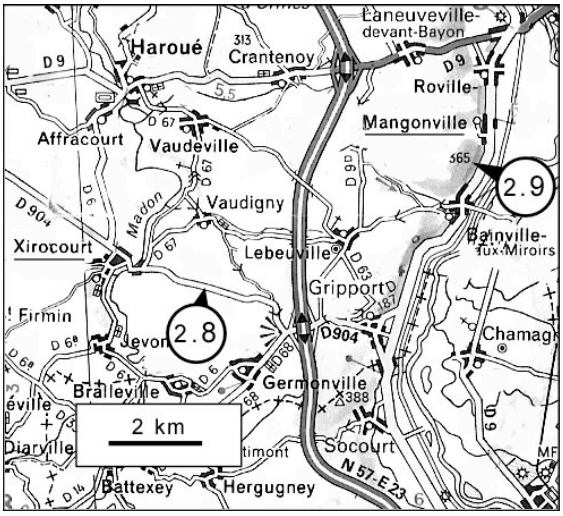


**Figure 27**: Location of the outcrop of Xirocourt and Mangonville

In this quarry (Fig. 27), the 'Dolomie de Beaumont' can be seen in its whole thickness (about 8 m), between the 'Argiles bariolées intermédiaires' and the 'Argiles de Chanvilles' (Fig. I.1). The 'Dolomie de Beaumont' is characterized by homogeneous microcrystalline dolomite layers with sometimes:

- very thin lenses with marine fossils (*Costatoria goldfussi*, gastropods or ophiurids)
- current structures
- small sulfate dissolution cavities

This facies was deposited in a lacustrine environment ('Coorong' type). The presence of current structures, and the occasional introduction of exotic shells as well as marine water, attest high-hydrodynamics events within the calm environment, which can be attributed to storms.

In this outcrop the deformations of dolomite layers induced by salt dissolution in the 'Marnes irisées inférieures' are spectacular (Fig. 28). The 'Argiles de Chanville' overlain the dolostones.

**Figure 28**: Detail view of the deformations of dolomite layers induced by salt dissolution in the 'Marnes irisées inférieures' (Xirocourt quarry).

## Stop 2.9 - Mangonville (old gypsum quarry): Middle Keuper ('Formation salifère')

**Figure 29**: Detailed view of the Mangonville quarry (Fig. 28).

In this old gypsum quarry can be studied the sebkha deposits of the 'Formation salifère' with red, green and black clay layers. Gypsum appears as nodular masses, of various size and more or less coalescent, and as secondary veins crossing several strata (Fig. 29).

# Day 3 — Thursday, 05.10.2006

## Stop 3.1 - Saint-Hubert (old quarries and road cut): Upper Keuper ('Grès rhétiens' Fm)

This locality allows to study two particular facies of the 'Grès rhétien' Formation.

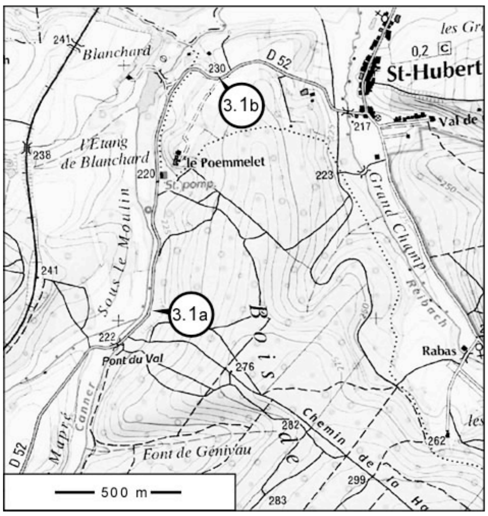



**Figure 30**: Location of the outcrop of Saint-Hubert

The first one crops out in old quarries (noted 3.1a, Fig. 30) with a thickness of about 10 m, and constitutes three superposed units of homogeneous sandstone, with some rare stratification. This could be attributed to shoreface or offshore tidal bars.

In the second outcrop (noted 3.1b, Fig. 30), tidal rhaetian sandstones are incised by a little channel filled with well rounded siliceous pebbles (white quartz and dark 'cherts') and platy black clay intraclasts (Fig. 31). This structure could be attributed to a storm channel, which carried out the detrital material from the coastal plain. Probably coeval deltaic deposits were described at Kédange, 8 km to the north (Hendricks (1982)

**Figure 31**: Outcrop of Saint Hubert (noted 3.1b, Fig. 30) and detailed view of tidal rhaetian sandstones are incised by a little channel filled.

## Stop 3.2 - Hombourg-Budange (D978 road cutting): Middle Keuper ('Dolomie de Beaumont' Fm, marginal facies)

This stop (see p. 7 for location), which exposes a particular facies of the 'Dolomie de Beaumont' Formation, makes possible to realize that the disappearance of the 'Dolomie de Beaumont' in the region of Thionville corresponds to a primary pinching out (Fig. 32). Laterally to the north, only two discontinuous dolomitic levels crop out within red clays. This marginal facies characterizes the northward ending of playa-lake deposits. In this part of the basin the Eo-Cimmerian unconformity doesn't eroded the 'Dolomie de Beaumont' Fm but occur above the 'Argiles de Chanville' Formation, which are well developed (Fig. III.2, IV.1).

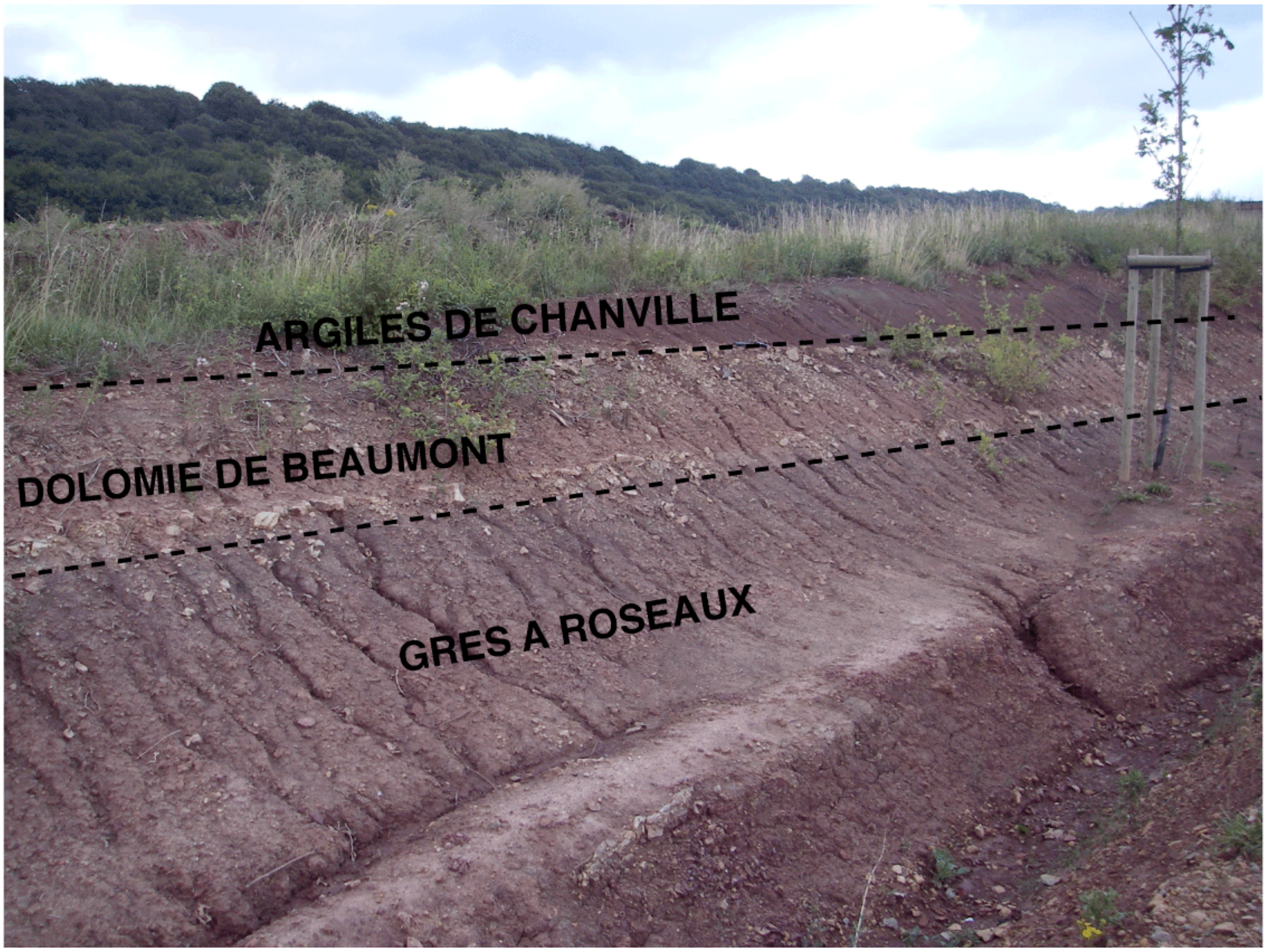



**Figure 32**: Outcrop of Hombourt-Budange showing a pinching out of the 'Dolomie de Beaumont' Fm in the region of Thionville

## Stop 3.3 - Kemplich (old gypsum quarry): Middle Keuper ('Marnes irisées supérieures' Fm, with Eo-Cimmerian unconformity)

In this stop (see p. 7 for location), the Eo-Cimmerian unconformity eroded a gypsum bed that could be equivalent to the Heldburg Gypse (Fig. 33).

Between the SE part of the basin to the NE the 'Argiles de Chanvilles' Fm is more and more developed (Fig. III.2), but less developed than in the centre part of the Paris Basin, where thicker anhydrite formation occur.

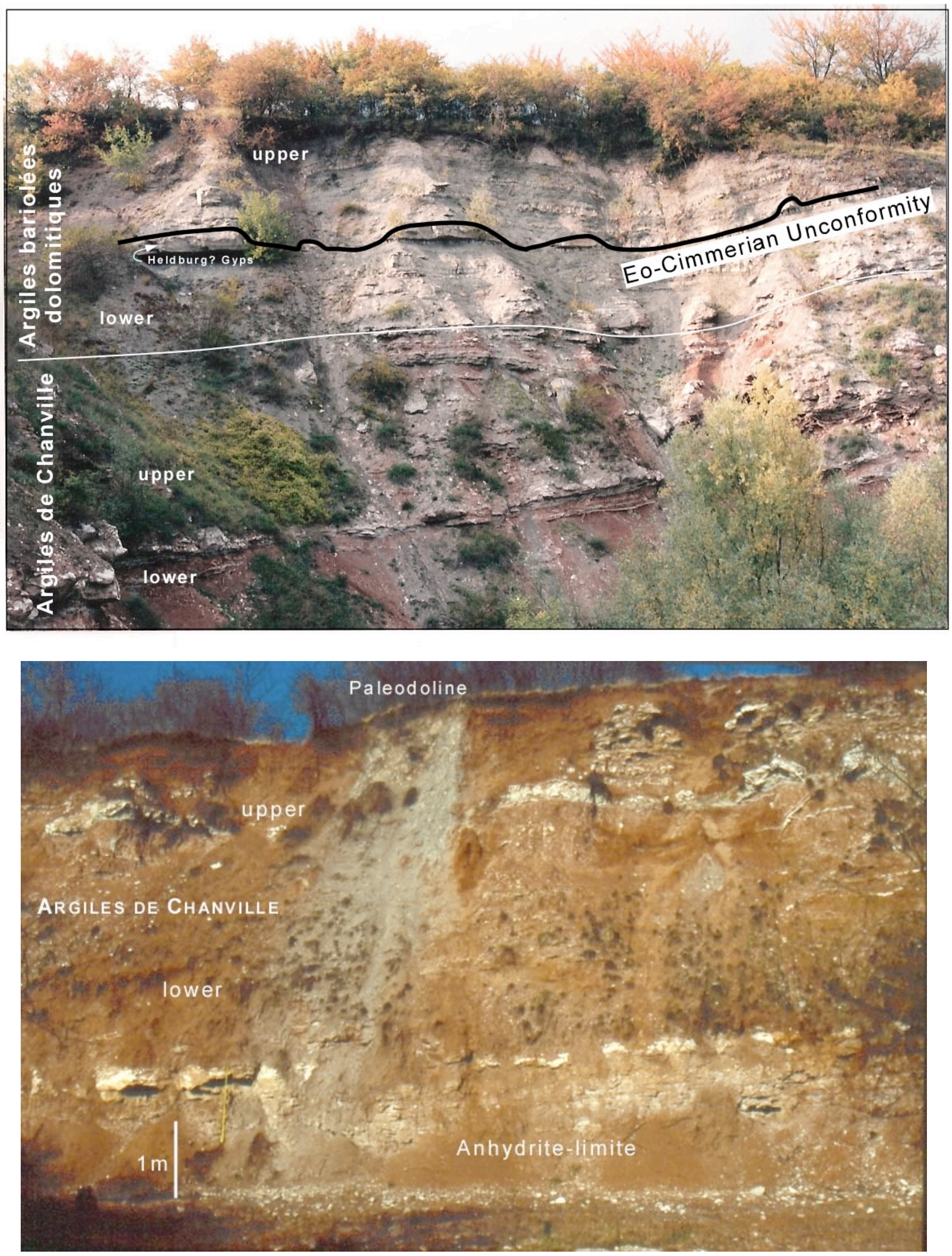



**Figure 33**: Outcrop of the old gypsum quarry of Kemplich showing the Eo-Cimmerian unconformity at its top and paleodoline at its base.

## Stop 3.4 - Rémelfang: Middle Keuper (basal part of the 'Grès à roseaux' Fm.)

**Figure 34**: Outcrop of the basal fluvial deposits of 'Grès à roseaux' Formation at Rémelfang (see p. 7 for location).

## Stop 3.5 - Helstroff (D19 road cutting): Uppermost Muschelkalk (‘Calcaire à cératites’ and dolomitized ‘Calcaire à térébratules’ Fms)

In this stop (see p. 7 for location), the upper part of the ‘Calcaires à cératites’ display a tempestite bed overlain by small *Placunopsis* reefs (Fig. 35). The top of the outcrop shows the ‘Calcaire à térébratules’ Formation. This characterizes an evolution from upper offshore to shoreface environments. The 'Calcaire à térébratules' is here pervasively dolomized and was thus included in the Lettenkohle on the "official" geological map.


**Figure 35**: Outcrop of Helstroff and detailed view of the tempestite bed overlain by small *Placunopsis* reefs.

## Stop 3.6 - Saint-Avold (N3 road cutting): Middle Buntsandstein ('Conglomérat principal' and 'Zone limite violette' Fms)

The basal contact of the 'Conglomérat principal' on the 'Grès vosgien' (Karlstal facies) is very even (Fig. 36). Like at Relanges (Stop 2.2), the conglomerate is overlain by the 'Zone limite violette' (ZLV) Formation which contains dolomite nodules and carnelian.


**Figure 36**: Outcrop of Saint Avold (see p. 7 for location).

## Stop 3.7 - Sankt-Arnual (cliffs in Stiftswald): Upper Buntsandstein ('Couches intermédiaires' Fm.)

This outcrop (Fig. 37) of the 'Couches intermédiaires' Formation has been described by Dachroth (1972) (Fig. 38). This formation overlain the 'Grès vosgien' (Karlstal facies, Fig. II.3, II.4). The cliffs shows several levels with paleosols ('violet zones') which display nearly the same characteristic than the 'Zone limite violette', but carnelian is lacking. The sandstones (that contains at lot of feldspar) and conglomeratic facies where mainly deposited as 3D and 2D megaripples forming longitudinal and transversal bars. The paleocurrents are mainly oriented to the NE. The depositional environment is attributed to low sinuosity rivers, within a semi-arid to sub-humid environment (temporary lakes or ponds) like attests the presence of hydromorphic sols. Even if some paleosols have the same expression as the 'Zone limite violette', this formation seems not to be present in these outcrops.

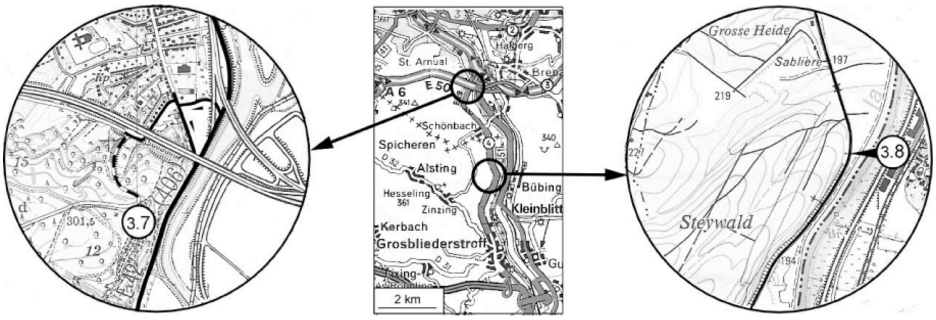



**Figure 37**: Location of the outcrops of Sankt-Arnual and Grosbliederstroff

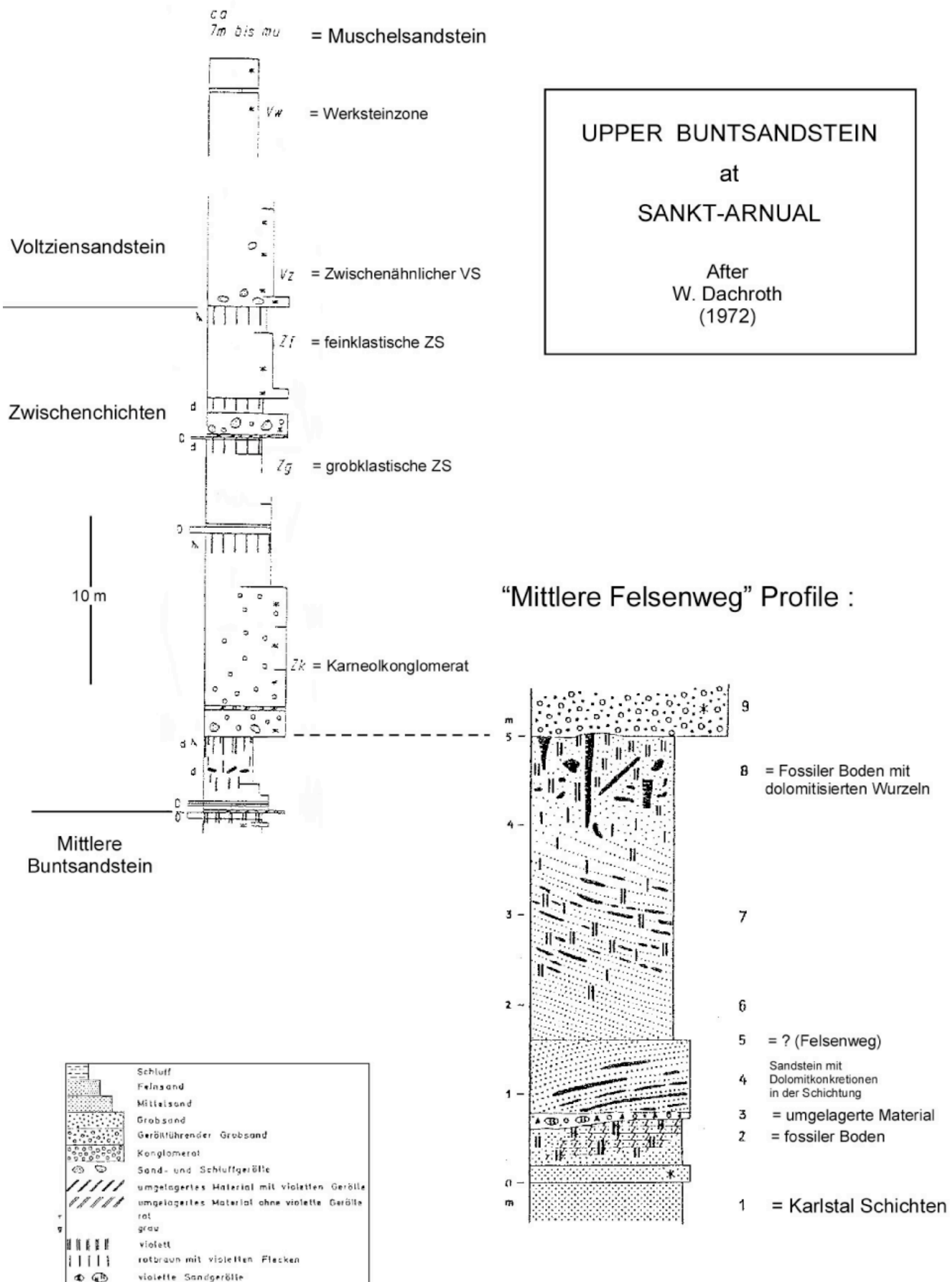



**Figure 38**: Sedimentological log of the 'Couches intermédiaires' Formation in Sankt-Arnual outcrop (after Dachroth (1972).

## Stop 3.8 - Grosbliederstroff (N61 road cutting): Hardegsen unconformity (between Middle and Upper Buntsandstein)

The Hardegsen unconformity (Fig. III.2, III.3, III.4) is well marked in this outcrop (Fig. 37). The 'Grès vosgien' Formation is truncated by channel like structures filled with conglomerate facies (Fig. 39). This conglomerate facies is attributed to the 'Conglomérat de Bitche', very different of the 'Conglomérat principal'; it contains 'Conglomérat principal' pebbles mixed with pedogenic carbonate and carnelian pebbles reworked from the 'Zone Limite Violette'. In some places this conglomerate is completely lacking, and the 'Couches intermédiaires' Fm rests directly above the 'Grès vosgien' separated by the Hardegsen unconformity. The two formations can be easily distinguished by the systematic presence of micas, numerous (and sometimes very coarse) feldspars and subangular quartz grains in the 'Couches intermédiaires' Fm.

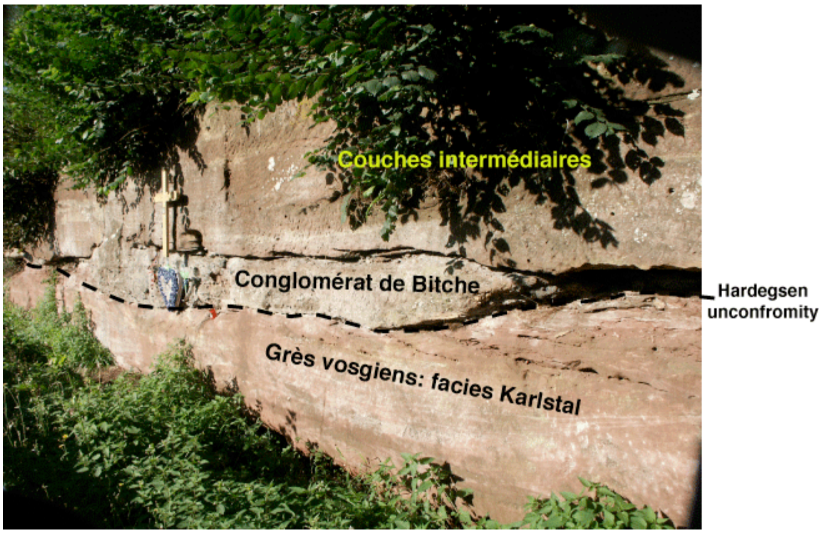



**Figure 39**: Outcrop of Grosbliederstroff and detailed view of the channel like structures filled with conglomerate facies which truncated the 'Grès vosgien' Formation

# Day 4 — Friday, 06.10.2006

## Stop 4.1 - Weiskirch: Lower Muschelkalk ('Grès coquillier' Fm, with ball-and-pillow structures)

A particular structure is observed in the 'Grès coquillier' Fm (Table 1): ball and pillow (Figs. 40, 41). This is a particular load-cast structure, which occurs on the lower surfaces of beds of sandstones interbedded with mudstone, and forms pseudonodules in the sandstone facies. In some case, there is no sign of an overlying sandstone and the isolated pseudonodules 'float' in the mudstones (Collison and Thomson, 1993).

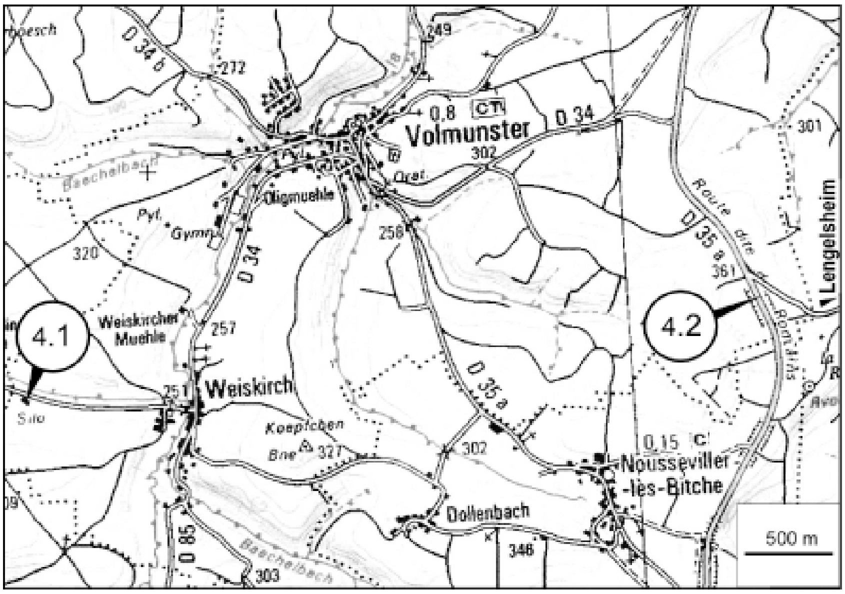


**Figure 40**: Location of the outcrops of Weiskirch and Volmunster-Lengelsheim


**Figure 41**: Outcrop of Weiskirch and detailed views of the ball and pillow structures of the 'Grès coquillier' Fm.

## Stop 4.2 - Volmunster-Lengelsheim: Lower Muschelkalk (‘Volmunster’ Formation, Wellenkalk facies)

The Volmunster Formation (Figs. 40, 42) encompasses the major part of the Lower Muschelkalk described in this area by Schumacher (1890), with the exception of the basal 'Grès coquillier' and the 'Dolomie à Myophoria orbularis' at the top (Fig. 43). In many places lithology evolves upwards, more or less progressively, from clays and marls to dolostones and limestones. The particular structure of the 'Wellenkalk facies' ('calcaire ondulé'), rather badly exposed here, results not only from depositional processes but also from synsedimentary seismic activity (Schwarz, 1975).

**Figure 42**: Outcrop of Volmunster-Lengelsheim.

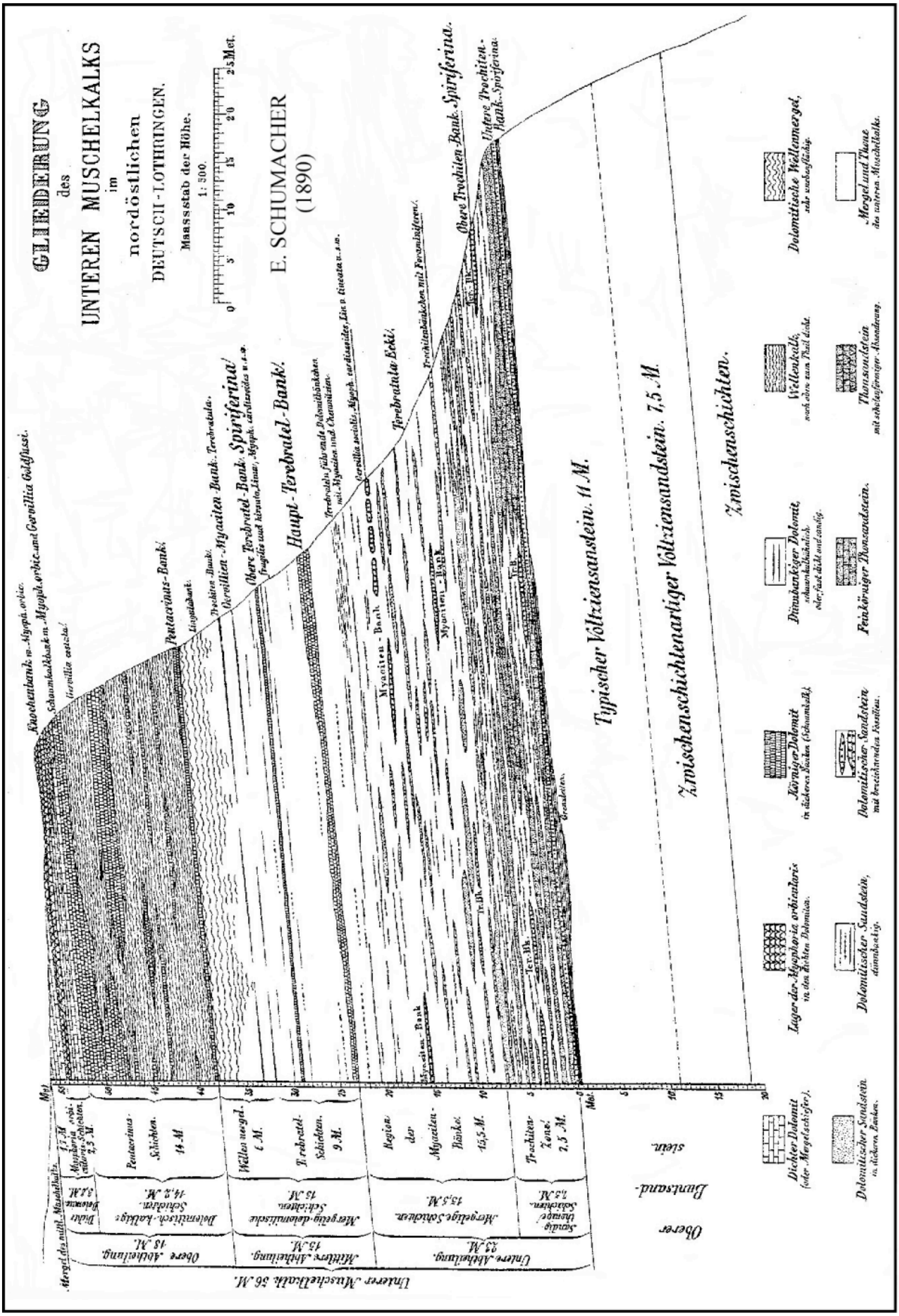



**Figure 43**: Lower Muschelkalk description in the Volmunster-Lengelsheim area by Schumacher (1890).

## Stop 4.3 - Bitche (N62 road): Hardegsen unconformity (between Middle and Upper Buntsandstein)

In this outcrop (Fig. 44), the 'Grès vosgien' Fm is directly overlain by the 'Couches intermédiaires' Fm (Fig. 45) which displays several pedogenic horizons ('violet zones') like at the stop 3.7. The Hardegsen unconformity, with a wide channel-like shape, can be observed between these two formations. A very different interpretation (Fig. 46) was proposed by Bock et al. (2001).

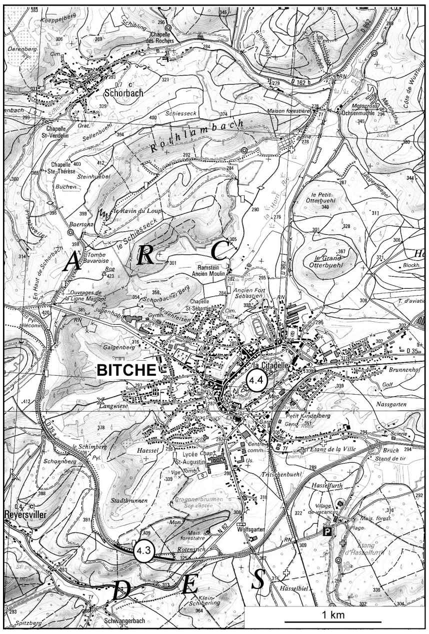



**Figure 44**: Location of rhe two outcrops of Bitche

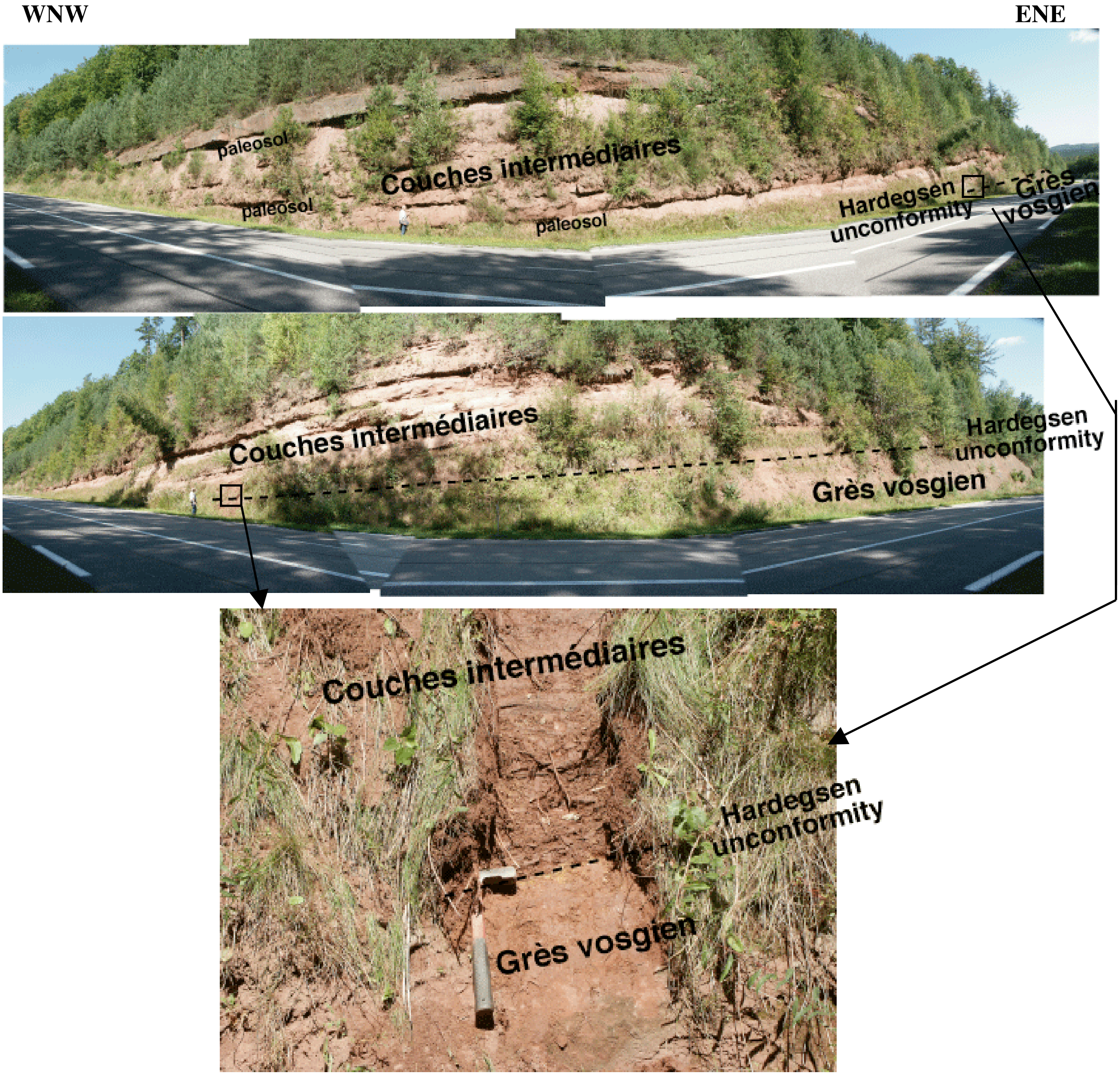



**Figure 45**: The Hardegsen unconformity at the south Bitche outcrop: in general view and in detail.

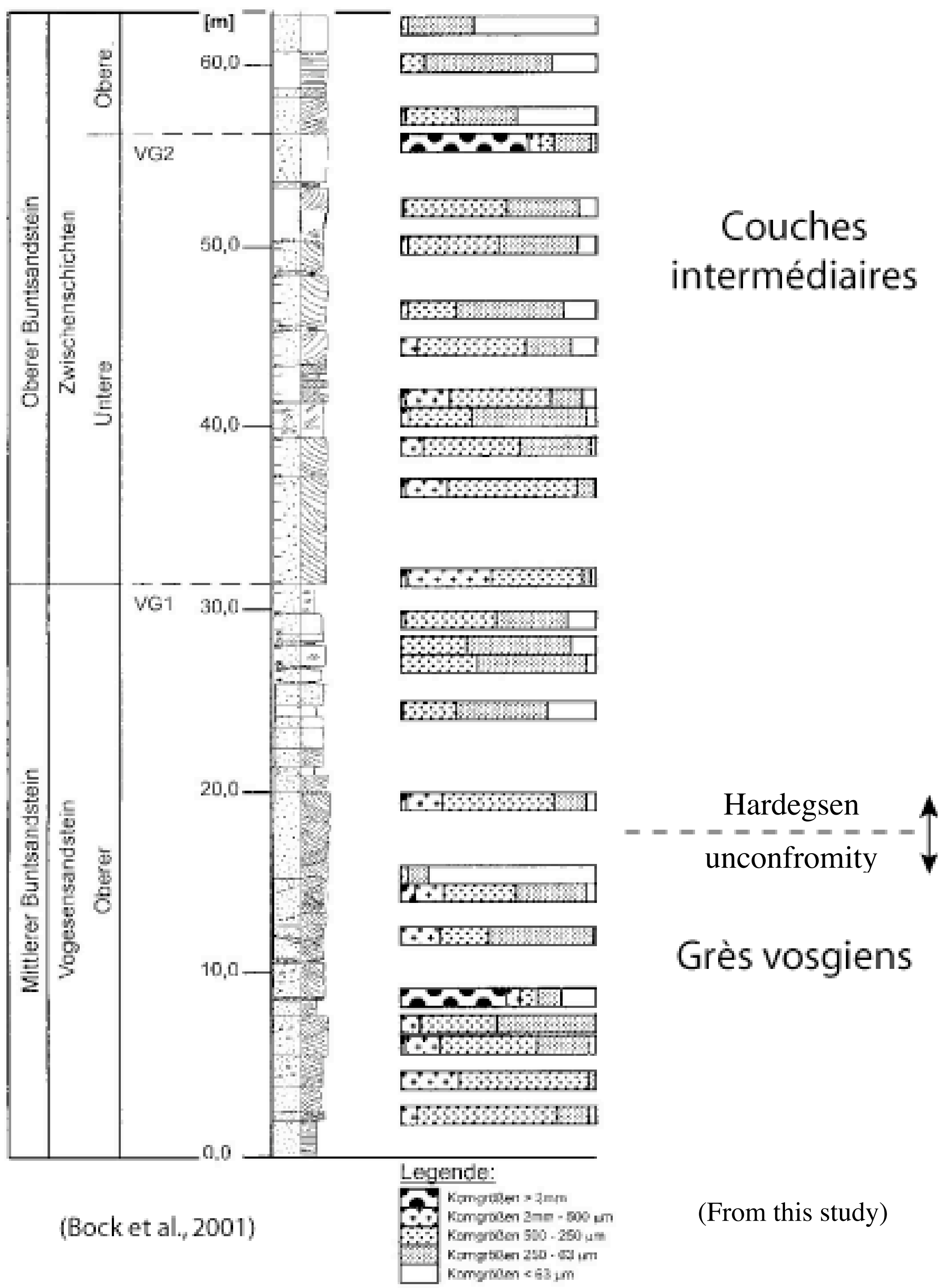



**Figure 46**: Sedimentary log of Bitche (Stop 4.3) by Bock et al. (2001) which differs from our observations. VG1 and VG2 are paleosol key-beds defined by Müller (1954)

**Stop 4.4 - Bitche (Citadel): Middle Buntsandstein (Karlstal facies of the 'Grès vosgien' Fm)**

In this outcrop (Fig. 44), the Karlstal facies of the 'Grès vosgien' Formation are well exposed (Fig. 47). These facies are characterized by fluvial and aeolian deposits.

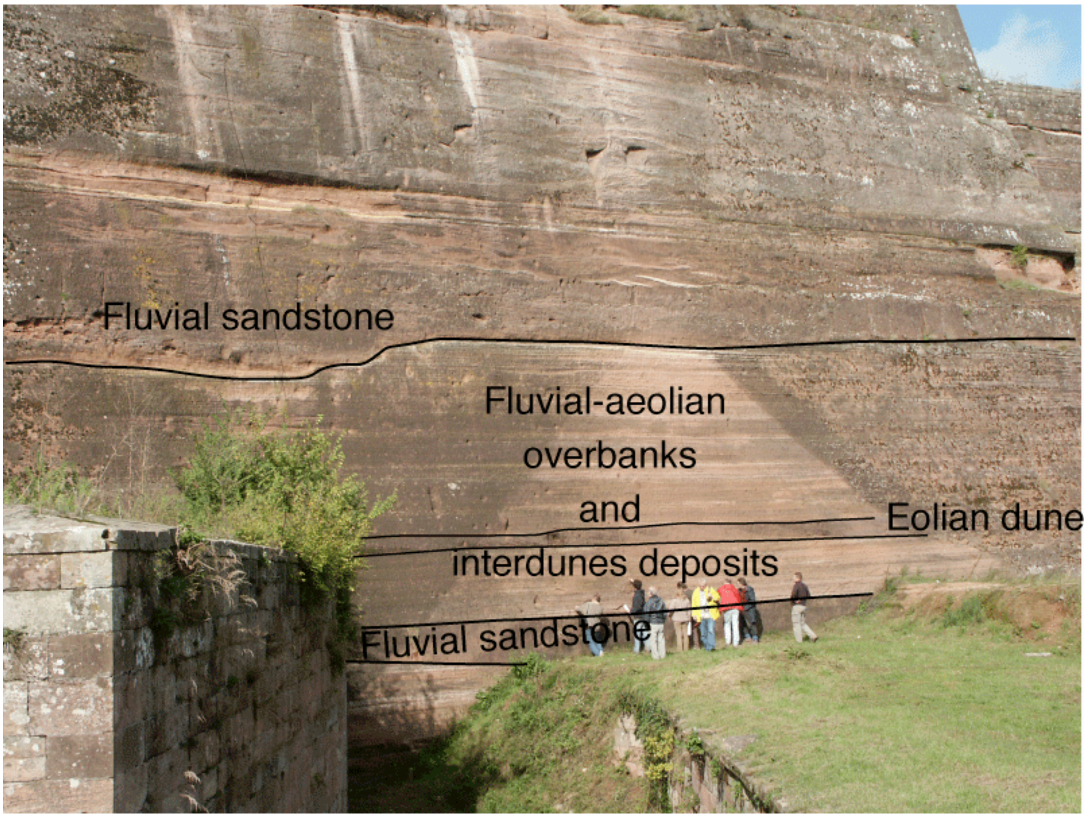



**Figure 47**: Outcrops of Bitche Cidatel.

### Facies association: Fluvio-aeolian overbank environments

This facies association is observed in the upper 'Grès vosgiens' Formation, so-called the Karlstal Formation (Fig. II.3, II.4). This association is very sandy and characterized by vertical pattern, from the base to top (defined on the cores of the Soultz-sous-Forêts well):

- planar laminated sands containing cm-thick coarse sand layers,
- cm-thick planar laminations of fine to medium sand, that sometimes grade upward into oscillatory ripples
- laminated silstones, or fine sandstones, along with red mudstones, sometimes bioturbated.

These facies can be more or less bioturbated. They form fining-upward sequences ranging in thickness from dm up to 5 m, with frequent mud-crack structures at their top. Locally, aeolian facies can be interbedded within these deposits. The first facies, interpreted as fluvial sheet flood deposit evolves vertically into wave-ripple facies that suggest flood currents entering a subaqueous environment, a hypothesis supported by the occurrence of bioturbation. The interbedded aeolian sand sheets, sometimes bioturbated, and mud-crack structures indicate frequent subaerial exposure. The occurrence of sheet flood deposits, aeolian sand-sheets and mudcracks in fine-grained sediments point to an ephemeral hydrologically-closed lake formed under arid condition (Rogers and Astin, 1991). This facies association characterizes fluvio-aeolian overbank environments.

## Stop 4.5 - Niedersteinbach (forest trail): Permian ('French Lower Buntsandstein' ('Grès d'Annweiler' Fm.) on Rotliegends)

In this outcrop (See p. 7 for location), just at the western end of Niedersteinbach, the 'French Lower Buntsandstein' is represented by the 'Grès d'Annweiler'. In the region of the eponyme locality, north of Wissembourg, the basal part of the formation yielded a marine malacofauna typical of the Zechstein I; thus the 'French Lower Buntsandstein' is Permian in age. The lithofacies are very similar to those of the 'Couches intermédiaires'.

## Stop 4.6 - Fleckenstein Castle: 'Grès d'Annweiler' Fm. and Trifels facies of the 'Grès vosgien' Fm

The lowermost fluvial conglomerate facies association is located at the base of the Lower Triassic, characterizing the 'Conglomérat basal' Formation. This formation, well observed on well-logs, overlies the basement and is located in the western part of the basin. It is diachronous and represents the landward equivalent of the 'Grès vosgiens' Formation (See stop 1.4). It corresponds to more proximal braided-river deposits, that evolve in space (laterally, i.e. eastwards) and time (vertically) into braided river of the 'Grès vosgiens' Formation.

In this outcrops (See p. 7 for location, Fig. 48), the 'Grès vosgiens' Formation shows typical fluvial facies (see Stop 1.1) and in its upper part aeolian deposits (Fig. 49) well preserved between to fluvial episods (see stop 1.4 for facies description).

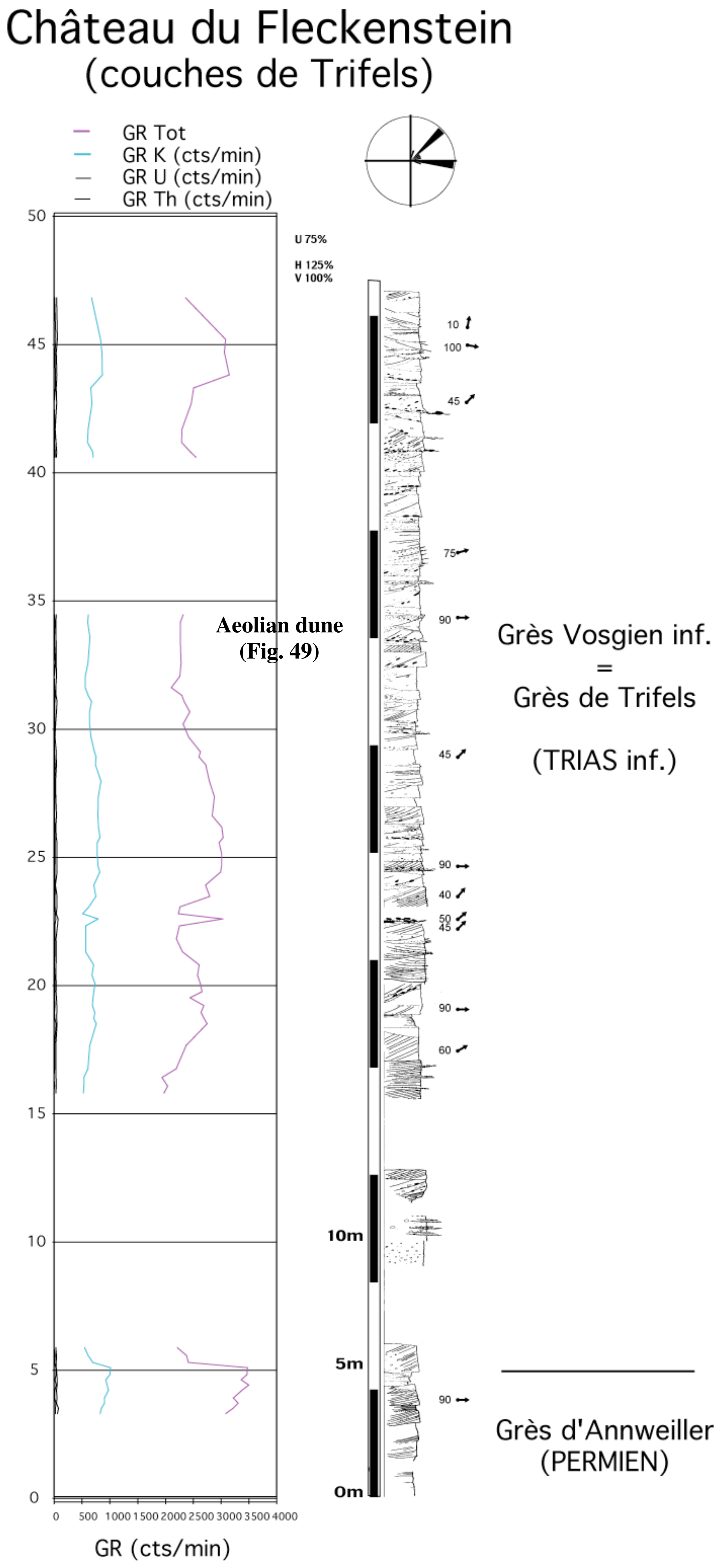



**Figure 48**: Sedimentological log of Fleckenstein Castle (after Péron, 2004).

**Figure 49**: Detailed view of the aeolian deposits well preserved between to fluvial episodes of the ‘Gès vosgien’ Fm

# References

Adloff, M.C., Doubinger, J., Geisler, D. (1982). Étude palynologique et sédimentologique dans le Muschelkalk moyen de Lorraine. *Sciences de la Terre,* Nancy, 25, 91-104.

Aigner, T., Bachmann, G.H. (1992). Sequence-stratigraphic framework of the German Triassic. *Sediment. Geol.*, 80, 115-135.

Ainardi R. (1976). Etude comparée de deux ensembles marginaux littoraux. Microfaciès, evolution séquentielle, paléopaysage. Le passage Muschelkalk – Keuper (Vosges occidentales), le Purbekien (Jura méridional). PhD thesis, Institut National Polytechnique de Lorraine, 103 p., unpublished.

Ainardi R. (1988). Séquence biologique en milieu paradeltaïque, exemple de la Lettenkohle. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 65: 173–181

Al Khatib R. (1976) Le Rhétien de la bordure orientale du Bassin de Paris et le "Calcaire à gryphée" de la région de Nancy. Etude pétrographique et sédimentologique. Thesis Univ. Nancy I, 278 p., unpublished

Arp G., Bielert F., Hoffmann V.-E., Löffler T. (2005) Palaeoenvironmental significance of lacustrine stromatolites of the Arnstadt Formation ("Steinmergelkeuper", Upper Triassic, N-Germany). *Facies*, 51, 419-441.

Bachmann G. H., Kozur, H. W. (2005). The Germanic Triassic: correlations with the international chronostratigraphic scale, numerical ages and Milankovitch cyclicity. *Hallesches Jahrb. Geowiss*., B26, 17-62.

Bock H., Müller E., Muller A., Schwietering C. (2001) Erweiterung des Ablagerungsareals der Buntsandstein-sedimente am Westrand des Germanischen Triasbeckens. *Zbt. Geol. Paläont*., Teil I, 1/2, 1-14.

Bourquin S., Boehm C., Clermonté J., Durand M., Serra O. (1993). Analyse faciologique et séquentielle du Trias du centre-ouest du Bassin de Paris à partir des données diagraphiques. *Bull. Soc. Géol. France*, 2: 177–188

Bourquin S., Guillocheau F. (1993). Géométrie des séquences de dépôt du Keuper (Ladinien à Rhétien) du Bassin de Paris: implications géodynamiques. *C. R. Acad. Sci. Paris*, 317: 1341–1348

Bourquin, S., Friedenberg, R., Guillocheau, F. (1995). High-resolution sequence stratigraphy in the Triassic series of the Paris Basin: geodynamic implications. *Cuadernos de Geologia Ibérica*, 19, 337-362.

Bourquin S., Guillocheau F. (1996). Keuper stratigraphic cycles in the Paris Basin and comparison with cycles in other Peritethyan basins (German Basin and Bresse-Jura Basin). *Sediment. Geol.,* 105, 159-182.

Bourquin S., Vairon J., Le Strat P. (1997). Three-dimensional evolution of the Keuper of the Paris Basin based on detailed isopach maps of the stratigraphic cycles: tectonic influences. *Geologische Rundchau*, 86, 670-685.

Bourquin S., Rigollet C., Bourges P. (1998). High-resolution sequence stratigraphy of an alluvial fan - fan delta environment: stratigraphic and geodynamic implications — Example of the Chaunoy Sandstones, Keuper of the Paris Basin. *Sediment. Geology*, 121, 207-237.

Bourquin S., Robin C., Guillocheau F., Gaulier J.-M. (2002). Three-dimensional accommodation analysis of the Keuper of the Paris Basin: discrimination between tectonics, eustasy, and sediment supply in the stratigraphic record, *Mar. Petrol. Geol* 19, 469-498.

Bourquin S., Péron S., Durand M. (2006). Lower Triassic sequence stratigraphy of the western part of the Germanic Basin (west of Black Forest): fluvial system evolution through time and space. *Sedimentary Geology,* 186, 187-211.

Bourquin S., Durand M., Diez J.B., Broutin J. (in press). The Permian-Triassic boundary and the early Triassic sedimentation in the Western Peritethys basins. *Journal of Iberian Geology*.

Brayard A., Bucher H., Escarguel G., Fluteau F., Bourquin S., Galfetti T. (2006). The Early Triassic ammonoid recovery: paleoclimatic significance of diversity gradients. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 239, 374-395.

Clemmensen, L.B. (1979). Triassic lacustrine red-beds and palaeoclimate: The "Buntsandstein" of Helgoland and the Malmros Klint Member of East Greenland. *Geol. Rundsch.*, 6, 748-774.

Clemmensen L.B., Abrahamsen K. (1983). Aeolian stratification and facies association in desert sediments, Arran basin (Permian), Scotland. *Sedimentology*, 30: 311-339.

Clemmensen, L.B.,Tirsgaard, H. (1990). Sand-drift surfaces: a neglected type of bounding surface. *Geology*, 18, 1142-1145.

Collison J.D., Thomson D.B. (1989). Sedimentary structures. Second Edition. Chapman & Hall, 207 p.

Courel, L., Durand, M., Maget, P., Maiaux, C., Menillet, F., Pareyn, C, et al. (1980). Trias. In: Mégnien, C. (Ed), Synthèse géologique du Bassin de Paris. *Mém. BRGM*., 101, 37–74.

Dabard, M.-P. (2000). Petrogenesis of graphitic cherts in the Armorican segment of the Cadomian orogenic belt (NW France). *Sedimentology*, 47, 787-800.

Dachroth W. (1967). Stratigraphie und Tektonik im Hauptbuntsandstein des östlichen Saarlandes. *Ann. Universitatis Saraviensis (Sci.)*, 5, 173-219.

Dachroth W. (1972) Der Obere Buntsandstein im Saarland. *Oberrhein. geol. Abh*., 21, 117-144.

Dachroth, W. (1985). Fluvial sedimentary styles and associated depositional environments in the Buntsandstein west of River Rhine, in Saar area and Pfalz (F.R. Germany) and Vosges (France). In: Mader, D. (ed) Aspects of fluvial sedimentation in the Lower Triassic Buntsandstein of Europe. Lecture Notes in Earth Sciences 4, Springer, Berlin, 197-248.

Dittrich D. (1989). Beckenanalyse der Oberen Trias der Trier-Luxemburger Bucht. Revision der stratigraphischen Gliederung und Rekonstruktion der Paläogeographie. *Publ. Serv. Géol. Luxembourg*, 26, 223 p.

Dromart, G., Monier, P., Curial, A., Moretto R., Guillocheau, F. (1994). Triassic transgressive-regressive cycles in the Bresse-Jura and adjacent Basins, eastern France. In: Mascle, A., Eds, Hydrocarbon and petroleum geology of France. Springer-Verlag. *Eur. Assoc. Petrol. Geol.*, 347-360.

Dubois P., Umbach P. (1974). A propos du Trias de deux bassins sédimentaires français: le Bassin de Paris et le bassin du Sud-Est. *Bull. Soc. Geol. France*, 6: 796–707

Durand M. (1972). Répartition des galets éolisés dans le Buntsandstein moyen lorrain. *C.R. somm. Soc. Géol. France*, 5, 214-215.

Durand M. (1978). Paléocourants et reconstitution paléogéographique: L'exemple du Buntsandstein des Vosges méridionales (Trias inférieur et moyen continental). *Sciences de la Terre*, Nancy, 22, 4, 301-390.

Durand M. (2006). The problem of the transition from the Permian to the Triassic Series in southeastern France: comparison with other Peritethyan regions. In: S.G. Lucas, G. Cassinis & J.W. Schneider, Eds., Non-marine Permian biostratigraphy and biochronology. *Geol. Soc. London Sp. Publ.,* 265, 281–296

Durand M., Jurain, G. (1969). Eléments paléontologiques nouveaux du Trias des Vosges méridionales. *C.R. Acad. Sci. Paris*, 269 D, 1047-1049.

Durand M., Meyer R. (1982). Silicifications (silcrètes) et évaporites dans la Zone-limite violette du Trias inférieur lorrain. Comparaison avec le Buntsandstein de Provence et le Permien des Vosges. *Sciences Géologiques*, *Bull.,* Strasbourg, 35, 17-39.

Durand M., Meyer R., Avril G. (1989) Le Trias détritique de Provence, du dôme de Barrot et du Mercantour: exemples de sédimentation continentale en contexte anorogénique. Livret-guide de l'excursion des 15-16-17 juin 1988. Publication de l'Association des Sédimentologistes Français, 6, 135 p.

Durand M., Chrétien J.C., Poinsignon J.M. (1994). Des cônes de déjection permiens au grand fleuve triasique: Evolution de la sédimentation continentale dans les Vosges du Nord autour de – 250 Ma. Livret-guide d'excursion du Congrès national de l'APBG. Editions Pierron, Sarreguemines, 32 p.

Duringer P., Hagdorn H. (1987). La zonation par cératites du Muschelkalk supérieur lorrain (Trias, Est de la France). Diachronisme des faciès et migration vers l'Ouest du dispositif sédimentaire. *Bull. Soc. géol. France*, (8), 3, 3, 601-609.

Duringer P., Vecsei A. (1998). Middle Triassic shallow-water limestones from the Upper Muschelkalk of eastern France: the origin and depositional environments of some early Mesozoic fine-grained limestones. *Sedimentary Geology*, 121, 57-70.

Frisch U., Kockel F. (1999). Quantification of Early Cimmerian movement in NW-Germany. In: G.H., Bachmann, & I., Lerche, *Epicontinental Triassic* (571-600). *Zbl. Geol. Paläont.,* Teil I, 7-8.

Gall J.C. (1971). Faunes et paysages du Grès à Voltzia du Nord des Vosges. Essai paléoécologique sur le Buntsandstein supérieur. *Mém. Serv. Carte géol. Als.-Lorr.*, 34, 318 p.

Gall J.C., Durand M., Müller E. (1977). Le Trias de part et d'autre du Rhin: corrélations entre les marges et le centre du Bassin germanique. *Bull. BRGM,* sér. 2, sect. IV, 3, 193-204.

Gastaldo R.A., Adendorff R., Bamford M., Labandeira C.C., Neveling J., Sims H. (2005). Taphonomic trends of macrofloral assemblages across the Permian-Triassic boundary, Karoo Basin. *Palaios*, 20: 479-497.

Geisler D., Adloff M.-C., Doubinger J. (1978). Découverte d'une microflore du Carnien inférieur dans la série salifère lorraine. *Sciences de la Terre,* Nancy, 22: 391-399.

Geluk M.C. (1998). Palaeogeographic and structural development of the Triassic in the Netherlands - new insights. *Zbl. Geol. Paläont.*, Teil I, 1, 545-570.

Guillocheau F. (1991). Mise en évidence de grands cycles transgression-régression d'origine tectonique dans les sédiments mésozoïques du Bassin de Paris. *C. R. Acad. Sci. Paris*, 312: 1587–1593

Guillocheau F., Robin C., Allemand P., Bourquin S., Brault N., Dromart G., et al. (2000). Meso-cenozoic geodynamic evolution of the Paris Basin: 3D stratigraphic constraints. *Geodinamica Acta*, vol. 13, 189-246.

Guillocheau F., Péron S., Bourquin S., Dagallier G., Robin C. (2002a). Les sédiments fluviatiles (faciès Buntsandstein) du Trias inférieur et moyen de l'Est du Bassin de Paris. *Bull. Information Géol. Bassin de Paris*, 39, 5-12.

Guillocheau F., Péron S., Robin C., Bourquin S., Dagallier G. (2002b). L'inondation marine du Trias Moyen (Calcaires à Cératites) dans l'Est du bassin de Paris. *Bull. Inf. Géol. Bass. Paris*, vol. 39, n° 3, 23-47.

Gunatilaka A. (1989) Spheroidal dolomites – origin by hydrocarbon seepage? *Sedimentology*, 36: 701-710.

Hagemann H.W. (1967). Umgelagerte Karbonsporen aus den Rät-Lias-Schichten SE-Luxemburgs. *Publ. Serv. Géol. Luxembourg*, 17, 207-221.

Hanzo M., Péniguel G., Doubinger J., Adloff M.-C. (1990). Zonation palynologique et analyse géochimique organique, pour préciser les paléomilieux lors de la transgression liasique à Cattenom (Moselle, France). *Cahiers de Micropaléontologie*, Paris, N.S., 5, 55-74.

Hauschke N. (1989). Steinsalzkristallmarken - Begriff, Deutung und Bedeutung für das Playa-Playasee-Faziesmodell. *Zeit. deutsch. Gesell. Geowiss.*, 140, 355-369.

Hendriks F. (1982). Ein Modell der Rätsedimentation am Ostrand des Pariser Beckens. Untersuchungen zur Granulometrie, Schwermineralvergesellschaftung und Tongeologie. Dissert., R.W.T.H., Aachen, 294 p., unpublished.

Junghans W.-D., Rösler W., Aigner, T., Appel, E. (2002). Magnetostratigraphie an der Perm/Trias-Grenze der Bohrung Kraichgau 1002 (SW-Deutschland). *N. Jb. Geol. Paläont. Mh.*, 2, 92-106.

Kannegieser E., Kozur, H. (1972). Zur Micropaläontologie des Schilfsandsteins. *Geologie,* Berlin, 21: 185-214.

Kockel F. (1995). Structural and palaeogeographical development of the German North sea sector. *Beitr. Region Geol der Erde*, 26, 1-96.

Kocurek G., Nielson J. (1986). Conditions favourable for the formation of warm-climate aeolian sand sheets. *Sedimentology*, 33, 795-816.

Kozur H. (1972). Vorläufige Mitteilung zur Parallelisierung der germanischen und tethyalen Trias sowie einige Bemerkungen zur Stufen- und Unterstufengliederung der Trias. *Mitt. Ges. Geol. Bergbaustud.*, Innsbruck, 21, 361-412.

Kozur H. W. (1993). Annoted correlation tables of the Germanic Buntsandstein and Keuper. In: Lucas, S. G. and Morales, M. (eds): The nonmarine Triassic. *New Mexico Mus. Nat. Hist & Sci., Bull*, 3, 243-248.

Kozur H. W., Bachmann G. H. (2004). Correlation of the Germanic Triassic with the international scale. *Albertiana*, 32, 21-34

Langford R.P., Chan M.A. (1989). Fluvial-aeolian interactions: Part II, ancient systems. *Sedimentology*, 36: 1037-1051.

López-Gómez J., Arche A., Marzo M., Durand M. (2005). Stratigraphical and palaeogeographical significance of the continental sedimentary transition across the Permian - Triassic boundary in Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 229: 3-23.

Matray J.M., Meunier A., Thomas M., Fontes J.C. (1989). Les eaux de formation du Trias et du Dogger du Bassin parisien: histoire et effets diagénétiques sur les réservoirs. *Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine*, 13: 483–504

Meyer R. (1973). La carte géologique au 1/ 50 000 de Rambervillers (Vosges). Présentation générale et commentaires sédimentologiques. PhD thesis, Univ. Nancy I, 150 p., unpublished.

Ménillet F., Coulombeau C., Geissert F., Konrad H.J., Schwoerer P. (1989). Notice explicative de la feuille Lembach. 1:50,000 Geological map of France, BRGM, Orléans, 91 p.

Müller E.M. (1954). Beiträge zur Kenntnis der Stratigraphie und Paläogeographie des Oberen Buntsandsteins im Saar-Lothringischen Raum. *Ann. Universitatis Saraviensis (Sci.)*, 3, 176-201.

Orti Cabo F. (1982). Sur les conditions de dépôt, la diagenèse et la structure des évaporites triasiques dans l'Est de l'Espagne. *Sciences de la Terre,* Nancy, 25: 179-199.

Ortlam D. (1967). Fossile Böden als Leithorizonte für Gliederung des höheren Buntsandsteins im nördlichen Schwarzwald und südlichen Odenwald. *Geol. Jahrb.*, 84, 485-590.

Palain C. (1966). Contribution à l'étude sédimentologique du "Grès à roseaux" (Trias supérieur) en Lorraine. *Sciences de la Terre*, Nancy, 11, 245-291.

Péron S. (2004). Nature et contrôle des systèmes fluviatiles du domaine Ouest Péri-Téthysien au Trias inférieur: sédimentologie de faciès, reconstitutions paléoenvironnementales et simulations climatiques, Thèse Univ. Rennes1

Péron S., Bourquin S., Fluteau F., Guillocheau F. (2005). Paleoenvironment reconstructions and climate simulations of the Early Triassic: impact of the water and sediment supply on the preservation of fluvial system. *Geodinamica Acta*, 18/6, 431-446

Perrodon A., Zabek J. (1990). Paris Basin. In: Interior cratonic basins. *Am. Assoc. Pet. Geol. Mem.*, 51: 633–679

Rauscher R., Hilly J., Hanzo M., Marchal C. (1995). Palynologie des couches de passage du Trias supérieur au Lias dans l'Est du Bassin parisien. Problèmes de datation du "Rhétien" de Lorraine. *Sciences Géologiques, Bull.,* Strasbourg, 48, 1-3, 159-185.

Reis O.M., von Ammon L. (1903). Erlaüterungen zu Blatt Zweibrücken der geognostischen Karte 1/100 000 des Königreiches Bayern.

Richter-Bernburg, G. (1974). Stratigraphische Synopsis des deutschen Buntsandsteins. *Geol. Jahrb.*, 25, 127-132.

Ricour J. (1962). Contribution à une révision du Trias français. Mém. Carte. Geol. Fr, 63, 471 p.

Roche M. (1994). Palynologie et palynofacies du Rhaetian (Trias supérieur) du nord-est du Bassin de Paris. Thèse Univ. Liège, 138 p., unpublished.

Rogers D.A., Astin T.R. (1991). Ephemeral lakes, mud pellet dunes and wind-blown sand and silt: re-interpretations of Devonian lacustrine cycles in north Scotland. In: Lacustrine facies analysis, Anadon, P., Cabrera, L. et Kelts, K. (eds), *IAS Special Publication*, Oxford, 13: 199-222.

Röhling H.-G. (1991). A lithostratigraphic subdivision of the Lower Triassic in the Northwest German Lowlands and the German sector of the North Sea, based on gamma-ray and sonic logs. *Geologisches Jahrbuch*, Reihe A, 119, 3-24.

Roman A. (2004). Sequenzstratigraphie und Fazies des Unteren und Mittleren Buntsandsteins im östlichen Teil des Germanischen Beckens (Deutschland, Polen). Dissertation University of Wittenberg Halle, 140 p., unpublished.

Schumacher E. (1890). Zur Kenntniss des unteren Muschelkalks im nordöslichen Deutsch-Lothringen. *Mitt. Com. Geol. Landes-Untersuch. Elsass-Lothr.*, 2, 111-182.

Schuurmann W.M.L. (1977). Aspects of Late Triassic palynology.2. Palynology of the "Grès et Schistes à Avicula contorta and "Argiles de Levallois" (Rhaetian) of northeastern France and southern Luxembourg. *Rev. Palaeobot. Palynol.*, 23: 159-253.

Schwarz H.-U. (1975). Sedimentary structures and facies analysis of shallow marine carbonates (Lower Muschelkalk, SW Germany). Contributions to Sedimentology 3, 100 p., Scheizerbart, Stuttgart.

Simms M.J., Ruffell A.H. (1990). Climatic and biotic change in the late Triassic. *J. Geol. Soc.* London, 147: 321-327.

Szurlies M., Bachmann G.H., Menning M., Nowaczyk N.R., Käding K.-C. (2004). Magnetostratigraphy and high-resolution lithostratigraphy of the Permian-Triassic boundary interval in Central Germany. *Earth and Planetary Science Letters*, 212, 263-278.

Trewin N.H. (1993). Mixed aeolian sandsheet and fluvial deposits in the Tumblagooda Sandstone, Western Australia. In: North C.P. and Prosser D.J. (eds), Characterization of fluvial and aeolian reservoirs. *Geol Soc. Spec. Pub.*, 73, 219-230.

Trusheim F. (1961). Über Diskordanzen im mitlleren Buntsandstein Norddeutschlands zwischen Weser und Ems. *Erdöl-Zeitschrift*, 77, 361-367.

Trusheim F. (1963). Zur Gliederung des Buntsandsteins. *Erdöl-Zeitschrift*, 79, 277-292.

Ulicny D. (2004). A drying-upward aeolian system of the Bohdasin Formation (Early Triassic), Sudetes of NE Czech Republic: record of seasonality and long-term palaeoclimate change, *Sediment. Geol.*, 167 17-39.

van der Zwan C.J., Spaak P. (1992). Lower to Middle Triassic sequence stratigraphy and climatology of the Netherlands, a model, *Palaeogeogr., Palaeoclimatol., Palaeoecol,* 277-290.

Vecsei A., Duringer P. (2003) Sequence stratigraphy of Middle Triassic carbonates and terrigenous deposits (Muschelkalk and Lower Keuper) in the SW Germanic Basin: maximum flooding versus maximum depth in intracratonic basins. *Sedimentary Geology*, 160, 81-105.

Warrington G., Audley-Charles M.G., Elliott R.E., Evans W.B., Ivimey-Cook H.C., Kent P.E., Robinson P.L., Shotton F.W., Taylor F.M. (1980). A correlation of Triassic rocks in the British Isles. *Geol. Soc. Spec. Rep.* London, 13: 78.

Wolburg J. (1968). Vom zyklischen Aufbau des Buntsandsteins. *N. Jb. Geol. Paläont. Mh.*, 9, 535-559.

Wolburg J. (1969). Die epirogenetischen Phasen der Muschelkalk- und Keuper- Entwicklung Nordwest-Deutschlands, mit einem Rückblick auf den Buntsandstein. *Geotekt Forsch.*, 32, 1-65.

Ziegler P.A. (1990). Permo-Triassic development of Pangea. In: Ziegler, P.A., (Ed), Geological Atlas of Western and Central Europe. Shell International Petroleum Maatschappij B.V., The Hague, 68-90.