ANTHROPOLOGICA ET PRAEHISTORICA

**Bulletin de la
Société royale belge d'Anthropologie
et de Préhistoire**

**Bulletin van de
Koninklijke Belgische Vereniging
voor Antropologie en Prehistorie**

123/2012

2013

*Ce volume a été publié
grâce à l'appui de*

*Deze bundel werd gepubliceerd
met de steun van*

l'Institut royal des Sciences naturelles de Belgique • het Koninklijk Belgisch Instituut voor Natuurwetenschappen

et grâce au soutien financier de   *en met de financiële steun van*

la Fondation universitaire de Belgique • de Universitaire Stichting van België
la Politique scientifique fédérale • het Federal Wetenschapsbeleid
et du   *en het*
Ministère de la Communauté Française de Belgique
(Direction de la Recherche scientifique & Service général du Patrimoine culturel)
Ministère de la Région Wallonne (Division du Patrimoine)
Fonds National de la Recherche Scientifique – FNRS

Instructions aux auteurs / Richtlijnen voor auteurs / Guide for authors

http://srbap.naturalsciences.be/

Le Bulletin de la Société royale belge d'Anthropologie et de Préhistoire a une vocation strictement scientifique et se veut ouvert à toutes les thèses scientifiques, sans parti pris idéologique ou dogmatique.
Aussi le contenu du Bulletin de la Société royale belge d'Anthropologie et de Préhistoire est-il contrôlé par un comité de rédaction permanent et des comités de lecture internationaux, établis en fonction du thème de chaque contribution. Ces différents comités n'ont aucun droit d'établir une censure, sinon en l'absence d'une démarche scientifique manifeste. Dans tous les cas, les auteurs sont responsables du contenu de leurs articles.

Het tijdschrift van de Koninklijke Belgische Vereniging voor Antropologie en Prehistorie heeft enkel een wetenschappelijk doel. Het staat open voor alle wetenschappelijke bijdragen zonder ideologisch of dogmatisch streven.
De wetenschappelijke inhoud van het tijdschrift wordt bewaakt door een permanente redactieraad en een internationaal leescomité dat is samengesteld in functie van het thema van de individuele bijdrage. Deze raad en comité hebben in geen geval het recht om de manuscripten te censureren, behalve bij manifest gebrek aan wetenschappelijke ernst. De auteurs zijn steeds de enige verantwoordelijken voor de inhoud van hun bijdrage.

Société royale belge d'Anthropologie et de Préhistoire
a.s.b.l.
Rue Vautier, 29
B-1000 Bruxelles

Koninklijke Belgische Vereniging voor Antropologie en Prehistorie
v.z.w.
Vautierstraat, 29
B-1000 Brussel

Fondée en 1882, la Société d'Anthropologie de Bruxelles est devenue la Société royale belge d'Anthropologie et de Préhistoire à partir de 1931. Elle réunit des chercheurs professionnels ou non, belges et étrangers, spécialistes en archéologie préhistorique, en anthropologie physique, en anthropologie génétique ou en paléontologie humaine.

De Vereniging voor Antropologie van Brussel, gesticht in 1882, kreeg vanaf 1931 de benaming van Koninklijke Belgische Vereniging voor Antropologie en Prehistorie. Ze verenigt al dan niet professionele onderzoekers, zowel Belgische en buitenlandse, gespecialiseerd in de prehistorische archeologie, in de fysische antropologie, in de genetische antropologie of in de menselijke paleontologie.

☎ +32 2 627 41 45

srbap@naturalsciences.be

Compte bancaire
Bankrekening
BE46 0000 3074 2936

ISSN 1377-5723

SPY CAVE

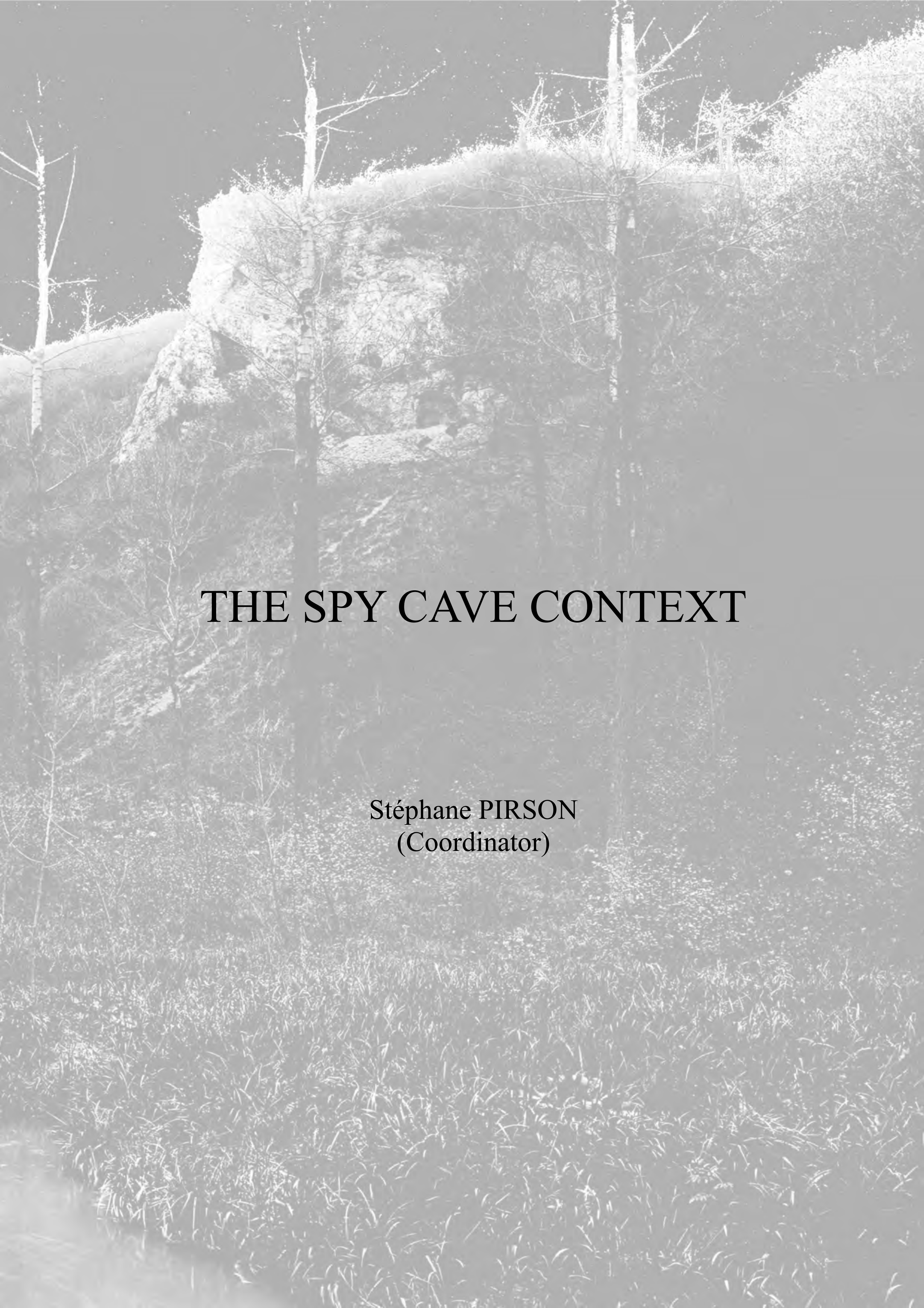
125 years of multidisciplinary research
at the Betche aux Rotches
(Jemeppe-sur-Sambre, Province of Namur, Belgium)

Edited by Hélène ROUGIER & Patrick SEMAL

Volume 1

2013

TABLE OF CONTENTS



THE SPY CAVE CONTEXT

Stéphane PIRSON
(Coordinator)

CHAPTER V

PIRSON S., DELCAMBRE B. & GOEMAERE É., 2013.
Geological context: 73-90.

CHAPTER VI

PIRSON S., DI MODICA K., JUNGELS C., FLAS D., HAUZEUR A., TOUSSAINT M. & SEMAL P., 2013.
The stratigraphy of Spy cave. A review of the available lithostratigraphic and archaeostratigraphic information: 91-131.

In: H. ROUGIER & P. SEMAL (ed.), *Spy cave. 125 years of multidisciplinary research at the Betche aux Rotches (Jemeppe-sur-Sambre, Province of Namur, Belgium), Volume 1.* Anthropologica et Præhistorica, **123/2012**. Brussels, Royal Belgian Institute of Natural Sciences, Royal Belgian Society of Anthropology and Praehistory & NESPOS Society.

Supporting information available at:
http://mars.naturalsciences.be/bibliop4plone/rbins-publications/spy-cave-volume-1/supporting-information/

CHAPTER V

GEOLOGICAL CONTEXT

Stéphane PIRSON, Bernard DELCAMBRE & Éric GOEMAERE

Abstract

The geological context of the Spy area is presented, from Lower Palaeozoic to Quaternary. It focuses on Upper Palaeozoic, including the Lower Carboniferous limestone in which the Spy cave opens. Special attention is also given to the Quaternary.

INTRODUCTION

Despite the small size of its territory (ca. 30,500 km²), Belgium shows a rich geology, encompassing various lithologies and covering a large part of the geological timescale, from Lower Palaeozoic to Holocene. Figure 1 presents the geological map of Belgium. Figure 2 represents the simplified N-S geological section showing the geometrical relationships between the different geological units.

Excepting the Quaternary cover, rocks outcropping in Belgium can broadly be divided into two large areas (Figures 1-2; Fourmarier, 1954; Robaszynski & Dupuis, 1983). The northern part of the country mainly exhibits Cenozoic deposits consisting in predominantly marine and unconsolidated sediments (Vandenberghe *et al.*, 1998). They may reach a thickness of several hundreds of metres. Sediment accumulation in this area resulted from relative sea-level fluctuations and migration of the sea to the north/north-west. The situation in Southern Belgium is completely different as consolidated Palaeozoic rocks dominate over large areas. These rocks underwent strong deformations at the end of Carboniferous. However, Mesozoic rocks occur in the area of Mons (Cretaceous), Liège (Cretaceous) and Arlon (Triassic and Jurassic). Thin Cenozoic deposits are rather poorly represented, except in the Mons Basin area, the Hesbaye region and the northern part of the Hainaut province.

Almost all these rocks are of sedimentary origin (Bultynck & Dejonghe, 2001). Occurrences of magmatic rocks are rather rare (Denaeyer & Mortelmans, 1954; Corin, 1965; André, 1983) and metamorphic rocks are restricted to the Ardenne Anticlinorium and the Brabant Massif (Beugnies, 1986; Fielitz & Mansy, 1999).

The Spy cave is located on the eastern slope of the Orneau Valley. Tributary of the Meuse River, the Orneau River flows between Gembloux and Jemeppe-sur-Sambre from north to south along the southern flank of the Brabant Massif and its Upper Palaeozoic cover. The valley exposes one of the most interesting and complete outcrops in the Palaeozoic series of the area. The new geological maps of the valley are now published at 1:25,000 (Figures 3-5; Delcambre & Pingot, 2002, 2008). This paper aims at replacing the cave of Spy in its geological background, both at regional (Belgium) and local (Orneau Valley) scales.

LOWER PALAEOZOIC

In Belgium, Lower Palaeozoic rocks (Cambrian, Ordovician and Silurian) crop out in the Stavelot, Rocroi, Serpont and Givonne inliers as well as in the *Bande silurienne du Condroz* and in some valleys of the Brabant Massif (Figures 1-2). Most Lower Palaeozoic sediments are marine, siliciclastic and often turbiditic (Robaszynski & Dupuis, 1983; Verniers *et al.*, 2001).

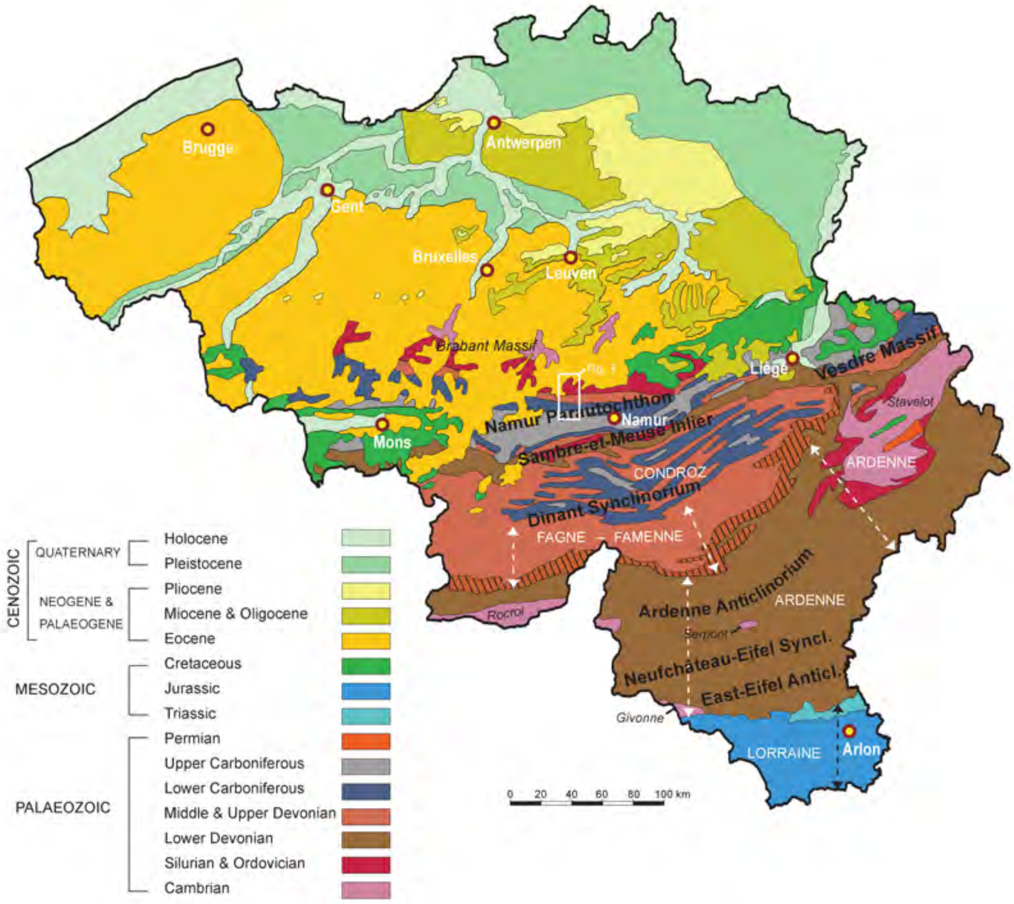


Figure 1. Geological map of Belgium (after Pirson *et al*., 2008). In white: natural regions of Southern Belgium. In bold black: Variscan structural units. The white rectangle positions the studied area of Figure 3.

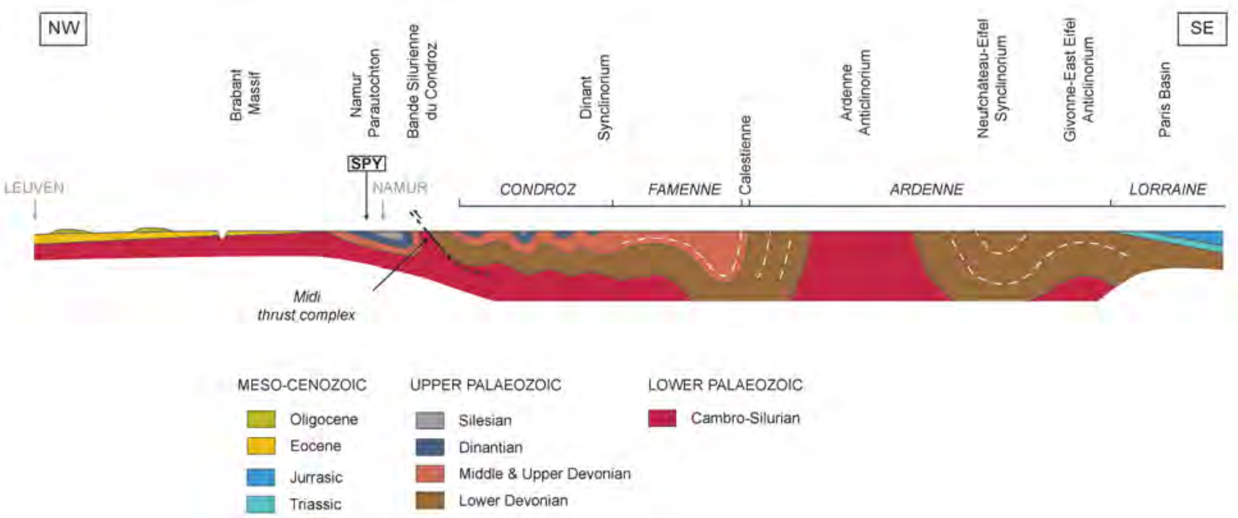


Figure 2. Simplified N-S geological section showing the geometrical relationships between the different geological units (after Pirson *et al*., 2008, modified from Raoult & Meilliez, 1986). The Ardenne Allochton corresponds to the rocks which have been overthrusted to the north-west on the Brabant Parautochton by the Midi Thrust. Thicknesses and dips are not respected.

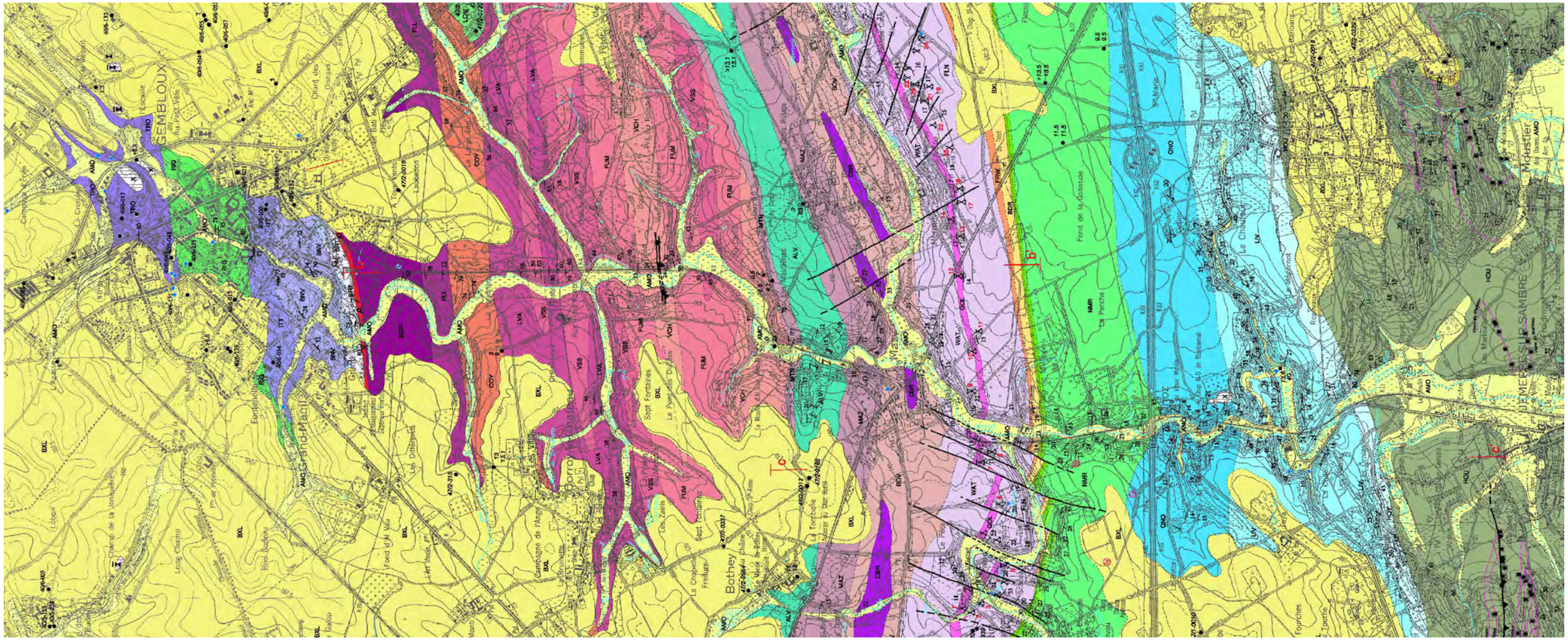


Figure 3. Geological map centred on the Orneau River. Close up of the Fleurus-Spy and Chastre-Gembloux geological maps (after Delcambre & Pingot, 2002, 2008). The geographical setting of this detailed geological map is shown in Figure 1.

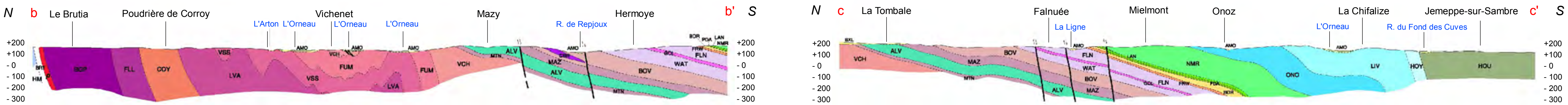


Figure 4. Geological N-S cross-sections of the Orneau River (after Delcambre & Pingot, 2008). The position of these sections is shown in Figure 3.

Between Gembloux and Alvaux, the Orneau Valley crops Ordovician and Silurian layers especially constituted of shales and siltites. Their age extends between Llanvirn to the upper part of Wenlock. In Grand-Manil, to the south of the city of Gembloux, the shales contain a thick (50 m) volcanic bed located more or less at the limit between Ordovician and Silurian stages. Strongly kaolinised, this bed (designed as Nivelles Horizon in Brutia Formation) is considered as the result of an ignimbritic flow. It shows a very heterogeneous and brecciated texture with fragments of rhyolithic material and dark sedimentary shale as well as fine-grained whitish matrix. Two other sub-metric to metric pyroclastic deposits are observed in the Ashgill (Grand Manil Horizon) and at the top of Llandoverian shales (Pitet Horizon). They correspond to weathered sub-metric to metric ash falls deposits.

The Ordovico-silurian formations seem rather monotonous. But in details, a lithostratigraphic chart can be established (Verniers *et al.*, 2001; Delcambre & Pingot, 2002, 2008), based on the shape of the sedimentary turbiditic records (Figure 5). The biostratigraphic column relies on rare occurrences of graptolites and on the distribution of chitinozoans (Michot, 1954; Samuelsson & Verniers, 1999; Verniers *et al.*, 2001). Macrofauna is very poor except in the Huet-Madot Group characterised by a rich fauna of Brachiopods, Crinoids, Bryozoans and Trilobites (Upper Caradoc to Ashgill; Lespérance & Sheehan, 1987).

These deposits were deformed by the Avalonia-Baltica-Laurentia collisions between Late Ordovician to Early Devonian (e.g. Sintubin, 1999; Verniers *et al.*, 2001). These Lower Palaeozoic deformations have been called “Caledonian Orogeny” in the literature and are sometimes referred to as the “Caledonian Cycle”. The strains caused by the orogen print cleavage in these fine-grained sedimentary rocks. The Lower Palaeozoic rocks are unconformably covered by Devonian sediments.

UPPER PALAEOZOIC: THE VARISCAN CYCLE

Upper Palaeozoic rocks overlay unconformably the Lower Palaeozoic basement and form the main part of the outcrops in Southern Belgium. Classically, several structural units caused by the Variscan Orogeny are recognised (Figures 1-2). From a structural point of view, Belgium constitutes the northern border of the European Variscan Belt and belongs to the Rheno-hercynian fold-and-thrust belt, or Rheno-hercynian Zone (RHZ) (Matte, 1986a, 1986b; Franke, 1989). To the north of this belt lies the Brabant Massif, which is not or little affected by Variscan deformation. The RHZ encompasses mainly marine or coastal sediments, deposited in the Rhenohercynian Sea and subsequently deformed during Variscan Orogeny. This marine area is developed on the passive margin between the Brabant Massif to the north (southern flank of the Old Red Sandstone Continent; Ziegler, 1990) and the Lizzard-Giessen-Ostharz Ocean to the south. The history of the RHZ is intimately linked to the opening and closing of that ocean, according to the mechanisms of plate tectonics (Oncken *et al.*, 1999; Vanbrabant *et al.*, 2002).

In Belgium, the sedimentation during the Variscan cycle can be divided into two main distinct phases (Robaszynski & Dupuis, 1983): the Devono-Dinantian and the Upper Carboniferous.

The first Variscan sedimentation phase corresponds to the Devono-Dinantian transgressions, which reached the continent lying north in three main successive transgression-regression pulses of the Rhenohercynian Sea:

a. The Lower Devonian (Godefroid *et al.*, 1994) is characterised by fluvio-littoral and low marine environments and the sedimentation is mainly detrital. The sea receded to the south in the Late Lower Devonian time and sedimentation had a more continental character.

b. During the Middle Devonian (Bultynck *et al.*, 1991) and Frasnian (Boulvain *et al.*, 1999), marine transgression resumed to the north and reached the Namur sedimentation area. Sedimentation was more calcareous (Tsien, 1980). Major regressions took place in the Upper Givetian and in the Famennian, with the comeback of terrigenous inputs (Thorez & Dreesen, 1986; Bultynck *et al.*, 1991).

c. The third pulsation corresponds to the Dinantian (Paproth *et al.*, 1983a; Hance *et al.*, 2001;

Poty *et al.*, 2001) and is clearly dominated by carbonate marine sediments.

The second Variscan sedimentation phase relates to the Upper Carboniferous (Namurian and Westphalian; Paproth *et al.*, 1983b; Delmer *et al.*, 2001). Sedimentation radically changes during this period as the Variscan orogenic belt is forming, leading to deformation and exhumation of the pre-orogenic sediments. The tectonic uplift forces the sea to retreat to the north and leads to the formation of a foreland basin collecting siliciclastic sediments. The environment progressively grades from coastal (Namurian) to more continental and deltaic facies (Westphalian). Variscan structural units are broadly oriented NE-SW in most areas of the RHZ (Figure 1) as a result of the prevailing NW-SE compressive strains. The Variscan Orogeny ends with the development of the Midi Thrust, during the Late Westphalian (Figures 1-2). An important thrust sheet known as the “Ardenne Allochton” is overlying the Lower Palaeozoic foreland (Brabant Massif) and its Devono-Carboniferous cover (Namur Parautochton). The rocks situated north of this thrust complex belong to the Brabant Massif (Robaszynski & Dupuis, 1983; Raoult & Meilliez, 1986; Bless *et al.*, 1989).

The Devono-Carboniferous of the Orneau Valley is located in the Namur Parautochton and corresponds to the northern deformation front of the Variscan Belt. This area then belongs to the North-Variscan Externides or to the Rhenohercynian Zone. Between Alvaux and Onoz, the Devono-Dinantian beds are gently dipped to the south and only affected by some large undulations. The layers are cut by radial faults. South of the Betche aux Rotches cave, the rocks become strongly folded and faulted. Thrusts as well as synclines and anticlines with axial planes dipping to the south affect the Upper Visean and the Coal Measures.

A long period of emersion prevails after the Variscan deformation, i.e. from the end of Carboniferous to Mid-Cretaceous (ca. 150 Ma). Very few deposits are related to this period. Permian coarse continental rocks (conglomerate) are known in the Stavelot-Malmedy area (Bultynck *et al.*, 2001) and Permian marine deposits were cored at depth in the Campine Basin (Dusar *et al.*, 2001).

The Devonian formations of the Orneau River

The Lower Devonian and the Eifelian are missing in the Orneau Valley as in the other outcrops in the southern flank of the Caledonian Brabant Massif. The sea covers the Lower Palaeozoic basement during the Givetian age. The sedimentation begins with red detritic material containing marine fauna. The contact with the underlying Silurian represents an angular unconformity and is underlined by a small conglomeratic bed (de Dorlodot, 1885; Devivier, 1913; Figure 6). These sandy to argillaceous deposits represent the first member of the Bois de Bordeaux Formation (Les Mautiennes Member). They rapidly pass to the well-bedded limestones of the Alvaux Member (Lacroix, 1972; Bultynck *et al.*, 1991), consisting especially of organoclastic limestones with thin intercalations of shales. The upper part of the member contains a biostromal horizon. A thick argillaceous bed of brown shale with some calcareous lenses marks the top of the Alvaux Limestone.

The end of the Givetian sedimentation is characterised by a strong regressive event corresponding to the Mazy Member of the Bois de Bordeaux Formation. It contains red sandstones and siltstones with some conglomeratic layers and fine-grained grayish to variegated limestones.

The carbonates are particularly developed in the Orneau area during Givetian, compared with the other outcrops covering the southern flank of Brabant Massif where the detritic facies prevail. At the top of the Givetian, the sea probably gives up the region.

A second transgressive movement occurs during the Frasnian time. The Bovesse Formation, badly exposed in the Orneau Valley, begins with a thin metric bed of shale with, according to Asselberghs (1936), a fine basal ferruginous gravel (Bossière Member). These deposits are covered by shaly to sandy materials containing dolomitic or argillaceous fine-grained limestones, sometime nodular. The formation includes large lenticular and decametric-bedded units of strongly dolomitised limestones (Combreuil Member). In some places, relicts of macrofauna (corals) can be recognised.

The second part of the Frasnian sedimentation corresponds to the Rhisnes Formation. This unit is divided into three members (Watiamont, Golzinne and Falnuée). The first and the third ones contain argillaceous to nodular brachiopods-rich limestone, partly dolomitised. The central member includes the *Marbre noir de Mazy* or *de Golzinne*, consisting of very fine and strongly metric-bedded black limestone with conchoidal fractures. This member produces a marble of great value sought-after for the smoothness of its grain and its major black colour. Fine-bedded platy clayey limestones separate each bed of marble (Kaisin, 1912; Dumon, 1933).

The Rhisnes Formation is overlaid by greenish to yellowish shales attributed to the Franc-Waret Formation, which is Frasnian and Lower Famennian in age. This unit contains some traces of brachiopods. To the east, near Les Isnes, it contains a sub-metric bed of oolithic hematite mined in the 19th century. To the west, around Balâtre, the formation disappears: Carboniferous deposits directly overlie the Rhisnes Formation.

The Lower Carboniferous formations of the Orneau River

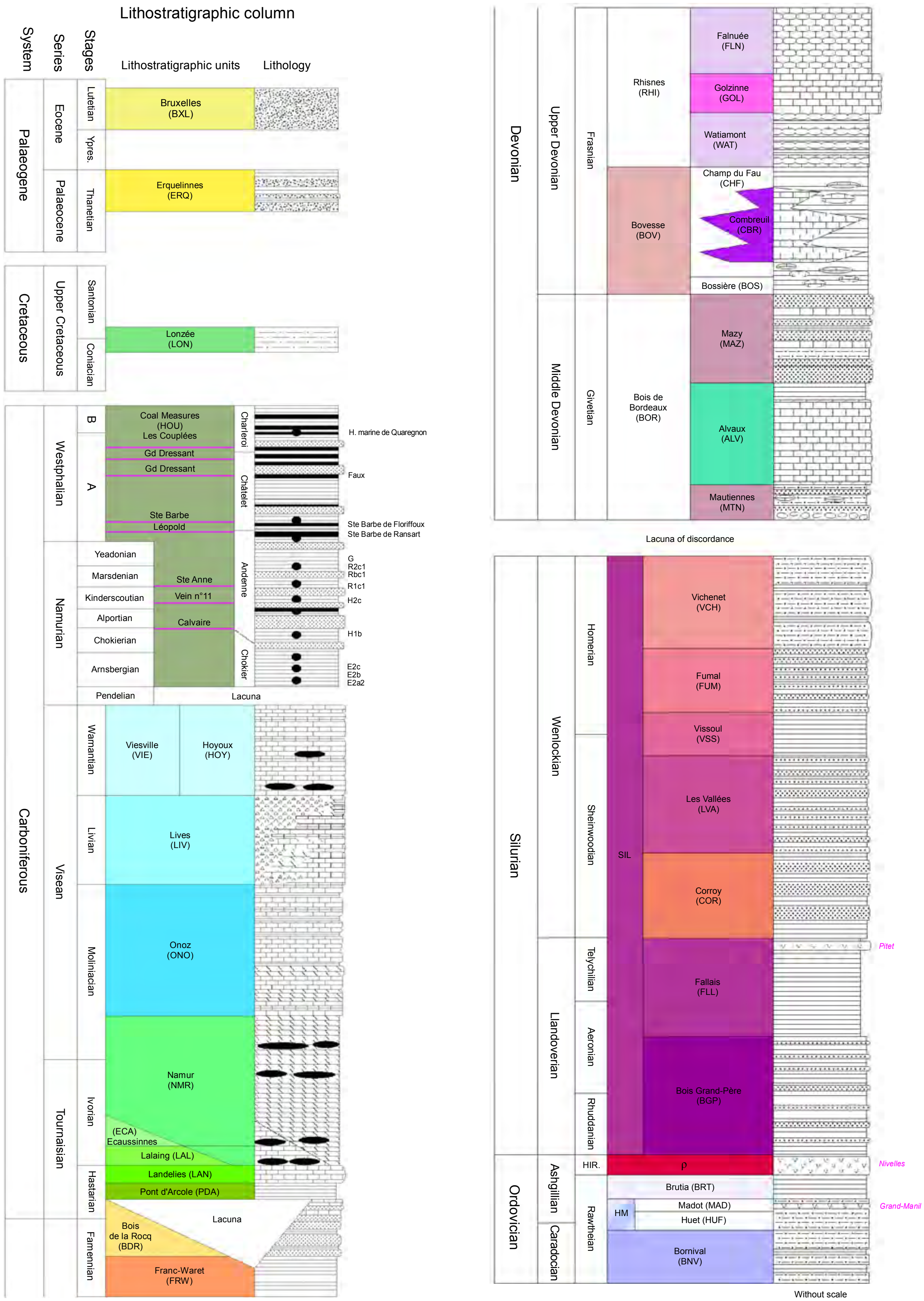
In the Orneau Valley, a gap corresponding to a major part of the Famennian stage occurs between the top of the Franc-Waret Shales (or the Rhisnes Limestones) and the arenaceous Bois de la Rocq Formation. The latter unit displays various lithologies, mainly carbonated sandstones and subsidiary sandy limestones, black limestones with *Cryptophyllus* (Conil, 1959) and dolostones. The upper part of the Bois de la Rocq Formation is clearly of Hastarian age (Lower Tournaisian). The lower part could still belong to the top of the Famennian stage.

Limestones and dolomites dominate the Dinantian strata (Delépine, 1911). The Pont d'Arcole Formation makes exception to this rule and is characterised by brownish shales poorly fossiliferous except at the top. They are overlaid by some crudely bedded layers of crinoidal limestone, which quickly passes to dolomite. These layers are attributed to the Landelies Formation that closes the Hastarian succession.

Along the Orneau Valley, the Ivorian is completely represented by the dolomites of the Namur Formation. The Lalaing Formation and the Ecaussines Formation (not represented in the geological map of Figure 3) are not observed along the Orneau Valley but are recognised westward of Tongrinne and St Martin-Balâtre. The lower part comprises thick-bedded to massive coarse-grained crinoid-rich dolomite (Hance *et al.*, 1981). These layers are overlaid by well-bedded and cherty dark dolomite that constitutes an easily recognisable member of the Namur Formation (Ivorian to Lower Moliniacian). The upper part contains again crinoidal dolomite with, at the top, oolithic limestone and dolomitic limestone.

In the Orneau area, important disused quarries expose the Onoz Formation that succeeds the Tournaisian dolomites. North of the railway tunnel, a quarry exposes dark limestones, dolomitic limestones and dolomites (Carrière du Parc Member in Delcambre & Pingot, 2008). In the south flank of the tunnel, a second quarry shows by fine-grained and well-bedded black limestones (Carrière Leurquin Member in Delcambre & Pingot, 2008). Algal facies are well developed (oncolites, stromatolites,…). This unit contains some layers of oolithic coarse limestone and breccias. The Onoz Formation represents the Moliniacian stage in the Orneau Valley (Lower Visean; Hance *et al.*, 1981).

Lives Formation succeeds to the Moliniacian strata. It includes well-bedded pale or dark limestones arranged in sequences. Each sequence contains at the base bioclastic dark grey limestone and at the top fine-grained and algal limestones. The formation gradually and laterally passes to breccias with boulders of limestone and calcitic or micritic matrix. In the Orneau Valley, the Lives Formation contains at the top massive pale limestone generally completely brecciated. The Betche aux Rotches cave is developed in the top of this massive and brecciated part of Lives Formation.



Lithostratigraphic column
System
Series
Stages
Lithostratigraphic units
Lithology
Palaeogene
Eocene
Palaeocene
Lutetian
Ypres.
Thanetian
Bruxelles (BXL)
Erquelinnes (ERQ)
Cretaceous
Upper Cretaceous
Santonian
Coniacian
Lonzée (LON)
Carboniferous
Westphalian
Namurian
Visean
Tournaisian
B
A
Yeadonian
Marsdenian
Kinderscoutian
Alportian
Chokierian
Arnsbergian
Pendelian
Warnantian
Livian
Moliniacian
Ivorian
Hastarian
Famennian
Coal Measures (HOU) Les Couplées
Gd Dressant
Gd Dressant
Ste Barbe
Léopold
Ste Anne
Vein n°11
Calvaire
Charleroi
Chatelet
Andenne
Chokier
H. marine de Quaregnon
Faux
Ste Barbe de Floriffoux
Ste Barbe de Ransart
G
R2c1
Rbc1
R1c1
H2c
H1b
E2c
E2b
E2a2
Lacuna
Viesville (VIE)
Hoyoux (HOY)
Lives (LIV)
Onoz (ONO)
Namur (NMR)
(ECA) Ecaussinnes
Lalaing (LAL)
Landelies (LAN)
Pont d'Arcole (PDA)
Lacuna
Bois de la Rocq (BDR)
Franc-Waret (FRW)
Devonian
Upper Devonian
Middle Devonian
Frasnian
Givetian
Rhisnes (RHI)
Falnuée (FLN)
Golzinne (GOL)
Watiamont (WAT)
Champ du Fau (CHF)
Combreuil (CBR)
Bovesse (BOV)
Bossière (BOS)
Bois de Bordeaux (BOR)
Mazy (MAZ)
Alvaux (ALV)
Mautiennes (MTN)
Lacuna of discordance
Silurian
Wenlockian
Llandoverian
Homerian
Sheinwoodian
Telychian
Aeronian
Rhuddanian
SIL
Vichenet (VCH)
Fumal (FUM)
Vissoul (VSS)
Les Vallées (LVA)
Corroy (COR)
Fallais (FLL)
Bois Grand-Père (BGP)
Pitet
Ordovician
Ashgillian
Caradocian
HIR.
Rawtheian
ρ
Nivelles
Brutia (BRT)
Madot (MAD)
HM
Huet (HUF)
Grand-Manil
Bornival (BNV)
Without scale

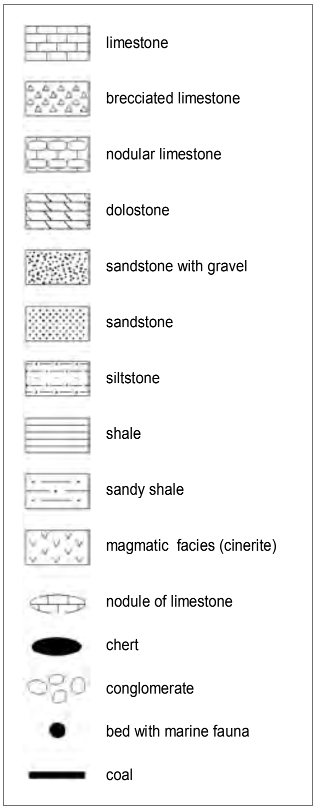


Figure 5. (opposite page and above) Lithostratigraphic and chrono-stratigraphic patterns of the Spy area (after Delcambre & Pingot, 2008).

The Hoyoux Group closes the carbonated sedimentation of the Visean. It contains thin-bedded and well-stratified limestones. The lower part of the group exposes especially pluricentimetric to decimetric-bedded fine-grained and stromatolitic limestones (Thon-Samson and Poilvache Formations). The upper part (Anhée Formation) corresponds to parasequences of dark well-bedded limestones with thicker bioclastic bases. The top of the formation contains very coarse-grained and fossiliferous layers. Thin seams of dirty coal are inserted in limestones. One of them has been mined 100 m in the south of the cave.

The Upper Carboniferous formations of the Orneau River

Before joining the Sambre River, Orneau River crops the Upper Carboniferous Coal Measures. At a small scale, coal seams were mined before World War I in the lowest part of the valley; after the war, some of them persisted (Delcambre & Pingot, 2008). At Spy, mining in the Hordin gallery started in the first half of the 19th century and lasted until 1925 (Demanet & Biot, 1951). The Coal Measures consist of shales, siltites and sandstones. They start with Namurian strata containing marine fauna. Then, parallic sedimentary conditions progressively occur towards the Westphalian where the main coal seams are developed. These layers correspond to the *Comble Nord* of the productive *Bassin houiller de Charleroi*. At the base of the Namurian, the Pendleian strata are missing: a gap occurs between Visean and Namurian without evidence of unconformity in this area.

MESOZOIC

Lower Mesozoic deposits are poorly represented in Belgium due to dominant continental conditions during this period. Marine sediments from Triassic and Jurassic only crop out in Southern Belgium (Belgian Lorraine; Boulvain *et al.*, 2001; Figures 1-2). They are also known from boreholes in the Campine Basin (Dusar *et al.*, 2001). Only continental deposits of the Lower Cretaceous are preserved in the Mons Basin (Robaszynski *et al.*, 2001; Pirson *et al.*, 2008).

During Upper Cretaceous, an epicontinental sea progressively floods a large part of Belgium (Robaszynski *et al.*, 2001). Today, Cretaceous strata mainly crop out in the Liège-Maastricht area and in the Mons Basin (Figure 1). Southern Belgium may have been only sparsely covered with marine deposits from this period as this area constituted a small continent connected with Variscan formations in Germany (positive Ardenno-Rhenish Massif; Ziegler, 1990).

During Permo-Triassic and Jurassic, the Orneau Valley remains a continental area. The first traces of marine deposits attributed to Coniacian or Santonian (Upper Cretaceous) are preserved around Gembloux: outliers of the glauconitic Sands of Lonzée with chalky boulders, invertebrate macrofauna and remains of marine reptiles (*Mosasaurus*, *Hainosaurus*). During Upper Cretaceous, Orneau Valley is located at the western flank of the Ardenno-Rhenish Massif.

PALAEOGENE AND NEOGENE

During the Palaeogene and Neogene, the sea episodically invades Belgium, first from both the west and the north, then only from the north. From the Miocene onward, marine sediments are more and more distant from the Sambre and Meuse axis (de Heinzelin, 1963; Laga *et al.*, 2001). This is linked with the generalised uplift of the Ardenne (Macar, 1976; Demoulin, 1995a) and the subsidence of the Netherlands Basin. During the same period, the Belgian Basin is definitely isolated from the Paris Basin by the Weald-Boulonnais-Artois bulge, which is associated with the Ardenne uplift (Vandenberghe *et al.*, 1998).

In Northern Belgium, Palaeogene and Neogene deposits are mainly marine sediments, reaching several hundreds of metres (Vandenberghe *et al.*, 1998; Laga *et al.*, 2001). In Southern Belgium, the Palaeogene sea only makes a few incursions that rarely crossed over the Sambre and Meuse axis southwards, mainly during the "Bruxellian" (Lutetian *pro parte*) and Oligocene (Ek & Ozer, 1976; Robaszynski & Dupuis, 1983; Demoulin, 1995b). Residual superficial deposits (mainly marine sands) in the Liège and Namur areas as well as marine sands trapped in karstic sink-holes in the Condroz are evidence of these marine incursions (Robaszynski & Dupuis, 1983; Demoulin, 1995b). There is, however, an exception with the subsiding Mons Basin, which continued to act as a sedimentary trap for marine deposits during the first part of Palaeogene (Cornet, 1927; Robaszynski & Dupuis, 1983; Dupuis & Robaszynski, 1986; Vandenberghe *et al.*, 1998; Laga *et al.*, 2001). Neogene marine sediments are absent in Southern Belgium.

Traces of Eocene transgressions appear on the two sides of the Orneau Valley, where Lutetian sands of the Bruxelles Formation cover the Palaeozoic basement. The North Sea transgresses on the northern flank of the Ardenne and develops a system of sand bars and channels (Houthuys & Gullentops, 1985). In Orneau Valley, diagenetic processes lead to the cementation of these Lutetian sands and the development of the "Fayat sandstones" facies of the Bruxelles Formation (Rutot, 1887). This cemented sand was used by prehistoric humans in Velaine-sur-Sambre, both as polishing stones and as a standing stone (Rutot, 1887; Pirson *et al.*, 2003).

QUATERNARY

Apart from a few marine and fluvio-marine deposits related to the coastal plain, Quaternary

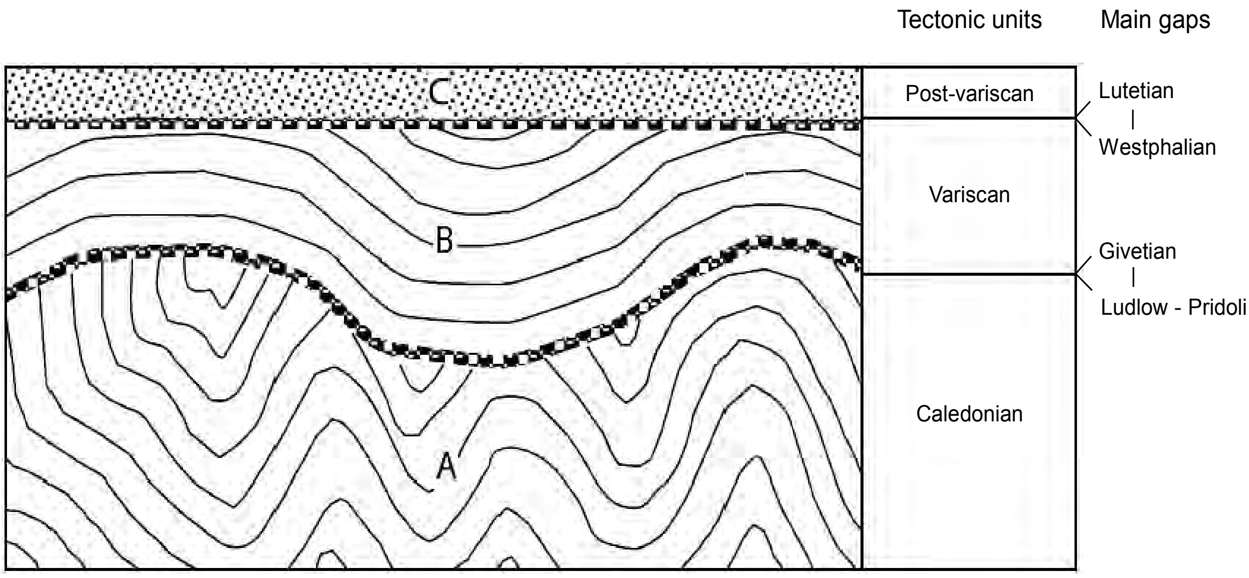


Figure 6. Synthetic sketch of the geometric relations between the tectonic units exposed along the Orneau Valley, where the main orogenic angular unconformities (ᙀᙀᙀ) and sedimentary gaps are summarised.

sediments are of continental origin in Belgium (e.g. Paepe & Vanhoorne, 1967, 1976; Haesaerts, 1984a; Gullentops *et al*., 2001; Baeteman, 2004).

The glaciers from Northern Europe never reached Belgium. However, at their maximum extent, they went as far as Southern Netherlands. Belgium was thus situated at their border. Climate was then periglacial. Several times, permafrost affected the territory (Haesaerts & Van Vliet, 1973; Haesaerts, 1984a).

Fluviatile environment

The formation of today's drainage pattern goes back to the end of Neogene and to Quaternary (de Heinzelin, 1963; Laurent, 1976; Grimbérieux *et al.*, 1995). During the retreat of the Oligocene sea, rivers were flowing to the north on top of the Palaeogene marine sands, originating most of the rivers (consequent streams). Shoreline being situated to the north, preferential orientation of rivers was thus south/north. The direction of some of the present streams is still perpendicular to the Variscan structures. These rivers then equally cut carbonated rocks, shales or sandstones. It is generally considered that once passed through the loose Cenozoic cover, rivers carried on channeling in the Palaeozoic hardened rocks but keeping the same general orientation (superimposition; e.g. Grimbérieux *et al.*, 1995). However, the impact of transversal Variscan geological structures should not be neglected.

After the retreat of the Oligocene sea, High Belgium underwent a generalised uplift (Macar, 1976; Demoulin, 1995a) leading to an increase of erosion rate and to the down-cutting of rivers. This, combined to the Quaternary global climatic changes, allowed the preservation of alluvial terraces (Alexandre-Pyre & Kupper, 1976; Cornet, 1995). The best-studied alluvial terraces in Belgium are those of the Meuse (e.g. Pissart, 1975; Juvigné & Renard, 1992) and the Escaut Basins (Tavernier & De Moor, 1975), although their chronology remains rather inaccurate. The terraces of the Haine Basin are an exception. The four preserved terraces, which yield interesting Lower and Middle Palaeolithic series, have recorded MIS 12 to 6 in a quite well-defined chronostratigraphic framework (Briart *et al*., 1868; Haesaerts, 1978, 1984b; Pirson *et al*., 2009).

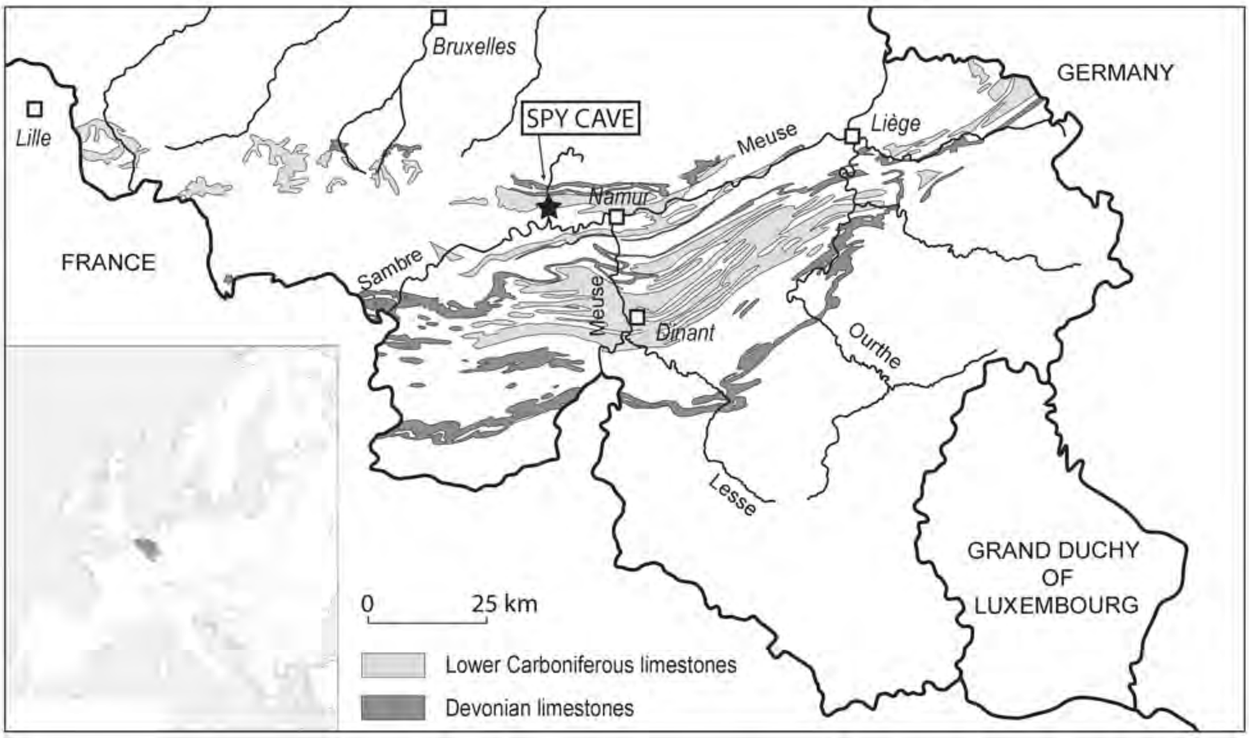


Figure 7. Distribution of the Palaeozoic carbonated rocks in Belgium (after Toussaint & Pirson, 2007, modified from Ek, 1976).

The story of the Orneau River drainage pattern remains very badly known. In front of Spy cave, the size of the valley appears too big for this small river. This has been interpreted as a result of the growing meanders of the Sambre River intersecting each other and cutting off a meander loop. The resulting abandoned meander of the Sambre River was then partly used by the Orneau River. As a consequence, the confluence between the two rivers migrated 2 km southwards (Fichefet, 1933). The timing of this meander cut-off remains largely unknown. Fichefet (1933) reports the presence of several alluvial terraces with pebbles in the lower portion of the present Orneau Valley. He mentions one of them in the "*Fond-des-Cuves*" (in fact in "*Les Ôrnias*") at an altitude of 118 m, which can also be found on the other side of the present Orneau Valley, "at the Spy cave". According to this author, when the Sambre River was flowing in the present lower valley of the Orneau, the confluence was situated somewhere around the Spy cave.

Aeolian environment

During some particularly cold and dry climatic phases, aeolian deposits covered the region. In Middle Belgium, a thick silt cover settled down (loess), sometimes reaching 10 metres or more. To the north, these aeolian deposits became more sandy (Paepe & Vanhoorne, 1976).

Aeolian deposits from Middle Pleistocene are barely represented in Belgium and therefore remain poorly known, with the exception of the Eben-Emael/Maastricht area which yielded an important succession of loess and interglacial palaeosols dating back to MIS 12 (Meijs, 2002). The Upper Pleistocene deposits are much largely spread and were well studied during the last fifty years (e.g. Gullentops, 1954; Haesaerts, 1974, 2004; Paepe & Vanhoorne, 1976; Juvigné *et al.*, 2008; Pirson *et al.*, 2009). This led to better understand the palaeoenvironmental and chronostratigraphic framework of this kind of environment. Palaeoenvironment information is recorded through sedimentary dynamics, fossil soils and periglacial features (Haesaerts, 1974; Haesaerts & Van Vliet-Lanoë, 1981; Van Vliet-Lanoë, 1988), and further documented by palynological and faunal data (Bastin, 1971; Gautier *et al.*, 1973). The chronostratigraphic background is elaborated thanks to climatostratigraphy (Haesaerts, 1974, 2004; Haesaerts & Van Vliet-Lanoë, 1981) and completed by data from several disciplines: mineralogy, tephrochronology, TL stratigraphy, archaeology, radiocarbon dates and luminescence dates (see synthesis in Pirson *et al.*, 2009). A reference sequence has been elaborated for the Upper Pleistocene loessic deposits (Haesaerts, 1974, 1984a, 2004; Pirson *et al.*, 2009). Loessic sequences yielded some major Palaeolithic sites, associated with an accurate chronostratigraphic framework (Haesaerts, 1978, 2000, 2004).

Around Spy, especially in the Gembloux-Mazy area, a thick loess cover is present. It has been studied the last 60 years (Manil, 1949, 1952; Paepe, 1966; Paepe & Vanhoorne, 1967; Juvigné, 1977; Bolline *et al.*, 1980). The major pedolithostratigraphic units of the Upper Pleistocene are recorded, including MIS 5 with the Rocourt Pedocomplex and the Humiferous Complex of Remicourt bearing the Rocourt Tephra. One of the first palynological diagrams obtained from loess sections comes from Tongrinne (Bastin in Paepe *et al.*, 1968).

Karstic environment

Formation of Belgian caves mainly dates back to Quaternary (Ek & Poty, 1982). More than 3,000 caves are known in Belgium. Some of them have been recognised in the Jurassic of Southern Belgium (Gaume) or in the Malmedy Permian conglomerate, but most of them open in Middle and Upper Devonian limestones as well as in Dinantian limestones. Their geographic distribution is thus mainly restricted to Namur and Dinant Synclinoria and to Vesdre Massif (Figures 1 and 7). These Devono-Carboniferous limestones crop out on more than 1,600 km² (Ek, 1976). The larger caves of the country are located in the Devonian limestone of Calestienne (Eifelian, Givetian and Frasnian), at the edge of Ardenne. An overview of karstic phenomenon in Belgium is given in Ek (1976, 1995) as well as in Ek & Poty (1982).

Together with loess and lakes, caves are interesting environments for the study of Quaternary. They act as sedimentary traps, recording periods of time that are usually not preserved in the region because of the erosive dynamics dominating on a continental environment. In Belgium, karst is one of the few sedimentary environments allowing detailed study of Quaternary palaeoenvironments (Pirson *et al.*, 2006, 2008; Pirson, 2007), together with the loess from Middle Belgium and deposits from the Flemish Valley.

In the area of Spy, important karstic features have been reported in the Lower Carboniferous limestones (see Delcambre & Pingot, 2008). In the Lives Formation limestones, several cave networks have been described, the most famous being the cave of Spy. The age of the genesis of this cave is unknown. It must have been linked with the down-cutting of the Orneau River, the detail of which is largely unknown (see "Fluviatile environment" section above). The age of the cave filling is also very badly defined (see Pirson *et al.*, this volume: chapter VI); it cannot help defining a *terminus ante-quem* for the formation of the cave. As far as the cave sediments are concerned, the antiquity of the field research prevents any reliable analysis, either from stratigraphic or sedimentologic points of view.

ACKNOWLEDGEMENTS

The authors would like to thank Jean-Marc Baele (*Faculté Polytechnique de Mons*), Hélène Rougier (California State University Northridge), Michel Toussaint (*Direction de l'Archéologie du Service public de Wallonie*), Yves Vanbrabant (Royal Belgian Institute of Natural Sciences) and Johan Yans (*Facultés Universitaires Notre-Dame de la Paix*) as well as Philippe Pirson for helpful comments.

BIBLIOGRAPHY

ALEXANDRE-PYRE S. & KUPPER M., 1976. L'évolution des rivières. *In*: A. PISSART (coord.), *Géomorphologie de la Belgique. Hommage au Professeur P. Macar*. Liège, Laboratoire de Géologie et de Géographie physique, Université de Liège: 51-74.

ANDRÉ L., 1983. *Origine et évolution des roches éruptives du Massif du Brabant (Belgique)*. Thèse de doctorat inédite, Université libre de Bruxelles, Faculté des Sciences, Bruxelles, vol. **1**: 299 p., vol. **2**: 123 p.

ASSELBERGHS E., 1936. Le Dévonien au bord nord du Bassin de Namur. *Mémoire de l'Institut géologique de l'Université de Louvain*, **X**: 229-237.

BAETEMAN C., 2004. *The Holocene development of a tide-dominated coastal lowland. Western coastal plain of Belgium. Field Guide*. The QRA Third International Postgraduate Symposium Fieldtrip, September 17th 2004. Brussels, Belgian Geological Survey: 76 p.

BASTIN B., 1971. *Recherches sur l'évolution du peuplement végétal en Belgique durant la glaciation de Würm*. Louvain, Institut de Géographie de l'Université catholique de Louvain, Acta Geographica Lovaniensia, **9**: 136 p.

BEUGNIES A., 1986. Le métamorphisme de l'aire anticlinale de l'Ardenne. *Hercynia*, **II**: 17-33.

BLESS M.-J.-M., BOUCKAERT J. & PAPROTH E., 1989. The Dinant Nappes: a model of tensional listric faulting inverted into compressional folding and thrusting. *Bulletin de la Société belge de Géologie*, **98**: 221-230.

BOLLINE A., PISSART A., BASTIN B. & JUVIGNÉ E., 1980. Étude d'une dépression fermée près de Gembloux; vitesse de l'érosion des terres cultivées de Hesbaye. *Annales de la Société géologique de Belgique*, **103**: 143-152.

BOULVAIN F., BELANGER I., DELSATE D., DOSQUET D., GHYSEL P., GODEFROIT P., LALOUX M., ROCHE M., TEERLYNCK H. & THOREZ J., 2001. New lithostratigraphical, sedimentological, mineralogical and palaeontological data on the Mesozoic of Belgian Lorraine: a progress report. *Geologica Belgica*, **3**: 3-33.

BOULVAIN F., BULTYNCK P., COEN M., COEN-AUBERT M., LACROIX D., LALOUX M.,

CASIER J.-G., DEJONGHE L., DUMOULIN V., GHYSEL P., GODEFROID J., HELSEN S., MOU-RAVIEFF N. A., SARTENAER P., TOURNEUR F. & VANGUESTAINE M., 1999. *Les formations du Frasnien de la Belgique*. Bruxelles, Memoirs of the Geological Survey of Belgium, **44**: 124 p.

BRIART A., CORNET F. & HOUZEAU DE LEHAIE A., 1868. Rapport sur les découvertes géologiques et archéologiques faites à Spiennes en 1867. *Mémoires et publications de la Société des Sciences, des Arts et des Lettres du Hainaut, troisième série*, **2**/1866-1867: 355-392.

BULTYNCK P., COEN-AUBERT M., DEJONGHE L., GODEFROID J., HANCE L., LACROIX D., PRÉAT A., STAINIER P., STEEMANS P., STREEL M. & TOURNEUR F., 1991. *Les formations du Dévonien moyen de la Belgique*. Bruxelles, Mémoires pour servir à l'Explication des Cartes Géologiques et Minières de la Belgique, **30**: 106 p.

BULTYNCK P. & DEJONGHE L. (ed.), 2001. *Guide to a revised lithostratigraphic scale of Belgium*. Geologica Belgica, **4**: 168 p.

BULTYNCK P., GEUKENS F. & SMOLDEREN A., 2001. Permian lithostratigraphic units, Malmédy Graben (Belgium). *In*: P. BULTYNCK & L. DEJONGHE (ed.), *Guide to a revised lithostratigraphic scale of Belgium*. Geologica Belgica, **4**: 105-106.

CONIL R., 1959. Recherches stratigraphiques sur les terrains dinantiens dans le bord nord du Bassin de Namur. *Mémoire de l'Académie royale de Belgique, Classe des Sciences*, **XIV** (5): 1-159.

CORIN F., 1965. *Atlas des roches éruptives de Belgique*. Bruxelles, Mémoires pour servir à l'Explication des Cartes Géologiques et Minières de la Belgique, **4**: 190 p.

CORNET J., 1927. *Leçons de Géologie*. Bruxelles, Maurice Lamertin: 674 p.

CORNET Y., 1995. L'encaissement des rivières ardennaises au cours du Quaternaire. *In*: A. DEMOULIN (ed.), *L'Ardenne. Essai de géographie physique. Hommage au Professeur A. Pissart*. Liège, Département de Géographie physique et Quaternaire, Université de Liège: 155-177.

DE DORLODOT H., 1885. Note sur la discordance du Dévonien sur le Silurien dans le bassin de Namur. *Annales de la Société géologique de Belgique*, **12**: 207-241.

DE HEINZELIN J., 1963. Le réseau hydrographique de la région gallo-belge au Néogène. Essai de reconstitution. *Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie*, **72**: 137-148.

DELCAMBRE B. & PINGOT J.-L., 2002. *Carte géologique n°40/5-6: Chastre-Gembloux*. Namur, Carte géologique de Wallonie, Ministère de la Région wallonne, DGRNE: 72 p., 1 map.

DELCAMBRE B. & PINGOT J.-L., 2008. *Carte géologique n°47/1-2: Fleurus-Spy*. Namur, Carte géologique de Wallonie, Ministère de la Région wallonne, DGRNE: 96 p., 1 map.

DELÉPINE G., 1911. *Recherches sur le calcaire carbonifère de la Belgique*. Lille, Mémoires et Travaux de la Faculté Catholique de Lille, **8**: 419 p.

DELMER A., DUSAR M. & DELCAMBRE B., 2001. Upper Carboniferous lithostratigraphic units (Belgium). *In*: P. BULTYNCK & L. DEJONGHE (ed.), *Guide to a revised lithostratigraphic scale of Belgium.* Geologica Belgica, **4**: 95-103.

DEMANET F. & BIOT A., 1951. *La galerie d'Hordin à Spy*. Bruxelles, Mémoires de l'Institut royal des Sciences naturelles de Belgique, **119**: 36 p.

DEMOULIN A., 1995a. L'Ardenne bouge toujours. Néotectonique du massif ardennais. *In*: A. DEMOULIN (ed.), *L'Ardenne. Essai de géographie physique. Hommage au Professeur A. Pissart*. Liège, Département de Géographie physique et Quaternaire, Université de Liège: 110-135.

DEMOULIN A., 1995b. L'Ardenne des plateaux, héritage des temps anciens. Surfaces d'érosion en Ardenne. *In*: A. DEMOULIN (ed.), *L'Ardenne. Essai de géographie physique. Hommage au Professeur A. Pissart.* Liège, Département de Géographie physique et Quaternaire, Université de Liège: 68-93.

DENAEYER M.-E. & MORTELMANS G., 1954. Les roches éruptives. *In*: P. FOURMARIER (ed.), *Prodrome d'une description géologique de la Belgique.* Liège, Société géologique de Belgique: 745-792.

DEVIVIER P., 1913. Description d'un nouvel affleurement montrant le contact du Silurien et du Dévonien à Alvaux. *Annales de la Société géologique de Belgique*, **40**: B410-B413.

DUMON P., 1933. Quelques observations sur le marbre noir de Mazy (étage frasnien). *Bulletin de la Société belge de Géologie*, **43**: 237-284.

DUPUIS C. & ROBASZYNSKI F., 1986. Tertiary and Quaternary deposits in and around the Mons Basin. Documents for a field trip. *Mededelingen van de Werkgroep Tertiaire en Kwartaire Geologie*, **23**: 3-19.

DUSAR M., LANGENAEKER V. & WOUTERS L., 2001. Permian – Triassic – Jurassic lithostratigraphic units in the Campine basin and the Roer Valley Graben (NE Belgium). *In*: P. BULTYNCK & L. DEJONGHE (ed.), *Guide to a revised lithostratigraphic scale of Belgium.* Geologica Belgica, **4**: 107-112.

EK C., 1976. Les phénomènes karstiques. *In*: A. PISSART (coord.), *Géomorphologie de la Belgique. Hommage au Professeur P. Macar*. Liège, Laboratoire de Géologie et de Géographie physique, Université de Liège: 137-157.

EK C., 1995. Grottes et rivières des régions calcaires. *In*: A. DEMOULIN (ed.), *L'Ardenne. Essai de géographie physique. Hommage au Professeur A. Pissart*. Liège, Département de Géographie physique et Quaternaire, Université de Liège: 178-193.

EK C. & OZER A., 1976. Les dernières transgressions marines. *In*: A. PISSART (coord.), *Géomorphologie de la Belgique. Hommage au Professeur P. Macar*. Liège, Laboratoire de Géologie et de Géographie physique, Université de Liège: 9-16.

EK C. & POTY E., 1982. Esquisse d'une chronologie des phénomènes karstiques en Belgique. *Revue belge de Géographie*, **106**: 73-85.

FICHEFET J., 1933. Observations sur trois méandres recoupés de la Sambre. *Bulletin du cercle des géographes liégeois*, **5** (2): 15-22.

FIELITZ W. & MANSY J.-L., 1999. Pre- and synorogenic burial metamorphism in the Ardenne and neighbouring areas (Rhenohercynian zone, central European Variscides). *Tectonophysics*, **309**: 227-256.

FOURMARIER P. (ed.), 1954. *Prodrome d'une description géologique de la Belgique*. Liège, Société géologique de Belgique: 826 p.

FRANKE W., 1989. Tectonostratigraphic units in the Variscan belt of central Europe. *In*: R. D. DALLMEYER (ed.), *Terranes in the Circum-Atlantic Paleozoic Orogens*. Geological Society of America, **230**, Special Paper: 67-90.

GAUTIER A., BALLMANN P. & DE CONINCK J., 1973. *La faune du site paléolithique de Maisières-Canal*. Bruxelles, Mémoires de l'Institut royal des Sciences naturelles de Belgique, **172**: 29 p.

GODEFROID J., BLIECK A., BULTYNCK P., DEJONGHE L., GERRIENNE P., HANCE L., MEILLIEZ F., STAINIER P. & STEEMANS P., 1994. *Les formations du Dévonien inférieur du Massif de la Vesdre, de la Fenêtre de Theux et du Synclinorium de Dinant (Belgique, France)*. Bruxelles, Mémoires pour servir à l'Explication des Cartes Géologiques et Minières de la Belgique, **38**: 144 p.

GRIMBÉRIEUX J., LAURANT A. & OZER P., 1995. Les rivières s'installent. *In*: A. DEMOULIN (ed.), *L'Ardenne. Essai de géographie physique. Hommage au Professeur A. Pissart*. Liège, Département de Géographie physique et Quaternaire, Université de Liège: 94-109.

GULLENTOPS F., 1954. Contributions à la chronologie du Pléistocène et des formes du relief en Belgique. *Mémoires de l'Institut géologique de l'Université de Louvain*, **18**: 125-252.

GULLENTOPS F., BOGEMANS F., DE MOOR G., PAULISSEN E. & PISSART A., 2001. Quaternary lithostratigraphic units (Belgium). *In*: P. BULTYNCK & L. DEJONGHE (ed.), *Guide to a revised lithostratigraphic scale of Belgium.* Geologica Belgica, **4** (1-2): 153-164.

HAESAERTS P., 1974. Séquence paléoclimatique du Pléistocène supérieur du bassin de la Haine (Belgique). *Annales de la Société géologique de Belgique*, **97** (1): 105-137.

HAESAERTS P., 1978. Contexte stratigraphique de quelques gisements paléolithiques de plein air de Moyenne Belgique. *Bulletin de la Société royale belge d'Anthropologie et de Préhistoire*, **89**: 115-133.

HAESAERTS P., 1984a. Aspects de l'évolution du paysage et de l'environnement en Belgique au Quaternaire. *In*: D. CAHEN & P. HAESAERTS (ed.), *Peuples chasseurs de la Belgique préhistorique dans leur cadre naturel*. Bruxelles: 27-39.

HAESAERTS P., 1984b. Les formations fluviatiles pléistocènes du bassin de la Haine (Belgique). *Bulletin de l'Association française pour l'étude du Quaternaire*, **1-2-3**: 19-26.

HAESAERTS P., 2000. Stratigraphie de la station préhistorique de l'Hermitage à Huccorgne. *In*: L. G. STRAUS, M. OTTE & P. HAESAERTS (ed.), *La station de l'Hermitage à Huccorgne. Un habitat de plein-air à la frontière septentrionale du monde gravettien*. Liège, ERAUL, **94**: 15-34.

HAESAERTS P., 2004. Maisières-Canal (2000-2002): cadre stratigraphique. *In*: R. MILLER, P. HAESAERTS & M. OTTE (dir.), *L'atelier de taille aurignacien de Maisières-Canal (Belgique)*. Liège, ERAUL, **110**: 13-26.

HAESAERTS P. & VAN VLIET B., 1973. Évolution d'un permafrost fossile dans les limons du Dernier Glaciaire à Harmignies (Belgique). *Bulletin de l'Association française pour l'étude du Quaternaire*, **35**: 151-164.

HAESAERTS P. & VAN VLIET-LANOË B., 1981. Phénomènes périglaciaires et sols fossiles observés à Maisières-Canal, à Harmignies et à Rocourt. *Biuletyn Peryglacjalny*, **28**: 291-324.

HANCE L., HENNEBERT M. & OVERLAU P., 1981. Révision stratigraphique et sédimentologique du Tournaisien supérieur (Ivorien) et du Viséen inférieur (Moliniacien) de la vallée de l'Orneau (Belgique). *Mémoire de l'Institut géologique de l'Université de Louvain*, **31**: 183-207.

HANCE L., POTY E. & DEVUYST F.-X., 2001. Stratigraphie séquentielle du Dinantien type (Belgique) et corrélation avec le Nord de la France (Boulonnais, Avesnois). *Bulletin de la Société géologique de France*, **172**: 411-426.

HOUTHUYS R. & GULLENTOPS F., 1985. Brusseliaan faciëssen en hun invloed op het relief ten zuiden van Brussel. *Bulletin de la Société belge de Géologie*, **94**: 11-18.

JUVIGNÉ E., 1977. Zone de dispersion et âge des poussières volcaniques du tuf de Rocourt. *Annales de la Société géologique de Belgique*, **100**: 13-22.

JUVIGNÉ E. & RENARD F., 1992. Les terrasses de la Meuse de Liège à Maastricht. *Annales de la Société géologique de Belgique*, **115**: 167-186.

JUVIGNÉ E., TALLIER E., HAESAERTS P. & PIRSON S., 2008. Un nouveau stratotype du Téphra de Rocourt dans la carrière de Romont (Eben/Bassenge, Belgique). *Quaternaire*, **19** (2): 133-139.

KAISIN F., 1912. Observation sur le marbre noir de Golzinne. *Annales de la Société scientifique de Bruxelles*, Mémoires, **36**: 418-428.

LACROIX D., 1972. *La sous-assise du Poudingue d'Alvaux dans la vallée de l'Orneau*. Bruxelles, Professional Papers, **3**: 8 p.

LAGA P., LOUWYE S. & GEETS S., 2001. Paleogene and Neogene lithostratigraphic units (Belgium). *In*: P. BULTYNCK & L. DEJONGHE (ed.), *Guide to a revised lithostratigraphic scale of Belgium.* Geologica Belgica, **4**: 135-152.

LAURENT A., 1976. La formation du réseau hydrographique de la Belgique. *In*: A. PISSART (coord.), *Géomorphologie de la Belgique. Hommage au Professeur P. Macar.* Liège, Laboratoire de Géologie et de Géographie physique, Université de Liège: 29-50.

LESPÉRANCE J. & SHEEHAN P. M., 1987. Trilobites et brachiopodes asghilliens (Ordovicien supérieur) de l'Assise de Fosse, Bande de Sambre-et-Meuse (Belgique). *Bulletin de l'Institut royal des Sciences naturelles de Belgique*, **57**: 91-123.

MACAR P., 1976. Les mouvements épeirogéniques décelables en Belgique. L'aide de la Géomorphologie. *In*: A. PISSART (coord.), *Géomorphologie de la Belgique. Hommage au Professeur P. Macar.* Liège, Laboratoire de Géologie et de Géographie physique, Université de Liège: 93-106.

MANIL G., 1949. Le Quaternaire des environs de Gembloux. La tranchée de Mazy. *Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie*, **58**: 139-152.

MANIL G., 1952. Quelques considérations générales sur la stratigraphie quaternaire et la pédogénèse à propos de la description de trois coupes de Loess (Hesbaye Gembloutoise). *Annales de la Société géologique de Belgique*, **75**: B153-B165.

MATTE P., 1986a. La chaîne varisque parmi les chaînes paléozoïques péri-atlantiques, modèle d'évolution et position des grands blocs continentaux au Permo-Carbonifère. *Bulletin de la Société géologique de France*, **8** (II): 9-24.

MATTE P., 1986b. Tectonics and plate tectonics model for the Variscan Belt of Europe. *Tectonophysics*, **126**: 329-374.

MEIJS E. P. M., 2002. Loess stratigraphy in Dutch and Belgian Limburg. *Eiszeitalter und Gegenwart*, **51**: 114-130.

MICHOT P., 1954. Le Silurien. *In*: P. FOURMARIER (ed.), *Prodrome d'une description géologique de la Belgique*. Liège, Société géologique de Belgique: 39-82.

ONCKEN O., VON WINTERFELD C. & DITTMAR U., 1999. Accretion of a rifted passive margin: The Late Paleozoic Rhenohercynian fold and thrust belt (Middle European Variscides). *Tectonics*, **18**: 75-91.

PAEPE R., 1966. Comparative stratigraphy of Würm loess deposits in Belgium and Austria. *Bulletin de la Société belge de Géologie*, **75**: 203-216.

PAEPE R., BASTIN B. & PISSART A., 1968. Compte rendu de l'excursion du 15 juin 1968 consacrée à la stratigraphie des limons près de Liège (Vivegnis) et de Gembloux (Tongrinne) et aux dépôts de travertins d'Annevoie-Rouillon. *Annales de la Société géologique de Belgique*, **91**: 617-624.

PAEPE R. & VANHOORNE R., 1967. *The Stratigraphy and Palaeobotany of the Late Pleistocene in Belgium*. Bruxelles, Mémoires pour servir à l'Explication des Cartes Géologiques et Minières de la Belgique, **8**: 96 p.

PAEPE R. & VANHOORNE R., 1976. *The Quaternary of Belgium and its relationship to the stratigraphical legend of the geological map*. Bruxelles, Mémoires pour servir à l'Explication des Cartes Géologiques et Minières de la Belgique, **18**: 38 p.

PAPROTH E., CONIL R., BLESS M.-J.-M., BOONEN P., CARPENTIER N., COEN M., DELCAMBRE B., DEPRIJCK C., DEUZON S., DREESEN R., GROESSENS E., HANCE L., HENNEBERT M., HIBO D., HAHN G., HAHN R., HISLAIRE O., KASIG W., LALOUX M., LAUWERS A., LEES A., LYS M., OP DE BEEK K., OVERLAU P., PIRLET H., POTY E., RAMSBOTTOM W., STREEL M., SWENNEN R., THOREZ J., VANGUESTAINE M., VAN STEENWINKEL M. & VIESLET J. L., 1983a. Bio- and Lithostratigraphic Subdivisions of the Dinantian in Belgium, a review. *Annales de la Société géologique de Belgique*, **106**: 185-239.

PAPROTH E., DUSAR M., BLESS M.-J.-M., BOUCKAERT J., DELMER A., FAIRON-DEMARET M., HOULLEBERGHS E., LALOUX M., PIERART P., SOMERS Y., STREEL M., THOREZ J. & TRICOT J., 1983b. Bio- and Lithostratigraphic Subdivisions of the Silesian in Belgium, a review. *Annales de la Société géologique de Belgique*, **106**: 240-283.

PIRSON S., 2007. *Contribution à l'étude des dépôts d'entrée de grotte en Belgique au Pléistocène supérieur. Stratigraphie, sédimentogenèse et paléoenvironnement.* Thèse de doctorat inédite, Université de Liège et Institut royal des Sciences naturelles de Belgique, **2** vol.: 435 p. + 5 annexes.

PIRSON S., COURT-PICON M., HAESAERTS P., BONJEAN D. & DAMBLON F., 2008. New data on geology, anthracology and palynology from the Scladina cave Pleistocene sequence: preliminary results. *In*: F. DAMBLON, S. PIRSON & P. GERRIENNE (ed.), *Hautrage (Lower Cretaceous) and Sclayn (Upper Pleistocene). Field Trip Guidebook. Charcoal and microcharcoal: continental and marine records.* IVth International Meeting of Anthracology, Brussels, Royal Belgian Institute of Natural Sciences, 8-13 September 2008. Bruxelles, Memoirs of the Geological Survey of Belgium, **55**: 71-93.

PIRSON S., HAESAERTS P., COURT-PICON M., DAMBLON F., TOUSSAINT M., DEBENHAM N. & DRAILLY C., 2006. Belgian cave entrance and rock-shelter sequences as palaeoenvironmental data recorders: the example of Walou Cave. *Geologica Belgica*, **9** (3-4): 275-286.

PIRSON S., HAESAERTS P. & DI MODICA K., 2009. Cadre chronostratigraphique des principaux gisements du Paléolithique moyen du bassin de la Haine: un état de la question. *In*: K. DI MODICA & C. JUNGELS (ed.), *Paléolithique moyen en Wallonie. La collection Louis Eloy*. Collections du Patrimoine culturel de la Communauté française, **2**: 58-77.

PIRSON S., TOUSSAINT M. & FRÉBUTTE C., 2003. Les matières premières des mégalithes de Belgique: état de la question. *Notae Praehistoricae*, **23**: 147-172.

PISSART A., 1975. La Meuse en France et en Belgique. Formation du bassin hydrographique. Les terrasses et leurs enseignements. *In*: P. MACAR (ed.), *L'évolution quaternaire des bassins fluviaux de la Mer du Nord méridionale*. Liège, Société géologique de Belgique: 105-131.

POTY E., HANCE L., LEES A. & HENNEBERT M.,

2001. Dinantian lithostratigraphic units (Belgium). *In*: P. BULTYNCK & L. DEJONGHE (ed.), *Guide to a revised lithostratigraphic scale of Belgium.* Geologica Belgica, **4**: 69-94.

RAOULT J.-F. & MEILLIEZ F., 1986. Commentaires sur une coupe structurale de l'Ardenne selon le méridien de Dinant. *Annales de la Société géologique du Nord*, **CV**: 97-109.

ROBASZYNSKI F., DHONDT A. V. & JAGT J. W. M., 2001. Cretaceous lithostratigraphic units (Belgium). *In*: P. BULTYNCK & L. DEJONGHE (ed.), *Guide to a revised lithostratigraphic scale of Belgium.* Geologica Belgica, **4**: 121-134.

ROBASZYNSKI F. & DUPUIS C. (ed.), 1983. *Belgique*. Paris, Masson (coll. Guides géologiques régionaux): 204 p.

RUTOT A., 1887. Sur l'âge du grès de Fayat. *Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie*, **1**: 42-48.

SAMUELSSON J. & VERNIERS J., 1999. Middle to Late Ordovician Chitinozoan Biozonation of the Sennette, Dyle-Thyle and Orneau Valleys, Brabant Massif, Belgium. *Acta Universitatis Carolinae-Geologica*, **43** (1/2): 299-302.

SINTUBIN M., 1999. Arcuate fold and cleavage patterns in the southeastern part of the Anglo-Brabant Fold Belt (Belgium): tectonic implications. *Tectonophysics*, **309**: 81-97.

TAVERNIER R. & DE MOOR G., 1975. L'évolution du bassin de l'Escaut. *In*: P. MACAR (ed.), *L'évolution quaternaire des bassins fluviaux de la Mer du Nord méridionale*. Centenaire de la Société géologique de Belgique. Liège, Société géologique de Belgique: 159-231.

THOREZ J. & DREESEN R., 1986. A model of a regressive depositional system around the Old Red Continent as exemplified by a field trip in the Upper Famennian “Psammites du Condroz” in Belgium. *Annales de la Société géologique de Belgique*, **109**: 285-323.

TOUSSAINT M. & PIRSON S., 2007. Aperçu historique des recherches concernant l'homme préhistorique dans le karst belge aux XIX^e^ et XX^e^ siècles: archéologie, géologie, paléoanthropologie, paléontologie, datations. *In*: J. EVIN (ed.), *Un siècle de construction du discours scientifique en préhistoire. Actes du XXVI^e^ Congrès préhistorique de France, Avignon, 21-25 septembre 2004. Volume 2*. Société préhistorique française: 117-142.

TSIEN H. H., 1980. Les régimes récifaux dévoniens en Ardenne. *Bulletin de la Société belge de Géologie*, **89**: 71-102.

VANBRABANT Y., BRAUN J. & JONGMANS D., 2002. Models of passive margin inversion: Implications for the Rhenohercynian fold-and-thrust belt, Belgium and Germany. *Earth and Planetary Science Letter*, **202**: 15-29.

VANDENBERGHE N., LAGA P., STEURBAUT E., HARDENBOL J. & VAIL P. R., 1998. Tertiary sequence stratigraphy at the southern border of the north sea basin in Belgium. *In*: *Mesozoic and Cenozoic Sequence Stratigraphy of European Basins*. SEPM Special Publication, **60**: 119-154.

VAN VLIET-LANOË B., 1988. *Le rôle de la glace de ségrégation dans les formations superficielles de l'Europe de l'ouest. Processus et héritages*. Thèse de doctorat d'état inédite, mention géographie, Université de Paris I - Sorbonne, Centre de Géomorphologie du CNRS, **2** vol.: 378 p. + 667 p.

VERNIERS J., HERBOSCH A., VANGUESTAINE M., GEUKENS F., DELCAMBRE B., PINGOT J.-L., BELANGER I., HENNEBERT M., DEBAC-KER T., SINTUBIN M. & DE VOS W., 2001. Cambrian-Ordovician-Silurian lithostratigraphic units (Belgium). *In*: P. BULTYNCK & L. DEJONGHE (ed.), *Guide to a revised lithostratigraphic scale of Belgium*. Geologica Belgica, **4**: 5-38.

ZIEGLER P. A., 1990. *Geological Atlas of Western and Central Europe (2^nd^ ed.)*. Shell Internationale Petroleum Maatschappij B.V.: 239 p.

AUTHORS AFFILIATION

Stéphane PIRSON
Department of Palaeontology
Royal Belgian Institute of Natural Sciences
29, Vautier Street
1000 Brussels
Belgium
stef.pirson@skynet.be
and
Direction de l'Archéologie, DGO4
Service public de Wallonie
1, rue des Brigades d'Irlande
5100 Namur
Belgium
stephane.pirson@spw.wallonie.be

Bernard DELCAMBRE
Earth & Life Institute
Université catholique de Louvain
3, place Louis Pasteur
1348 Louvain-la-Neuve
Belgium
bernard.delcambre@uclouvain.be

Éric GOEMAERE
Geological Survey of Belgium
Royal Belgian Institute of Natural Sciences
13, Jenner Street
1000 Brussels
Belgium
eric.goemaere@naturalsciences.be