KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN

INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE

ROYAL BELGIAN INSTITUTE OF NATURAL SCIENCES

MEMOIRS OF THE GEOLOGICAL SURVEY OF BELGIUM
N. 55 – 2008

IVth International Meeting of Anthracology
Royal Belgian Institute of Natural Sciences, 8-13 September 2008

Charcoal and Microcharcoal : Continental and Marine Records

Hautrage (Lower Cretaceous) and Sclayn (Upper Pleistocene)

Field Trip Guidebook

Edited by

F. DAMBLON, S. PIRSON & P. GERRIENNE

Excursion leaders:

Dominique BONJEAN – ASBL "Archéologie Andennaise" (Belgium)
Mona COURT-PICON – Royal Belgian Institute of Natural Sciences (Belgium)
Freddy DAMBLON – Royal Belgian Institute of Natural Sciences (Belgium)
Jean DEJAX – Musée National d'Histoire Naturelle de Paris (France)
Thomas GERARDS – Université de Liège (Belgium)
Philippe GERRIENNE – Université de Liège (Belgium)
Bernard GOMEZ – Université de Lyon I (France)
Stéphane PIRSON – Royal Belgian Institute of Natural Sciences (Belgium)
Paul SPAGNA – Faculté Polytechnique de Mons (Belgium)
Johan YANS – Facultés Universitaires Notre-Dame de la Paix (FUNDP), Namur (Belgium)

Cover illustration : Hunters in snow (1565), Pieter Bruegel the Elder

CONTENT

FIELD-GUIDE OF THE EXCURSION ON SEPTEMBER 13TH 2008, AN INTRODUCTION

Freddy DAMBLON[1], Stéphane PIRSON[1] & Philippe GERRIENNE[2]

1. Royal Belgian Institute of Natural Sciences, Department of Palaeontology
2. University of Liège, Department of Palaeontology

Research overview

The first charcoal analyses by a Belgian palaeontologist were performed in 1932 by Prof. Suzanne Leclercq (University of Liège) on the archaeological sites of Mitoc Malul Galben and Ripiceni Izvor in Romania (Leclercq, 1932). Later some attempt was made on the Palaeolithic site of La Belle Roche cave, Belgium (Fairon-Demaret, 1984). From this time, anthracology has been used in Belgium as a tool for past plant systematic, palaeo-ecology, palaeo-climatology, archaeology and dating, not only on Quaternary sites but also on material from other geological periods.

Since the nineties, the investigations in palaeobotany at the Royal Belgian Institute of Natural Sciences have been mainly focused on Quaternary plant remains. Charcoal and pollen analyses were performed on loessic deposits, cave infillings and peat deposits to define marker assemblages in sequences, allow palaeoecological reconstruction, provide material for dating and contribute to chronostratigraphy.

The investigations were mainly directed towards archaeological sites from the Atlantic border up to Siberia because large excavations give access to wide loess sections that make detailed stratigraphic studies possible and systematic collection of charcoal samples easier (Damblon, 1997, 2006; Damblon *et al.*, 1997; Haesaerts *et al.* 1996, 2003, 2005). Not only loess and loam deposits from open field were investigated but also silty and loamy infillings of caves in Belgium (Damblon *et al.*, in press). Some traces of wildfire were detected in some sequences. The results obtained on Scladina cave are explained hereafter (Pirson *et al.*, 2008).

Presently, the results are included in the EURASIAN MACROFOSSIL DATABASE (Program QUEST-Deglaciation) as a contribution to palaeo-mapping tree taxa during the last pleniglacial (Universities of Oxford, Southampton, Bristol).

The Department of Palaeontology also entered in collaboration with various foreign laboratories to promote new research on ancient charcoal material stored in the collections of the Museum. In this way, investigations started on several sites attributed to the Wealden in Belgium as Bernissart, Baudour and Hautrage. The main results are explained by different contributions in the present volume (Dejax *et al.* 2008; Gerards *et al.*, 2008; Gomez *et al.*, 2008).

The excursion of September 13th 2008

The field trip will be divided in two parts:

In the morning, visit of the clay/sand quarry of Hautrage (Mons basin) of the Wealden (Lower Cretaceous, Barremian/Aptian: about 130 - 112 Ma).

The site is estimated to be contemporaneous to the site of Bernissart which contained the famous Iguanodons exposed at the RBINS Museum (see contribution by Godefroit). New investigations were performed at the occasion of new drilling at Bernissart, while other Wealden sites were investigated, notably Hautrage with a very rich fossil plant flora. Not only leaves and fruits were found but also big pieces of trunks, some of them being charcoalified, and deposited in an alluvial context. The main results will be presented in different documents by the multidisciplinary team from Namur, Mons, Liège, Brussels, Paris and Lyon.

In the afternoon, visit of the Scladina cave at Sclayn (Meuse basin, nearby Namur).

This Middle Palaeolithic site is famous thanks to the discovery of human remains of Neandertal type. Another major interest of the site lies in a very fine pedostratigraphic study which allowed to understand the sedimentary dynamics and to carry out a multiproxy study combining sedimentology, micromorphology, geochemistry, anthracology, palynology, ^{14}C dating, magnetic susceptibility, macro- and micromammal studies. Preliminary results show a very good coherence between each discipline notably due to a high precision sampling in a detailed long sequence that may be compared with the long Upper Pleistocene cave sequence of Walou (Vesdre basin) and with the Belgian loess sequence.

References

DAMBLON, F., 1997. Palaeobotanical study of representative Upper Palaeolithic sites in the Central European Plain: a contribution to the Sc-004 Project. *Préhistoire Européenne,* Liège, 11: 245-253.

DAMBLON, F., 2006. Les restes paléobotaniques à Mitoc-Malu Galben. In: Otte, M., Chirica, V. & Haesaerts, P. (dir.), *L'Aurignacien et le Gravettien de Mitoc-Malu Galben (Moldavie roumaine)*. Etudes et Recherches archéologiques de l'Université de Liège (ERAUL), 72: 67-80.

DAMBLON, F., in press. Les analyses anthracologiques du site de Walou. *In*: Draily, C., Toussaint, M. & Pirson, S. (éd.), *La grotte Walou : fouilles 1996-2004. Volume 2 : les sciences de la vie et la chronologie*. Monographie (Etudes et document – Archéologie), Namur, Ministère de la Région wallonne.

DAMBLON, F., HAESAERTS, P. & VAN DER PLICHT, J., 1996. New datings and considerations on the chronology of Upper Palaeolithic sites in the Great Eurasiatic Plain. *Préhistoire Européenne*, 9: 177-231.

DEJAX, J., PONS, D. & YANS, J., 2008. Palynology of the Wealden facies from Hautrage quarry (Mons Basin, Belgium). This volume.

FAIRON-DEMARET M., 1984. Paléontologie végétale. Végétaux fossiles récoltés dans les paléokarsts de la Belgique. In : Ek, C. & Pfeffer, K.-H.(éd.), *Le karst belge. Karstphänomene in Nordrhein-Westfalen,* Cologne.Kölner Geographische Arbeiten, 45:107-116.

GERARDS, T., YANS, J., SPAGNA, P. & GERRIENNE, P., 2008. Wood remains and sporomorphs from the Wealden facies of Hautrage (Mons Basin, Belgium): palaeoclimatic and palaeoenvironmental implications. This volume.

GOMEZ, B., GILLOT, T., DAVIERO-GOMEZ, V., SPAGNA, P. & YANS, J., 2008. Palaeoflora from the Wealden facies strata of Belgium - mega- and meso-fossils of Hautrage. This volume.

HAESAERTS, P., F. DAMBLON, M. BACHNER & G. TRNKA, 1996 - Revised stratigraphy and chronology of the Willendorf II sequence (Lower Austria). *Archaeologia Austriaca,* 80 (1): 25-42.

HAESAERTS, P., BORZIAK, I., CHIRICA, V., DAMBLON, F., KOULAKOVSKA, L. & VAN DER PLICHT, J., 2003 - The East Carpathian loess record: a reference for the middle and late pleniglacial stratigraphy in Central Europe. *Quaternaire*, 14(3): 163-188.

HAESAERTS, P., CHEKHA, V.P., DAMBLON, F., DROZDOV, N.I., ORLOVA, L.A. & J. VAN DER PLICHT, 2005 – The lœss-palaeosol succession of Kurtak (Yenisei basin, Siberia): a reference record for the Karga Stage (MIS 3). *Quaternaire* (Paris), 16 (1): 3-24.

LECLERCQ, S., 1932.A propos de l'étude microscopique des Charbons de bois des foyers préhistoriques. *Annales de la Société Géologique de Belgique,* 55: 218-221.

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. This volume.

AN OVERVIEW OF THE GEOLOGY OF BELGIUM

Stéphane PIRSON[1,6], Paul SPAGNA[2], Jean-Marc BAELE[2], Freddy DAMBLON[1], Philippe GERRIENNE[3], Yves VANBRABANT[4] & Johan YANS[5]

1. Institut royal des Sciences naturelles de Belgique, Département de Paléontologie, 29 rue Vautier, B-1000 Bruxelles, Belgium. stef.pirson@skynet.be; freddy.damblon@naturalsciences.be
2. Faculté Polytechnique de Mons, Service de géologie fondamentale et appliquée, 9 rue de Houdain, B-7000 Mons, Belgium. Paul.Spagna@fpms.ac.be; Jean-Marc.Baele@fpms.ac.be
3. Université de Liège, Département de Géologie, Paléobotanique, Paléopalynologie et Micropaléontologie, B18, Sart Tilman, 4000 Liège. p.gerrienne@ulg.ac.be
4. Institut royal des Sciences naturelles de Belgique, Service géologique de Belgique, 13 rue Jenner, B-1000 Bruxelles, Belgium. yves.vanbrabant@naturalsciences.be
5. Facultés universitaires Notre-Dame de la Paix, 61 rue de Bruxelles, B-5000 Namur, Belgium. johan.yans@fundp.ac.be
6. Association wallonne d'Etudes mégalithiques, c/o Service de l'Archéologie en province de Liège, Ministère de la Région wallonne, 62 avenue des Tilleuls, B-4000 Liège, Belgium

(7 figures)

ABSTRACT. The geological context of the two stops of this palaeobotany field-trip, i.e. Hautrage quarry and Scladina cave, is presented. After an overview of the major features of geology of Belgium, from Lower Palaeozoic to Quaternary, two specific aspects of regional geology are examined. The first is Mons Basin, where Hautrage quarry is located. The second is caves and cave entrance deposits. A short introduction to the palaeobotany of Belgium is included.

KEYWORDS: Belgium, Palaeozoic, Mesozoic, Cenozoic, Palaeobotany, Mons Basin, Wealden facies, Cave deposits.

1. 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 Early Palaeozoic to Holocene. Figure 1 presents the regional geology in its European setting and Figure 2 focuses on the geology of Belgium.

Excepting the Quaternary cover, rocks outcropping in Belgium can broadly be divided into two large areas (Fig. 2; Fourmarier, 1954; Robaszynski & Dupuis, 1983; Boulvain & Pingot, 2002). The northern part of the country mainly exhibits Cenozoic deposits consisting of predominantly marine and unconsolidated sediments (Vandenberghe *et al.*, 1998). They may reach a thickness of several hundreds of meters. 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 have been subjected to strong deformation at the end of Carboniferous. However, Mesozoic rocks occur in the region of Mons (Cretaceous), Liège (Cretaceous) and Arlon (Triassic and Jurassic). Cenozoic deposits are rather poorly represented, except in the Mons Basin area.

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

The following synthesis will focus on the geological context of the two stops of the field trip, i.e. Hautrage Quarry and Scladina cave. Three aspects of the regional geology will then be more carefully examined: 1) the major steps of the evolution of terrestrial vegetation, 2) the Cretaceous deposits of Mons Basin, concerned by the Hautrage Quarry, and 3) the Quaternary cave deposits. Upper Palaeozoic deposits, in which are found the limestone where most caves developed in Belgium, will also be presented with some detail.

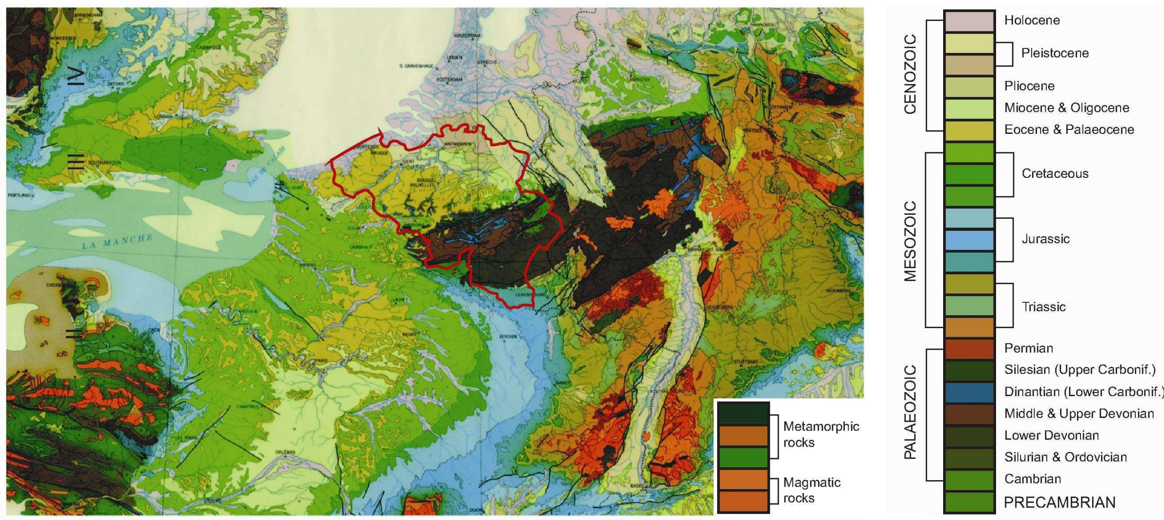

Figure 1. Geological map of Belgium and surrounding areas (extract from the Atlas de Belgique, reproduced with their kind permission).

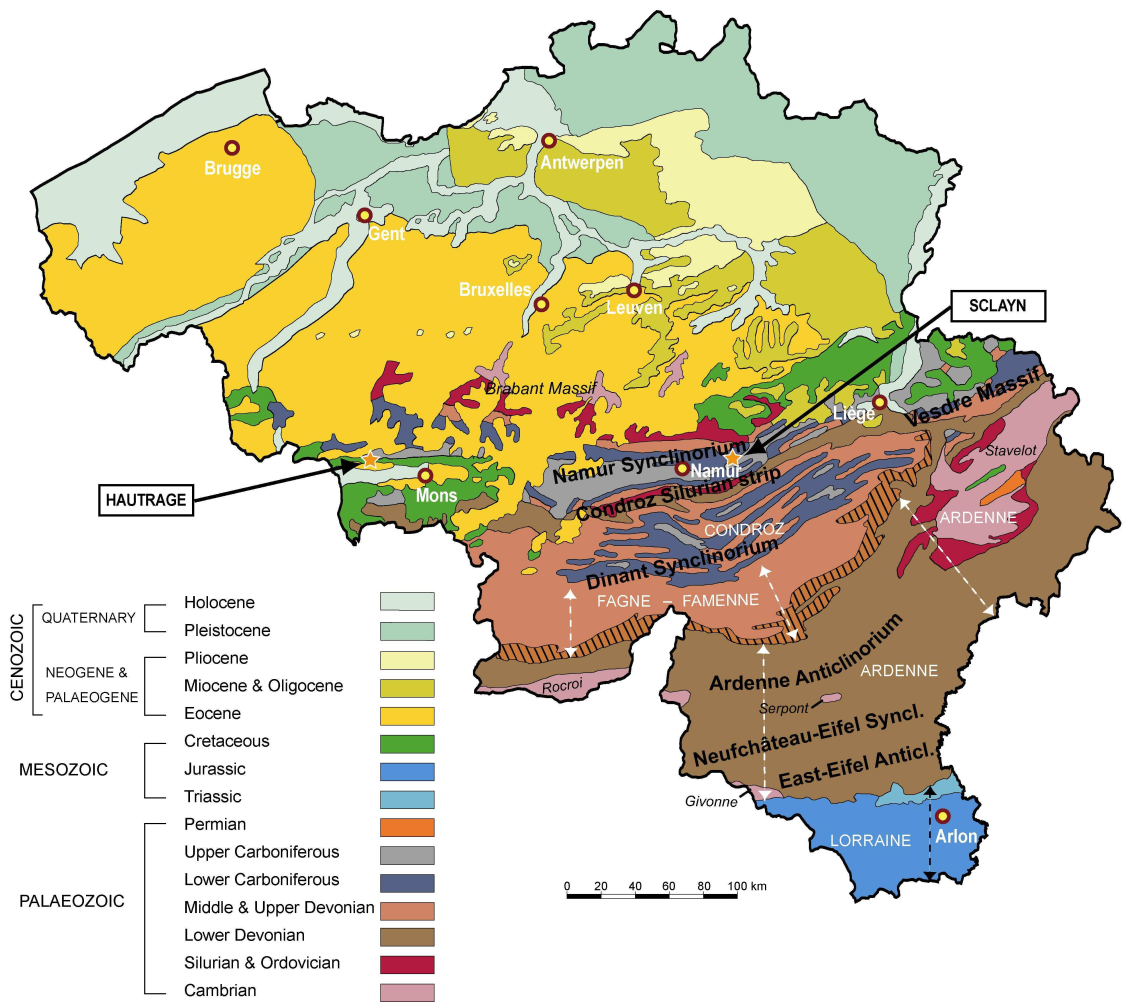

Figure 2. Geological map of Belgium (after Pirson, 2003; redrawn from a Geological Survey of Belgium document). In white: natural regions of Southern Belgium. In bold black: Variscan structural units.

2. The geology of Belgium

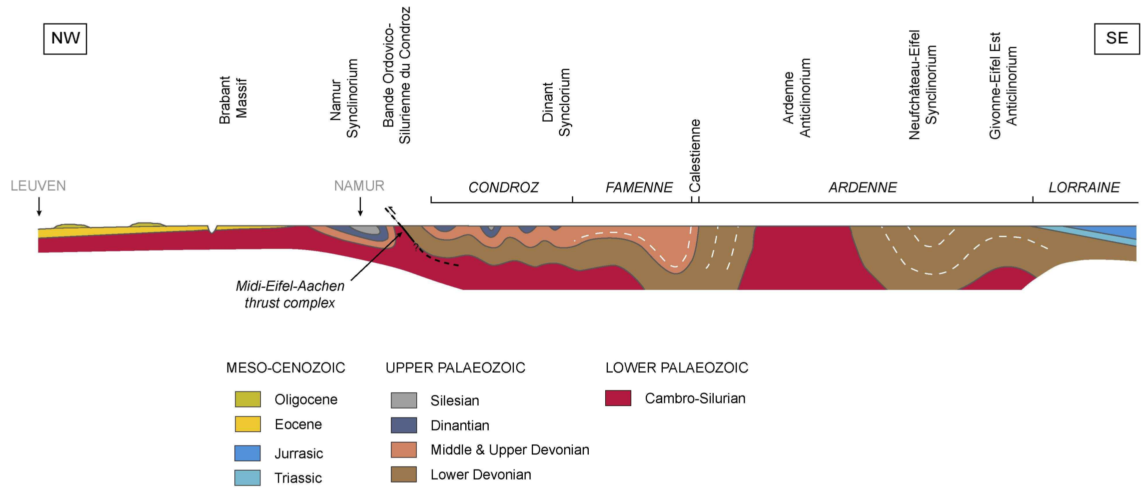

Figure 3. Simplified N-S geological section showing the geometrical relationships between the different geological units (after Pirson, 2003, modified from Raoult & Meilliez, 1986). The Ardenne allochthon corresponds to the rocks which has been overthrusted to the North-West on the Brabant Parautochthon by the Midi-Eifel-Aachen thrust complex. Thicknesses and dips are not respected.

2.1. 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" (Condroz Silurian Strip) and in the bottom of some valleys of the Brabant Massif (Figs 2-3). Most Lower Palaeozoic sediments are marine, siliciclastic and often turbiditic (Robaszynski & Dupuis, 1983; Verniers *et al.*, 2001). These deposits were deformed by the Avalonia-Baltica-Laurentia collisions between Late Ordovician to Early Devonian (Sintubin, 1999; Verniers *et al.*, 2001). These Lower Palaeozoic deformations have been called "Caledonian orogeny" in the literature and are sometimes referred to the "Caledonian Cycle". Most of the magmatic occurrences in Belgium date back to this period (André, 1983). The Lower Palaeozoic rocks are unconformably covered by Devonian sediments.

2.2. Upper Palaeozoic: the Variscan Cycle

Upper Palaeozoic rocks (Devonian, Carboniferous and Permian) overly unconformably the Lower Palaeozoic basement and form the main part of the outcrops in southern Belgium (Fig. 2). Classically, several structural units caused by the Variscan orogeny are recognized (Figs 2-4). From a structural point of view, Belgium constitutes the northern border of the European Variscan belt and belongs to the Rhenohercynian fold-and-thrust belt, or Rhenohercynian Zone (Matte, 1986a, 1986b; Franke, 1989). To the North of this belt lies the Brabant Massif, which was not or little affected by Variscan deformation. The north of the Rhenohercynian Zone (RHZ) thus corresponds to the Variscan front.

The RHZ encompasses mainly marine or coastal sediments which deposited during the Variscan cycle in the Rhenohercynian sea. These sediments were subsequently deformed by the end of the cycle, during Variscan orogeny. The Rhenohercynian sea developed on the passive margin between the Brabant Massif to the North (southern extremity of the Old Red Sandstone Continent; Ziegler, 1990) and the Lizzard-Giessen-Ostharz ocean (LGO) to the South. The history of RHZ is intimately linked to the opening and closing of that ocean, according to the mechanisms of plate tectonic (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 first Variscan sedimentation phase corresponds to the Devono-Dinantian transgression which reached the continent lying north in three main successive pulses of the Rhenohercynian sea. Most of the sediment input originated from the erosion of Lower Palaeozoic basement of the Brabant Massif and the Old Red Sandstone Continent (NW-Europe). Sediments were transported to the South by rivers discharging in the Rhenohercynian sea, on the continental shelf of the Brabant Massif. This situation lasted until the beginning of the Variscan orogeny; they are therefore pre-orogenic sediments.

a) During the Lower Devonian (Godefroid *et al.*, 1994), sedimentation is mainly detritic (sandstones and shales). As a result of the Late Lower Devonian regression, the sea receded to the South and sedimentation had a more continental character in the Dinant sedimentation area.

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 and reefs formed to the South (Tsien, 1980). During the next stage, i.e. in the Famennian (Thorez & Dreesen, 1986), an important regression took place and resulted in increasing terrigenous input (e.g. Famenne shales and Condroz sandstones).

c) The third pulsation, corresponding to the Dinantian (Paproth *et al.*, 1983a; Hance *et al.*, 2001; Poty *et al.*, 2001), was clearly dominated by carbonate marine sediments, indicating the comeback of warmer and dryer conditions. The polarity of marine influences changed during the Dinantian (Hance *et al.*, 2001). While the sea was still opened to the South during the Tournaisian, the situation reversed during the second half of the Visean, due to early Variscan deformation.

The second Variscan sedimentation phase relates to the Upper Carboniferous (Namurian and Westphalian; Paproth *et al.*, 1983b; Delmer *et al.*, 2001). Sedimentation radically changed during this period as the Variscan orogenic belt was forming, leading to deformation and exhumation of the pre-orogenic sediments. The tectonic uplift forced the sea to retreat to the North and led to the formation of a foreland basin collecting siliciclastic sediments resulting from the erosion of the Variscan mountain belt (tectonically-driven sedimentary succession). The direction of sedimentary fluxes had then totally changed: sediments no longer originated from the Brabant Massif to the North but from the uplifting Variscan belt to the South. The environment progressively graded from coastal (Namurian) to more continental and deltaic (Westphalian). Coal-bearing sediments are typical from this period.

This orogenic event is a direct result of the subduction of the LGO oceanic plate since Upper Devonian (Oncken *et al.*, 1999, p. 76) which led to the collision of RHZ (Avalonia) with Armorica continent situated to the South. Collisional tectonic lasted throughout the Namurian and Westphalian and resulted in intense deformation of the sediments previously deposited in the Rhenohercynian sea (Oncken, 1998; Vanbrabant, 2001). Variscan structural units are broadly oriented NE-SW in most areas of the RHZ (Fig. 2; Fig. 4) as a result of the prevailing NW-SE compressive direction.

The Variscan orogeny ended with the development of the Midi-Eifel-Aachen thrust complex, during the Late Westphalian (ca. 300 Ma; Fig. 3-4). An important thrust sheet known as the “Ardenne Allochthonous” is overlying the Lower Palaeozoic foreland (Brabant Massif) and its Devono-Carboniferous cover (Namur Synclinorium). The rocks situated north of this thrust complex belong to the “Brabant Parautochthonous” (Robaszynski & Dupuis, 1983; Raoult & Meilliez, 1986; Bless *et al.*, 1989).

A long period of emersion prevailed 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-Malmédy area (Bultynck *et al.*, 2001) and Permian marine deposits were cored at depth in the Campine Basin (Dusar *et al.*, 2001).

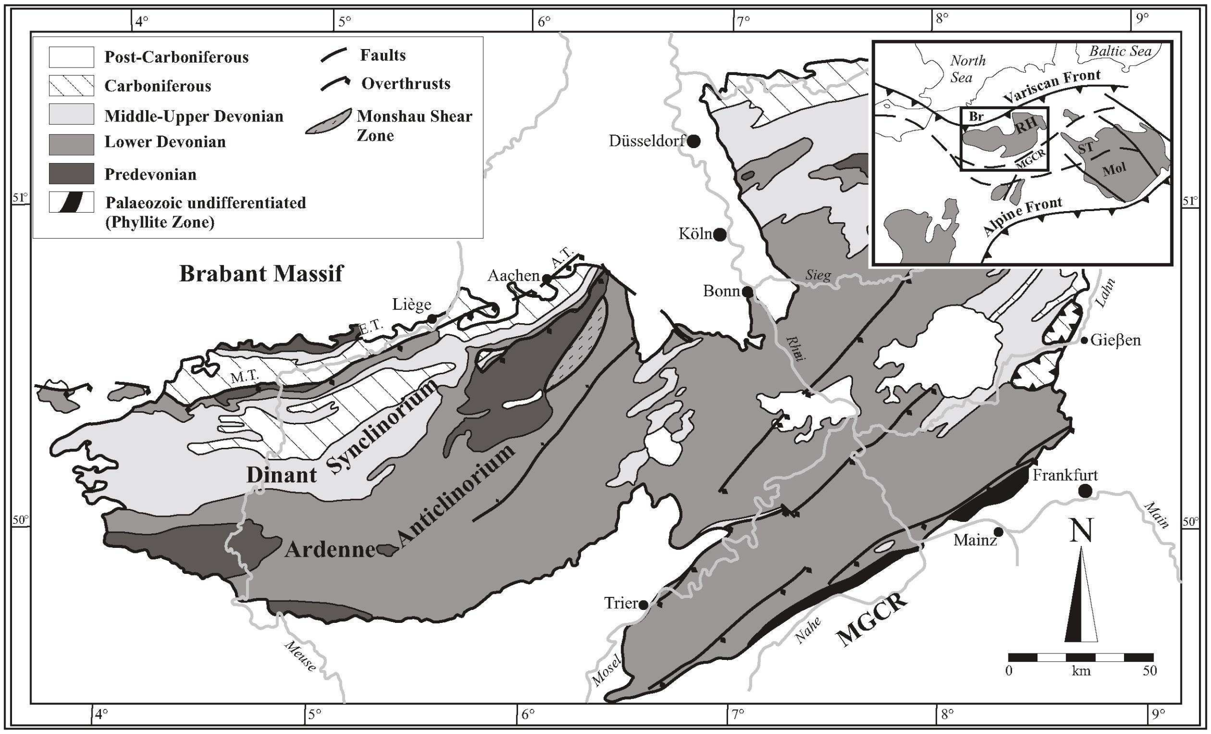

Figure 4. Detail of the Rhenohercynian Zone (after Vanbrabant et al., 2002). M.T. = Midi thrust; E.T. = Eifel thrust; A.T. = Aachen thrust. Cartouche: location of the Rhenohercynian Zone in the European Variscan Domain (Br = Brabant Massif; RH = Rhenohercynian Zone; ST = Saxothuringian Zone; Mol = Moldanubian Zone; MGCR = Mid-German Crystalline Rise).

2.3. Mesozoic

Lower Mesozoic deposits are poorly represented in our region 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; Fig. 2). Rocks from that period 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, in which the famous Bernissart *Iguanodon* were found (Robaszynski *et al.*, 2001 – see §4).

More or less extended marine deposits formed during Upper Cretaceous due to transgressive pulses. The Cretaceous sea progressively flooded 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 (Fig. 2). Southern Belgium may have only been sparsely covered with marine deposits from this period as this area constituted a small continent connected with Variscan formations in Germany (Ziegler, 1990).

2.4. Palaeogene and Neogene

During the Palaeogene and Neogene, the sea episodically invaded Belgium, first from both the West and the North, then only from the North. From the Miocene onward, marine sediments were more and more distant from the Sambre and Meuse axis (de Heinzelin, 1963; Laga *et al.*, 2001). This is linked with the generalized uplift of the Ardenne (Macar, 1976; Demoulin, 1995a) and the subsidence of the Netherlands Basin. During the same period, the Belgian Basin was 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 meters (Vandenberghe *et al.*, 1998; Laga *et al.*, 2001). In southern Belgium, the Palaeogene sea only made 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 testimonies 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, 1927a; Robaszynski & Dupuis, 1983; Dupuis & Robaszynski, 1986; Vandenberghe *et al.*, 1998; Laga *et al.*, 2001). Neogene marine sediments are absent in southern Belgium.

2.5. Quaternary

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

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 ca. 10 meters. To the North, these aeolian deposits became more sandy (Paepe & Vanhoorne, 1976).

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 our rivers (consequent streams). Shoreline being situated to the North, preferential orientation of rivers was thus South/North. The direction of some of actual 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 generalized 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 terrace (Alexandre-Pyre & Kupper, 1976; Cornet, 1995). The best-studied alluvial terraces are those of the Meuse river (e.g. Pissart, 1975; Juvigné & Renard, 1992) and the Escaut Basin (Tavernier & De Moor, 1975; Haesaerts, 1984b), although their chronology remains rather inaccurate.

3. The evolution of terrestrial flora and vegetation in Belgium: a short review

The earliest terrestrial flora most probably evolved during the Ordovician (Wellman *et al*., 2003), but in Belgium, the oldest macrofossils of plants are recorded from the Lower Devonian (Gerrienne, 1993, and references therein). Those plants are small and simple, but they are already diversified. *Sporogonites* (an early Bryophyte) has one terminal sporangium at the top of an unbranched short axis; *Zosterophyllum*, a vascular plant with lateral reniform sporangia, is an early representative of the Lycophytes; *Psilophyton*, a basal Euphyllophyte and a member of the Lignophyte stem group, shows axes with lateral branches ending in paired fusiform sporangia; *Foozia* with its numerous lateral axes ending in a pair of ovoid sporangia is another early Euphyllophyte probably related to the earliest Monilophytes (ferns sensu lato).

During the Middle Devonian, the terrestrial flora underwent one of its greatest diversification phase. All the modern phyla, Angiosperms excepted, are already present. In Belgium, Lycophyte representatives are inconspicuous, but Euphyllophytes are spectacularly large and abundant. At Goé (Leclercq & Banks, 1962; Leclercq & Bonamo, 1971), Monilophytes are represented by the arborescent *Pseudosporochnus* and *Calamophyton*; *Aneurophyton* and *Rellimia* are bushy Lignophytes. At Ronquières, the small, almost unnoticeable *Runcaria* (Stockmans, 1968; Gerrienne *et al*., 2004) is a major step towards the seed habit, one of the most important evolutionary innovations in the history of plants.

The Upper Devonian floras are known from localities belonging to the Evieux Formation (upper part of the Condroz Sandstones; Fairon-Demaret, 1996) and is better known as the Evieux flora. Lycophytes and Sphenophytes are rare, but the flora includes abundant remains of all other phyla. Ferns are represented by *Rhacophyton*, a shrub that thrived probably in dense stands in swampy or flood plain environments. *Archaeopteris* (Lignophytes) is everywhere, and forms the earliest true forests. Under its shadow, the seed plants (Spermatophytes) diversify: at least 4 different genera, including the well-known *Moresnetia*, have been described (Prestianni, 2005).

During the Carboniferous, Belgium belonged to the tropical Euramerican palaeogeographic province. More precisely, during the second part of the Carboniferous, Belgium was almost exactly under the equator. The climate was very humid, and the vegetation flourished in wetlands (peat swamps and their surroundings). Peat swamp vegetation has been extensively studied (see among others: Stockmans & Willière, 1953, 1961), often thanks to the plant permineralisation preserved in the coal balls (Holmes & Fairon-Demaret, 1984, and references therein). The dominant plants of those swamps were the massive, arborescent Lycophytes (*Lepidodendron*, *Sigillaria*, *Lepidophloios*). Other important members of the peat-forming community were the arborescent Sphenophytes (*Calamites*). All of those arborescent taxa went extinct in Belgium as soon as the climate became dryer, at the end of the period. The other phyla were also represented by *Psaronius* (Marattiales), a tree-fern that could reach 10 meters in height, *Lyginopteris* and *Medullosa* (arborescent Pteridosperms, Spermatophytes), and *Cordaites* (early conifers), which were either shrubs or large trees.

The Mesozoic plant record begins with the “Wealden facies” localities from for example Bernissart and Hautrage (Dejax *et al.*, 2008; Gomez *et al.*, 2008; Gerards *et al.*, 2008). During Early Cretaceous times, ferns were abundant in Belgium: one of the most famous is the *Weichselia*, which had a massive stem and large fronds. Gymnosperms were also diversified, including a range of large conifers. The palaeoenvironment from Bernissart has recently been reconstructed thanks to a detailed palynological study (Dejax *et al*., 2007a). Lycophytes, ferns, conifers (Taxodiacaeae, Pinaceae, Cheirolepidiaceae), and cycads were identified. To date, no macrofossil of Angiosperms has been collected from the Wealden facies of Belgium, but the presence of pollen grains with angiospermous affinities (biorecord Superret-croton) indicates that early angiosperms, presumably herbaceous, were already present during Lower Cretaceous times.

Angiosperm remains are much more common during the Upper Cretaceous: numerous leaves (*Dicotylophyllum, Dewalquea*) are reported by Stockmans (1946) from the Aachen sands in eastern Belgium. From that time onwards, the floras from Belgium become more and more similar to what we know today, with a large predominance of Angiosperms in all habitats.

The Tienen Formation, at the Palaeocene/Eocene boundary (Palaeogene) has been recently intensively studied. For example, Fairon-Demaret & Smith (2002) identified at Dormaal various fruits from Menispermaceae, Vitaceae, Icacinaceae, Lythraceae, Nyssaceae, ?Theaceae and ?Ericaceae suggesting a warm-humid to subtropical climate. At Hoegaarden, another locality from same Formation, an impressive *in situ Glyptostroboxylon* (Taxodiaceae) forest has been discovered (Fairon-Demaret *et al.*, 2003). The trees lived in a swampy lowland environment, comparable to the Florida Everglades National Park. Several species of *Palmoxylon* are reported by Stockmans & Willière (1943) from various Eocene localities.

The knowledge of the Quaternary floras of Belgium is based mainly on pollen and spores but also on various types of macroremains as wood, charcoal, leaves, fruits and seeds. Various studies were made by Vanhoorne in the Flemish Valley on the Lower (Early) Pleistocene Campine clay of the Formation of Weelde, and notably the peaty sediments of the Rijkevorsel Clay Member with *Azolla tegeliensis* and *Salvinia natans* (see Paepe & Vanhoorne, 1970; Vanhoorne 2005). Other investigations deal with peat and sand sequences attributed to Cromerian IV interglacial (Noorbergum) and Holsteinian (Vanhoorne, 2003). A discussion on chronostratigraphy of the Pleistocene sequences from northern Belgium is presented by Verbruggen (1999).

During the last glacial, the sand, loess and loamy plains of Belgium were covered by dry and cold steppes with grasses, *Artemisia*, chenopods, various Asteraceae and other herbs and forbs. It seems that tundra patches were restricted to humid areas and peaty substrates. Some conifers like pine and juniper were present in the valley slopes together with small deciduous malacophyll boreal trees as birch, willow and alder along the rivers. These tree taxa more or less expanded during episodes of climatic improvements, but during the last interglacial (MIS 5e) a more complex succession occurred with the development of dense temperate forests with well known elm, oak, ash, lime, yew, hornbeam and then beech, fire, spruce and pine. It should be noticed that no complete Eemian sequence was recorded in Belgium (Vanhoorne, 1963; Paepe *et al*., 1973). A similar succession did probably occur during the following interstadials of the early glacial (MIS 5c & 5a) but nowhere in Belgium are they completely recorded (Mullenders *et al*., 1966; Paepe & Vanhoorne, 1967; Paepe *et al*., 1973; Verbruggen, 1999; Bastin, 1971, 1992; Pirson *et al*., 2008). This is probably due to regular interactions between the sea and the sandy coast that sealed eroded peat deposits and led to the preservation of peaty lenses in the sands (see Baeteman, 1999, 2004, 2005).

Recently, new palynological and anthracological data from Walou and Scladina caves, notably on stalagmite floor (Bastin, 1979, 1990) have been obtained, providing accurate records of the succession of the vegetation during the last interglacial-glacial cycle (Bastin, 1992; Damblon *et al*., in press; Pirson *et al*., 2008; Pirson *et al*., in press). However, further investigations are needed in Scladina to improve the fine resolution of the chronostratigraphical frame (Pirson *et al*., 2008).

A great number of records of pollen, wood, charcoal, fruits, seeds and remains of plant tissue are available for the Holocene. They come essentially from peaty sediments for which the complete references cannot be given here (see notably: Mullenders & Gullentops, 1957; Mullenders & Coremans, 1961; Mullenders *et al*., 1963, 1967; Vanhoorne, 1951; Coûteaux, 1969; Munaut, 1967a & b; Munaut & Paulissen, 1973; Damblon, 1969, 1970, 1978a, 1978b, 1994) but also from particular archaeological structures. It is also worth to recall that surface pollen spectra records were obtained and used as a tool for interpreting Holocene pollen records (Heim, 1970).

Let us also notice that pollen and macroremain analyses of grass and sedge tussocks were used for reconstructing very recent history of vegetation and the impact of human activities on the peaty ecosystems (Damblon, 1981, 1992).

4. Introduction to Hautrage quarry: the geology of Mons Basin

The Mons Basin (MB) is located in the western part of Belgium, in the Hainaut Province (Fig. 5). It is connected to the Paris Basin to the West although the sedimentary records are significantly different in both basins. The MB may be considered as a gentle "syncline" developed on a folded and faulted Devonian-Carboniferous basement (Fig. 6A), and filled with Cretaceous-Cenozoic sediments (Robaszynski, 1975; Robaszynski *et al*., 2001). The MB is limited by the maximal extension of the Turonian deposits (Fig. 5).

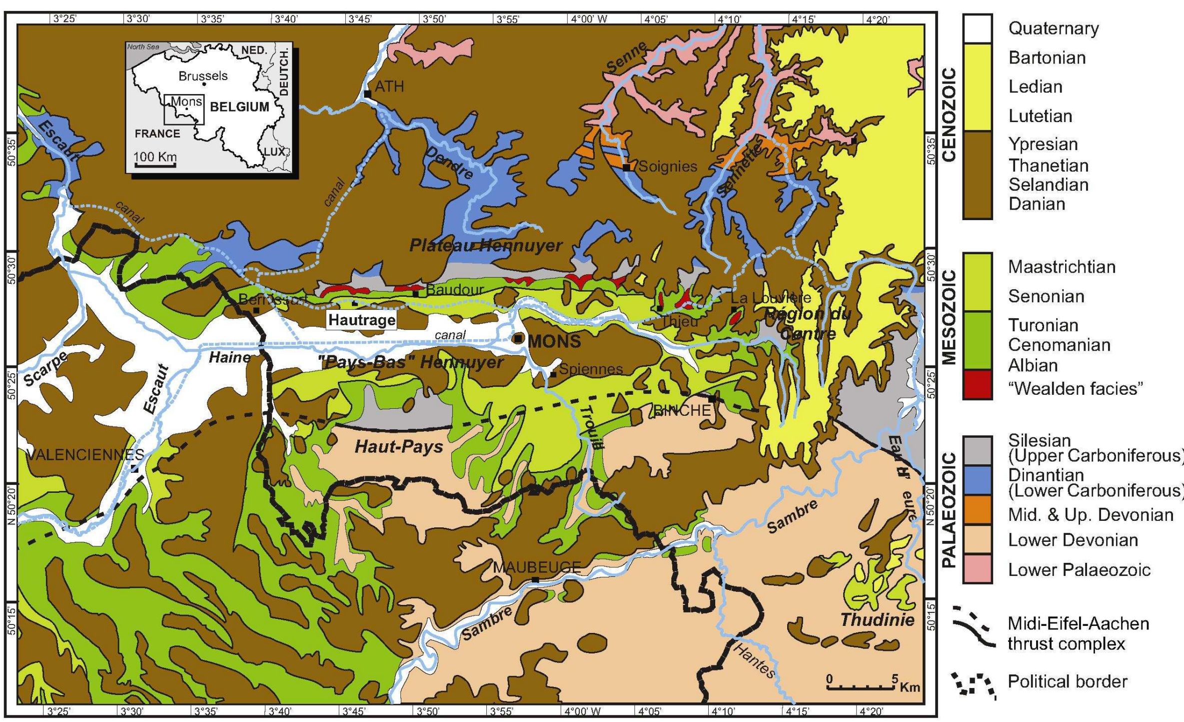

Figure 5. Schematic geological map of the Mons Basin.

4.1. Lithostratigraphy

The deposition of the sediments in the MB is the result of relative sea-level fluctuations, due to eustatism, subsidence and sedimentary supplies (Fig. 6B).

The oldest sediments of the MB are the "Wealden facies" recognized in three geological contexts:

- in kilometric outcrops ("pockets") or weakly buried sediments in the northern part of the MB, from Hautrage to La Louvière (Fig. 5; Marlière, 1946) – Hautrage Clays Formation, Baudour Formation and Saint-Pierre Formation;
- in filling several natural pits (also called "Cran") developed through the basement (for example at Bernissart);
- as white sands and sandstones containing lignite and glauconitic material in the eastern part of the MB (= "Strepy Formation" or "Cénomanien à faciès Wealdien" *sensu* Gulinck, 1974).

In the MB, the "Wealden facies" are locally covered by calcirudites, sandstones and conglomerates of the Albian-Cenomanian Haine Group (Marlière, 1946). Rich in glauconite and ferriferous illite, these Albian-Cenomanian deposits correspond to neritic sedimentation and can reach 180 meters of thickness in local depressions, or large "pockets", where the subsidence rate is higher than in adjacents areas (Cornet, 1927b). These depressions, called "cuves", are scattered throughout the basin.

The latest Cenomanian period characterizes the base of a large sea-level rise (probably due to eustatism) with the glauconiferous marls rich in *Actinocamax plenus*. Marls mainly dominate in the overlying Turonian sediments ("dièves"), showing frequent lateral variation of thickness. The Upper Turonian - Coniacian sedimentation probably recorded the eustatic regression / transgression event which is known world-wide during this period (Hack *et al*., 1987). Upper Turonian deposits consist of 5 to 40m of siliceous marls (Chailles de Ville-Pommeroeul) overlain by cherty limestone (Silex d'Hautrages) that exhibit increasing lateral changes with time and are capped by hardgrounds (Robaszynski, 1975). On top of the latter, a 0.5 to 2 m-thick bed of highly glauconitic sediments ("Craie" de Maisières, probably Coniacian in age) mark the lower, transgressive sequence of the white chalk deposits (Godfriaux, 1968).

Chalks are widespread in the MB during the Coniacian, Santonian, Campanian and Maastrichtian stages (Robaszynski *et al*., 2001). The chalk serie is locally covered by the phosphatic "Craie de Ciply" and by the "Tuffeau de Saint-Symphorien". During Late Maastrichtian, the MB experienced a (eustatic?) sea-level fall with condensed beds (hardgrounds) and hiatuses. The famous Cretaceous-Palaeogene boundary is thus not recorded in the MB, at least in known sections.

The Cenozoic sedimentation starts with the "Dano-Montian" and "Montian", Danian (-Selandian) in age. It partly corresponds to continental deposits with local mammal fossils like those excavated at Hainin, which are considered as a key-point for the stratigraphy of mammals in Europe (Folie *et al*., 2005). The latest Palaeocene consists in argillaceous, glauconiferous and locally carbonaceous Thanetian sands. During the Palaeocene-Eocene interval, continental conditions prevailed in the MB as shown by the occurence of fluviatile deposits, locally containing terrestrial fauna (like in Erquelinnes: Rutot, 1881) and terrestrial plant remains (e.g. M. Fairon-Demaret in Pirson *et al*., 2002) that are equivalent to the *Glyptostroboxylon* fossil forest of Hoegaarden (§ 3). Continental conditions are further attested by a large meteoric weathering of the latest Thanetian marine sands and the fluviatile sands, resulting in widespread quartzitic concretions (Dupuis *et al*., 1997; Pirson *et al*., 2001). The early Eocene is characterized by Ypresian sandy clays. Coarse Lutetian sand is located only in the eastern part of the MB.

4.2. Subsidence

As demonstrated in the Saint-Ghislain borehole (Delmer, 1972), high subsidence rates in the Mons area are recorded since Palaeozoic times. Kilometric-thick Upper Devonian and Carboniferous series accumulated in the EW-elongated basin called “sillon borain” by Michot (1980). Abnormal but of lower order of magnitude subsidence rates are still observed through the Meso-Cenozoic, with sedimentary sequences of ca. 200 m-thick in average. The most striking feature of subsidence in the MB is depocentre shift (Marlière, 1970). The thickness maxima for each sedimentary formation are not superimposed, showing that the location of areas of highest subsidence rate changed with time. The thickness maxima of the different formations in the Cenomanian-Lutetian sequence give 800 m when summed together. This demonstrates the significant impact of depocentre shift on sedimentary record in the MB. As a result of subsidence and except along fault-flexure zones where layers locally dip as 60°, bedding dips are rather small (about 10°; Angelier *et al*., 2006). The existence of evaporite dissolution in the deep Devono-Dinantian basement and its impact on the deformation of the overlying strata have been suggested to explain the depocentre shift (Delmer, 1972; Dupuis & Vandycke, 1989). However the very well oriented fault system in the MB may also be partly due to the regional crustal activity (Vandycke *et al*., 1991; Vandycke, 2002; Spagna *et al*., 2007).

4.3. Chronostratigraphy of the “Wealden facies”

In the last decade, stratigraphic studies of new boreholes and new sections allow to precise the age of the “Wealden facies” of the MB (Dejax *et al*., 2008). The “Wealden facies” of the western part of the MB - i.e. Hautrage Clays Formation, Baudour Clays Formation and Sainte-Barbe Formation - are Middle Barremian to Earliest Aptian in age (Yans *et al*., 2005a, 2005b; 2006; Dejax *et al*., 2007a, 2007b). On the other hand, the “Wealden facies” of the eastern part of the MB are Late Albian in age (Yans *et al*., 2007) and do contain dinoflagellates suggesting marine influences. The “Cénomanien à faciès wealdien” or “Strépy Formation” is Turonian in age (Yans *et al*., 2002; Yans, 2007).

The Wealden facies may have supplied the filling of regional endokarsts during Late Cretaceous to Early Cenozoic (Quinif *et al*., 2006).

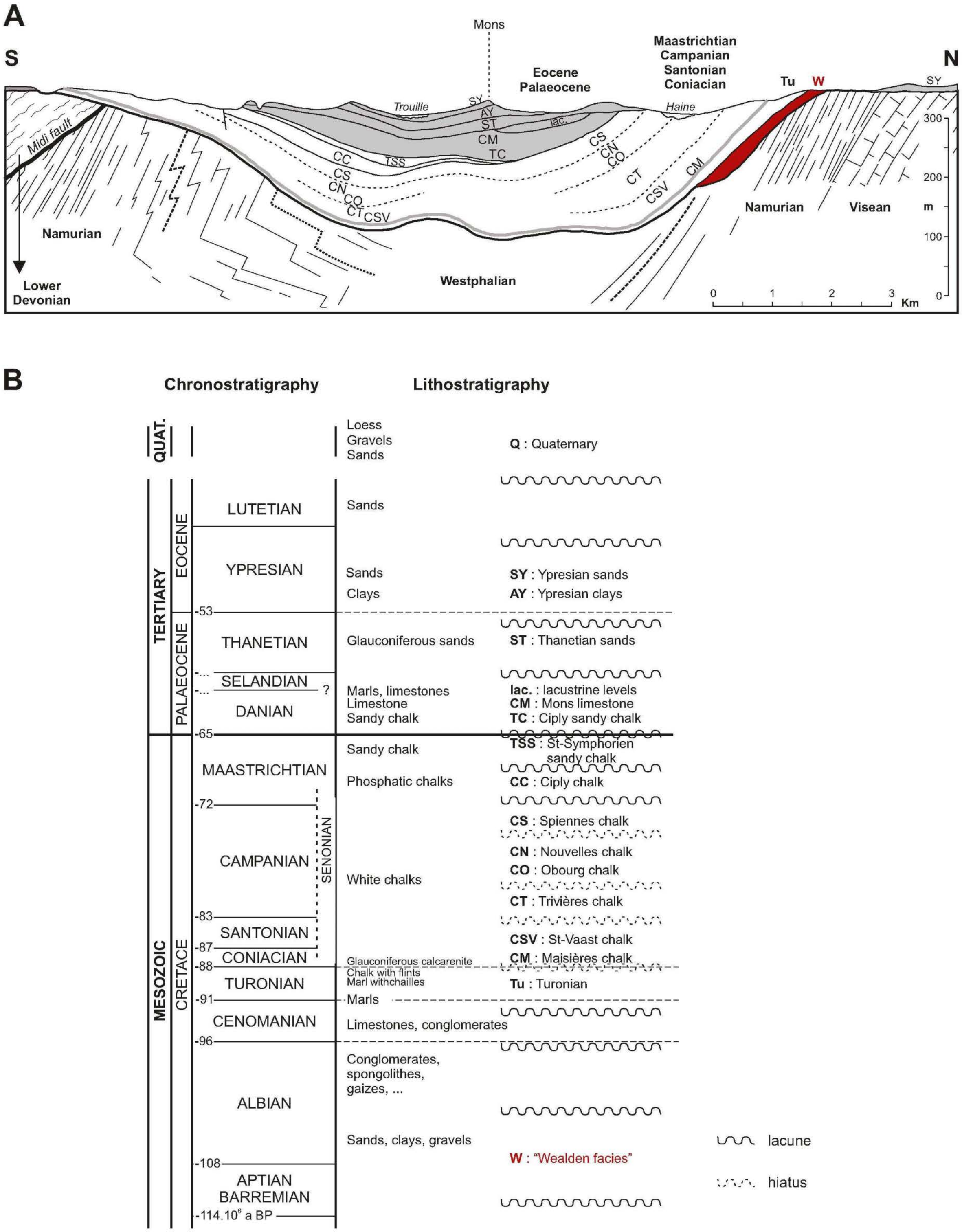

Figure 6. A. North-South section in the Mons Basin; vertical amplitude = x10. B. Simplified lithostratigraphy of the Mons Basin (from Marlière, 1970).

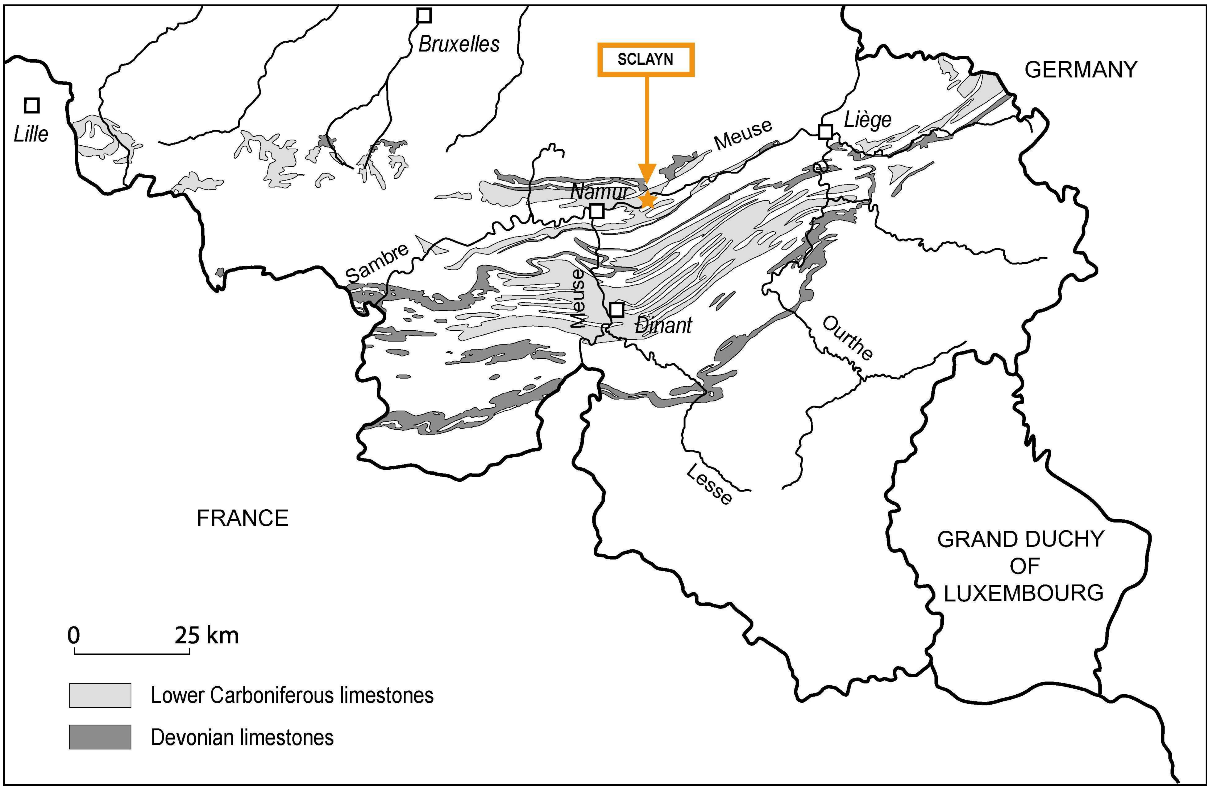

Figure 7. Distribution of the Paleozoic carbonate rocks outcropping in Belgium (after Toussaint & Pirson, 2007, modified from Ek, 1976).

5. Introduction to Scladina cave: caves and cave entrance deposits in Belgium

5.1. Caves in Belgium

More than 3000 caves are known in Belgium. Some of them have been recognized in the Jurassic of south 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 (Fig. 2; Fig. 7). These Devono-Carboniferous limestones crop out on more than 1600 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). Formation of Belgian caves mainly dates back to Quaternary (Ek & Poty, 1982).

5.2. Cave deposits

These last decades, Quaternary geologists have focused on marine and ice archives, where continuous records are preserved and quantitative data on climate changes possible to obtain. However, continental records alone allow a reconstruction of terrestrial palaeoenvironments. On the continent, thick sedimentary sequences allowing a detailed reconstruction of Quaternary climate changes are only found in a few sedimentary environments. In the loess sequences, the record is mainly based upon the succession of loess deposition and soil formation (e.g. Liu, 1985; Kukla & An, 1989). For Upper Pleistocene, some loess sequences allow high resolution climatic reconstructions, similar to those from the reference Greenland ice records (Haesaerts *et al.*, 2005; Haesaerts, 2007). In lake sequences, climatic information is mainly recorded by palynology. Today, in Europe, several important palynological sequences covering Upper Pleistocene and/or a rather large part of Middle Pleistocene are known (e.g. Woillard, 1979; de Beaulieu & Reille, 1992;

Reille *et al.*, 1998; Watts *et al.*, 2000). Caves are also 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 dynamic dominating on a continental environment (Pirson, 2007). In Belgium, karst is one of the few sedimentary environments allowing detailed study of Quaternary palaeoenvironments, together with the loess from Middle Belgium and deposits from the Flemish Valley.

Two sedimentary environments are usually recognized in caves: cave interior (endokarst) and cave entrance (Campy, 1982; Ek & Quinif, 1988). They often exhibit very different type of deposits, reflecting distinct steps in the evolution of a cave. Endokarstic deposits have mainly an alluvial origin and are characteristic of an active karstic system. On the contrary, cave entrance deposits have a colluvial origin. They lead to the fossilization of the cave after its abandon by the river due to the lowering of the water table. They are coming from various openings (cave porch, sink holes, fissures) and are rich in clasts from the cave walls.

In Belgium, endokarstic deposits have been studied these last 30 years in the course of multidisciplinary approaches. This led to the construction of a model integrating sedimentary dynamics and palaeoenvironmental reconstruction (see synthesis in Blockmans *et al.*, 1999 and Quinif, 2006). Cave entrance deposits have been studied for more than 175 years because of their abundant archaeological, palaeoanthropological and palaeontological remains (see Toussaint & Pirson, 2007). More than 300 caves and rock shelters have yielded prehistorical remains, from Lower Palaeolithic to Neolithic. Belgium played an important role in the XIXth century in the genesis of the two disciplines that are prehistory and palaeoanthropology (Toussaint & Pirson, 2006).

Cave entrance deposits consists of a mixture of several components, either autochthonous or allochthonous, either from a mineralogical, biological or anthropological origin (e.g. Ferrier, 2002; Jones, 2005; Goldberg & Sherwood, 2006; Pirson, 2007). In Belgium, the main components are: limestone fragments from the cave walls, reworked loess from outside, speleothems, reworked pebbles from fluvial terrace preserved on the plateau, bones and archaeological material (Pirson, 2007).

These last decades, major progress has been made in the understanding of slope processes (e.g. Bertran, 2004), with major applications for cave filling processes (Ferrier, 2002; Texier *et al*., 2004; Bertran, 2006). Generally, sediments accumulate under the cave porch and are later redistributed inside the cave through several sedimentary processes, the most common of which being rock fall, solifluction, wash and debris flow. In addition, several diagenetic processes can occur: frost action (e.g. stone uplifting, cryoturbation or platy structure), authigenic mineral formation (mainly carbonates and phosphates), animal burrowing, trampling, soil formation on the cave terrace, ...

It has recently been demonstrated that despite 1) the multiplicity of the origin of sediments and 2) the complexity of the sedimentary and post-sedimentary processes involved, reliable informations could be obtained from a careful study of Belgian cave sequences (Pirson *et al*., 2006; Pirson, 2007). In this view, the abundance of loessic sediments in regional caves plays a major role as it leads to a good record of the palaeoenvironmental fluctuations and allows a good chronostratigraphical correlation with the well-known pedostratigraphical reference sequence of Middle Belgium loess. Besides, charcoal and pollen grains are well preserved in these silt-rich sequences and lead to consistent reconstructions of Quaternary palaeoenvironments, as illustrated by the study of Scladina cave (Pirson *et al*., 2008).

6. Acknowledgements

The authors are grateful to Louis Bruzesse and Sylvianne Lambermont (Association wallonne d'Etudes mégalithiques) for computer graphics. Thanks are also due to the Lebailly S.A. in Hautrage, to Wanty S.A. and CBR-Heidelbergcement industry for their logistic cooperation.

7. References

ALEXANDRE-PYRE, S. & KUPPER, M., 1976. L'évolution des rivières. In: Pissart, A. (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), Bruxelles (Thèse de doctorat inédite, Université libre de Bruxelles, Faculté des Sciences), 2 vol. (299 & 123 p.).
ANGELIER, J., VANDYCKE, S., BERGERAT, F., GAVIGLIO, P., SCHROEDER, C. & COULON, M., 2006. Can belemnite distribution reveal pressure-solution processes along faults? A case study in the chalk of the Mons Basin, Belgium. *Journal of Structural Geology*, 28: 64-82.
BAETEMAN, C., 1999. Tidal crevasse splays as the cause of rapid changes in the rates of aggradation in the Holocene tidal deposits of the Belgian Coast Plain. *Quaternary International*, 56: 3-13.
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. Belgian Geological Survey, Brussels, Belgium, 76 p.
BAETEMAN, C., 2005. How subsoil morphology and erodibility influence the origin and pattern of late Holocene tidal channels: case studies from the Belgian coastal lowlands. *Quaternary Science Reviews*, 24: 2146-2162.
BASTIN, B., 1971. Recherches sur l'évolution du peuplement végétal en Belgique durant la glaciation de Würm. *Acta Geographica Lovaniensia*, 9 : 136 p.
BASTIN, B., 1979. L'analyse pollinique des stalagmites: une nouvelle possibilité d'approche des fluctuations climatiques du Quaternaire. *Annales de la Société Géologique de Belgique*, 101: 13-19.
BASTIN, B., 1990. L'analyse pollinique des concrétions stalagmitiques : méthodologie et résultats en provenance des grottes belges. *Karstologia Mémoire*, 2: 3-10.
BASTIN, B., 1992. Analyse pollinique des sédiments détritiques, des coprolithes et des concrétions stalagmitiques du site préhistorique de la grotte Scladina (province de Namur, Belgique). In: Otte, M. (ed.), Recherches aux grottes de Sclayn. Volume 1 : Le contexte. *Etudes et Recherches archéologiques de l'Université de Liège*, 27: 59-77.
BERTRAN, P. (dir.), 2004. Dépôts de pente continentaux. Dynamique et faciès. *Quaternaire*, hors-série n°1 : 259 p.
BERTRAN, P., 2006. Dépôts de versant et application au Paléolithique. Processus de formation des sites dans les porches de grottes et d'abris en Aquitaine. Bordeaux (Thèse inédite d'Habilitation à Diriger des Travaux, Université de Bordeaux 1), 70 p.
BLOCKMANS, S., QUINIF, Y., BINI, A. & ZUCCOLI, L., 1999. Dynamique sédimentaire et paléoenvironnements durant la transition Weichsélien - Holocène à partir des dépôts endokarstiques de la Grotte de Han-sur-Lesse (Belgique). *Bulletin de la Société géologique de France*, 170: 841-852.
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.
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., MOURAVIEFF, N. A., SARTENAER, P., TOURNEUR, F. & VANGUESTAINE, M., 1999. Les formations du Frasnien de la Belgique. *Memoirs of the Geological Survey of Belgium*, 44 : 124 p.
BOULVAIN, F. & PINGOT, J.-L., 2002. Une introduction à la géologie de la Wallonie. Cours en ligne, Université de Liège, Faculté des Sciences, Département de Géologie, unité de pétrologie sédimentaire. (http://www.ulg.ac.be/geolsed/geolwal/geolwal.htm). Mise à jour avril 2002.
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. *Memoirs of the Geological Survey of Belgium* (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*, 4/1-2, 168 p.

Bultynck, P., Geukens, F. & Smolderen, A., 2001. Permian lithostratigraphic units, Malmédy Graben (Belgium). In: Bultynck, P. & Dejonghe, L. (ed.), Guide to a revised lithostratigraphic scale of Belgium. *Geologica Belgica*, 4/2: 105-106.

Campy M., 1982. Le Quaternaire Franc-Comtois. Essai chronologique et paléoclimatique, Besançon (Faculté des Sciences et des Techniques, Université de Franche-Comté), 559 p.

Cornet, J., 1927a. Leçons de Géologie. Bruxelles, Maurice Lamertin, 674 p.

CORNET, J., 1927b. L'époque wealdienne dans le Hainaut. *Annales Société géologique de Belgique*, L: 89-103.

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

Coûteaux, M., 1969. Recherches palynologiques en Gaume, au pays d'Arlon, en Ardenne méridionale (Luxembourg belge) et au Gutland (Grand-Duché de Luxembourg). *Acta Geographica Lovaniensia*, 8: 1-193.

DAMBLON, F., 1969. Etude palynologique comparée de deux tourbières du plateau des Hautes Fagnes en Belgique: la Fagne Wallonne et la Fagne de Clefay. *Bulletin du Jardin Botanique National de Belgique*, 39: 17-47.

DAMBLON, F., 1970. Etude palynologique d'un profil de tourbe en Fagne Wallonne (Hautes Fagnes de Belgique). *Lejeunia*, n.s., 49: 1-13.

DAMBLON, F., 1978a. Le Gué du Plantin : étude paléo-écologique d'un site humide (Neufvilles, Province du Hainaut, Belgique). *Bulletin de la Société Royale de Botanique de Belgique*, 111: 261-276.

DAMBLON, F., 1978b. Etude paléo-écologique de tourbières en Haute Ardenne. Bruxelles, Ministère de l'Agriculture, Administration des Eaux & Forêts, Service de la Conservation de la Nature, Travaux 10: 145 p., 10 fig., 16 pl., 11 tabl., 14 diagr.

DAMBLON, F., 1981. De l'analyse pollinique des touradons de Monocotyledones comme témoins de l'histoire récente de la végétation. *Compte-rendus de l'Académie des Sciences de Paris*, 292, sér. 3: 1191-1194.

DAMBLON, F., 1992. Palaeobotanical analyses of Eriophorum and Molinia tussocks as a means of reconstructing recent history of disturbed mires in the Haute-Ardenne, Belgium. *Review of Palaeobotany and Palynology*, 75: 273-288.

DAMBLON, F., 1994. Les dépôts tourbeux et l'histoire de la végétation sur le plateau des Hautes-Fagnes (Belgique). *Annales de la Société géologique de Belgique*, 117: 259-276.

Damblon, F. , Court-Picon, M. & Pirson, S., in press. L'enregistrement palynologique de la séquence pléistocène et holocène de la grotte Walou (bassin de la Vesdre, Belgique). In: Draily, C., Toussaint, M. & Pirson, S. (eds), La grotte Walou : fouilles 1996-2004. Volume 2 : les sciences de la vie et la chronologie. Monographie (Etudes et document – Archéologie), Namur, Ministère de la Région wallonne.

de Beaulieu, J.-L. & Reille, M., 1992. The last climatic cycle at La Grande Pile (Vosges, France). A new pollen profile. *Quaternary Science Reviews*, 11: 431-438.

de Heinzelin, J., 1963. Le réseau hydrographique de la région gallo-belge au Néogène. Essai de reconstitution. *Bulletin de la Société belge de Géologie*, 72: 137-148.

DEJAX, J., DUMAX, E., DAMBLON, F. & YANS, J., 2007b. Palynology of Baudour Clays Formation (Mons Basin, Belgium): correlation within the "stratotypic" Wealden. *Notebooks on Geology* e-Journal. http://paleopolis.rediris.es/cg/CG2007_M01/CG2007_M01.pdf, 16-28.

DEJAX, J., PONS, D. & YANS, J., 2007a. Palynology of the dinosaur-bearing Wealden facies sediments in the natural pit of Bernissart (Belgium). Review of *Palaeobotany and Palynology*, 144: 25-38.

DEJAX, J., PONS, D. & YANS, J., 2008. Palynology of the Wealden facies from Hautrage quarry (Mons Basin, Belgium). This volume.

DELMER, A., 1972. Origine du Bassin crétacique de la Vallée de la Haine. *Service géologique de Belgique Professional Paper*, 1972/5 : 13 p.

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

DEMOULIN, A., 1995a. L'Ardenne bouge toujours. Néotectonique du massif ardennais. In: Demoulin, A. (ed.), L'Ardenne. Essai de géographie physique. Hommage au professeur Pissart, 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: Demoulin, A. (ed.), L'Ardenne. Essai de géographie physique. Hommage au professeur Pissart. Liège, Département de Géographie physique et Quaternaire, Université de Liège: 68-93.
DENAEYER, M.-E. & MORTELMANS, G., 1954. Les roches éruptives. In: Fourmarier, P. (ed.), Prodrome d'une description géologique de la Belgique, Liège, Société géologique de Belgique: 745-792.
DUPUIS, C., EGGERMONT, B. & HENNEBERT, M., 1997. Evidences of tectonic movements during the Paleocene-Eocene interval (P/E, NP8/NP11) in the Tournai area (Mélantois) and neighbouring regions (NW Paris Basin, Mons Basin). *Aardkundige Mededelingen*, 8: 73-74.
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.
DUPUIS, C. & VANDYCKE, S., 1989. Tectonique et karstification profonde: un modèle de subsidence original pour le Bassin de Mons. *Annales de la Société géologique de Belgique*, 112: 479-487.
DUSAR, M., LANGENAEKER, V. & WOUTERS, L., 2001. Permian – Triassic – Jurassic lithostratigraphic units in the Campine basin and the Roer Valley Graben (NE Belgium). In: Bultynck, P. & Dejonghe, L. (eds), Guide to a revised lithostratigraphic scale of Belgium. *Geologica Belgica*, 4: 107-112.
EK, C., 1976. Les phénomènes karstiques. In: Pissart, A. (ed.), Géomorphologie de la Belgique. Hommage au Professeur Paul Macar, Liège, Laboratoire de Géologie et de Géographie physique, Université de Liège: 137-157.
EK, C., 1995. Grottes et rivières des régions calcaires. In: Demoulin, A. (ed.), L'Ardenne. Essai de géographie physique. Hommage au Professeur Albert Pissart, Liège, Département de Géographie physique et Quaternaire, Université de Liège: 178-193.
EK, C. & OZER, A., 1976. Les dernières transgressions marines. In: Pissart, A. (ed.), 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. R*evue belge de Géographie*, 106: 73-85.
EK, C. & QUINIF,Y., 1988. Les sédiments détritiques des grottes: aperçu synthétique. *Annales de la Société géologique de Belgique*, 111: 1-7.
FAIRON-DEMARET, M., 1996. The plant remains from the Late Famennian of Belgium: a review. *The Palaeobotanist*, 45: 201-208.
FAIRON-DEMARET, M. & SMITH, T., 2002. Fruits and seeds from the Tienen Formation at Dormaal, Paleocene-Eocene transition in eastern Belgium. *Review of Palaeobotany and Palynology*, 122: 47-62.
FAIRON-DEMARET, M., STEURBAUT, E., DAMBLON, F., DUPUIS, C., SMITH, T. & GERRIENNE, P., 2003. The in situ Glyptostroboxylon forest of Hoegaarden (Belgium) at the Initial Eocene Thermal Maximum (55 Ma). *Review of Palaeobotany and Palynology*, 126: 103-129.
FERRIER, C., 2002. Les dépôts d'entrée de grotte. In: Miskovsky, J.-C. (ed.), Géologie de la préhistoire, Paris (Association pour l'étude de l'environnement géologique de la préhistoire): 189-205.
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.
FOLIE, A., SIGÉ, B. & SMITH, T., 2005. A new scincomorph lizard from the Palaeocene of Belgium and the origin of Scincoidea in Europe. *Naturwissenschaften*, 92: 542-546.
FOURMARIER, P. (éd.), 1954. Prodrome d'une description géologique de la Belgique. Société Géologique de Belgique, 826 p.
FRANKE, W., 1989. Tectonostratigraphic units in the Variscan belt of central Europe. In: Dallmeyer, R. D. (ed.), Terranes in the Circum-Atlantic Paleozoic Orogens. *Geological Society of America Special Paper*, 230: 67-90.
GERARDS, T., YANS, J., SPAGNA, P. & GERRIENNE, P., 2008. Wood remains and sporomorphs from the Wealden facies of Hautrage (Mons Basin, Belgium): palaeoclimatic and palaeoenvironmental implications. This volume.
GERRIENNE, P., 1993. Inventaire des végétaux éodévoniens de Belgique. *Annales de la Société Géologique de Belgique*, 116: 105-117.

GERRIENNE, P., MEYER-BERTHAUD, B., FAIRON-DEMARET, M., STREEL, M. & STEEMANS, P., 2004. Runcaria, a Middle Devonian Seed Plant Precursor. *Science,* 306: 856-858.

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). *Memoirs of the Geological Survey of Belgium* (Mémoires pour servir à l'Explication des Cartes Géologiques et Minières de la Belgique, 38 : 144 p.

GODFRIAUX, Y., 1968. Quelques aspects sédimentologiques de la Craie de Maisières. B*ulletin de la Société belge de Géologie*, 77: 289-305.

GOLDBERG, P. & SHERWOOD, S. C., 2006. Deciphering Human Prehistory Through the Geoarcheological Study of Cave Sediments. *Evolutionary Anthropology*, 15: 20-36.

GOMEZ, B., GILLOT, T., DAVIERO-GOMEZ, V., SPAGNA, P. & YANS, J., 2008. Palaeoflora from the Wealden facies strata of Belgium - mega- and meso-fossils of Hautrage. This volume.

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

GULINCK, M., 1974. L'Albien Cénomanien et le Wealdien dans la région de Thieu (sondage du canal du Centre). *Annales de la Société géologique de Belgique*, 97: 311-315.

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

HACK, B.U., HARDENBOL, J. & VAIL, P.R., 1987. Chronology of fluctuating sea levels since the Triassic. *Science*: 235: 1156-1167.

HAESAERTS, P., 1984a. Aspects de l'évolution du paysage et de l'environnement en Belgique au Quaternaire. In: Cahen, D. & Haesaerts, P. (eds), 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., 2007. Mitoc-Malu Galben : cadre stratigraphique et chronologique. In: Otte, M., Chirica, V. & Haesaerts, P. (eds), L'Aurignacien et le Gravettien de Mitoc-Malu Galben (Moldavie roumaine). *Etudes et Recherches archéologiques de l'Université de Liège*, 72: 15-41.

HAESAERTS, P., CHEKHA, V. P., DAMBLON, F., DROZDOV, N. I., ORLOVA, L. A. & VAN DER PLICHT, J., 2005. The loess-palaeosol succession of Kurtak (Yenisei basin, Siberia): a reference record for the Karga Stage (MIS 3). *Quaternaire*, 16: 3-24.

HAESAERTS, P. & VAN VLIET, B., 1973. Evolution 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.

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.

HEIM, J., 1970. Les relations entre les spectres polliniques récents et la végétation actuelle en Europe occidentale. Université de Louvain, Laboratoire de Palynologie et Phytosociologie, 181 p.

HOLMES, J. & FAIRON-DEMARET, M., 1984. A new look at the flora of the Bouxharmont coal balls from Belgium. *Annales de la Société Géologique de Belgique*, 107: 73-87.

JONES, B., 2005. Cave sediments. In: Middleton, G. V. (ed.), Encyclopedia of sediments and sedimentary rocks, Springer, Encyclopedia of Earth Sciences Series: 109-110.

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

KUKLA, G. & AN, Z.S., 1989. Loess stratigraphy in central China. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 72: 203-225.

LAGA P., LOUWYE S. & GEETS S., 2001. Paleogene and Neogene lithostratigraphic units (Belgium). In: Bultynck, P. & Dejonghe, L. (eds), 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: Pissart, A. (coord.), Géomorphologie de la Belgique. Hommage au Professeur P. Macar, Liège, Laboratoire de Géologie et de Géographie physique, Université de Liège: 29-50.
LECLERCQ, S. & BANKS, H.P., 1962. Pseudosporochnus nodosus sp. nov., a Middle Devonian plant with cladoxylalean affinities. *Palaeontographica* B, 110: 1-34.
LECLERCQ, S. & BONAMO, P.M., 1971. A study of the fructification of Milleria (Protopteridium) thomsonii Lang from the Middle Devonian of Belgium. *Palaeontographica* B, 136: 83–114.
LIU, T.S., 1985. Loess and the environment. China Ocean Press, Beijing. 251 p.
MACAR, P., 1976. Les mouvements épeirogéniques décelables en Belgique. L'aide de la Géomorpologie. In: Pissart, A. (coord.), Géomorphologie de la Belgique. Hommage au Professeur P. Macar, Liège, Laboratoire de Géologie et de Géographie physique, Université de Liège: 93-106.
MARLIERE, R., 1946. Deltas wealdiens du Hainaut; sables et graviers de Thieu; argiles réfractaires d'Hautrage. *Bulletin de la Société belge de Géologie*, 55: 69-100.
MARLIERE, R., 1970. Géologie du bassin de Mons. *Annales Société géologique du Nord*, XC, 4: 171-189.
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.
MICHOT, P., 1980. Belgique, introduction à la géologie régionale. 26e Congrès Géologique International, livret-guide de l'excursion, 211A: 487-576.
MULLENDERS, W. & COREMANS, M.,1961. Recherches palynologiques dans la vallée de la Grande Nèthe à Geel (Campine belge). *Bulletin de la Société Royale de Botanique de Belgique*, 93: 131-136
MULLENDERS, W., DUVIGNEAUD, J. & COREMANS, M., 1963. Analyse pollinique de dépôts de tuf calcaire et de tourbe à Treignes (Belgique). *Grana Palynologica*, 4: 439-448.
MULLENDERS, W., GILOT, E., ANCION, N. & CAPRON, P., 1967. Evolution of the vegetation in high Belgium, and its radiocarbon chronology. In: 7th Congress of the International Association for Quaternary Research: 333-339.
MULLENDERS, W. & GULLENTOPS, F., 1957. Palynologisch en geologisch onderzoek in de alluviale vlakte van de Dijle, te Heverlee - Leuven. *Agricultura*, 5: 57-64.
MULLENDERS, W., GULLENTOPS, F. & COREMANS, M., 1966. Les sédiments de la transition "Eemien-Wurm" à Oevel, Campine belge. Louvain. *Acta Geographica Lovaniensia*, 4: 57-67.
MUNAUT, A.V., 1967a. Recherches paléo-écologiques en Basse et Moyenne Belgique. Louvain. *Acta Geographica Lovaniensia*, 6 : 191 p.
MUNAUT, A.V., 1967b. Etude paléo-écologique d'un gisement tourbeux situé à Terneuzen. *Berichten van de Rijksdienst voor het Oudheidkundig Bodemonderzoek*, 17: 7-27.
MUNAUT, A.V. & PAULISSEN, E., 1973. Evolution et paléo-écologie de la vallée de la Petite Nèthe au cours du post-Würm (Belgique). *Annales de la Société Géologique de Belgique*, 96: 301-348.
ONCKEN, O., 1998. Orogenic mass transfer and reflection seismic patterns – evidence from DEKORP sections across the European Variscides (central Germany). *Tectonophysics*, 286: 47-61.
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. & VANHOORNE, R., 1967. The Stratigraphy and Palaeobotany of the Late Pleistocene in Belgium. Bruxelles, Service géologique de Belgique. *Memoirs of the Geological Survey of Belgium* (Mémoires pour servir à l'explication des Cartes géologiques et minières de la Belgique), 8 : 96 p.
PAEPE, R. & VANHOORNE, R., 1970. Stratigraphical position of periglacial phenomena in the campine clay of Belgium, based on palaeobotanical analysis and palaeomagnetic dating. *Bulletin de la Société belge de Géologie*, 79: 201-211.
PAEPE, R. & VANHOORNE, R., 1976. The Quaternary of Belgium and its relationship to the stratigraphical legend of the geological map. *Memoirs of the Geological Survey of Belgium* (Mémoires pour servir à l'Explication des Cartes Géologiques et Minières de la Belgique), 18 : 38 p.
PAEPE, R., VANHOORNE, R. & DERAYMAEKER, D., 1973. Eemian Sediments near Bruges (Belgian coastal plain). SH. Brugge - 23W, 372. *Geological Survey of Belgium Professional Paper*, 1973/9: 12 p.
PAPROTH, E., CONIL, R., BLESS, M-J-M., BOONEN, P., CARPENTIER, N., COEN, M., DELCAMBRE, B., DEPRIJCK, C., DEUZON, S., DREESEN, R., GROESSENS, É., 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., 2003. Contextes géologique et géomorphologique du « champ mégalithique de Wéris ». In: Toussaint, M. (dir.), Le « champ mégalithique de Wéris. Fouilles de 1979 à 2001 », volume 1, Contexte archéologique et géologique. Namur, Ministère de la Région wallonne (Etude et Documents, Archéologie, 9): 284-363.

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, 1 vol. texte (435 p.), 1 vol. (5 annexes).

PIRSON, S., COLLET, H., BAELE, J.-M., DUPUIS, C., MORTIER, T. & FAIRON-DEMARET, M., 2002. Mons/Spiennes : étude pétrographique de fragments de polissoirs et de meules. *Chronique de l'Archéologie wallonne*, 10: 38-40.

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. This volume.

PIRSON, S., DUPUIS, C., BAELE, J.-M., COLLET, H. & MORTIER, T., 2001. Fragments de polissoirs découverts à Petit-Spiennes : pétrographie et implications archéologiques. *Notae Praehistoricae*, 21: 145-156.

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

PIRSON, S., TOUSSAINT, M. & DRAILY, C (eds), in press. La grotte Walou : fouilles 1996-2004. Volume 1 : les sciences de la terre. Namur, Ministère de la Région wallonne, Monograph (Etudes et documents – Archéologie).

PISSART, A., 1975. La Meuse en France et en Belgique. Formation du bassin hydrographique. Les terrasses et leurs enseignements. In: Macar, P. (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: Bultynck, P. & Dejonghe, L. (eds), Guide to a revised lithostratigraphic scale of Belgium. *Geologica Belgica*, 4: 69-94.

PRESTIANNI, C., 2005. Early diversification of seed and seed-like structures. In: STEEMANS, P. & JAVAUX, E. (eds), Pre-Cambrian to Palaeozoic Palaeopalynology and Palaeobotany, *Carnets de Géologie / Notebooks on Geology*, Brest, Memoir 2005/02, Abstract 06 (CG2005_M02/06).

QUINIF, Y., 2006. Complex stratigraphic sequences in belgian caves. Correlation with climatic changes during the Middle, the Upper Pleistocene and the Holocene. *Geologica Belgica*, 9: 231-244.

QUINIF, Y., MEON, H. & YANS, J., 2006. Nature and dating of karstic filling in the Hainaut Province (Belgium). Karstic, geodynamic and paleogeographic implications. *Geodinamica Acta*, 19/2: 73-85.

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.

REILLE, M., ANDRIEU, V., DE BEAULIEU, J.-L., GUENET, P. & GOEURY, C., 1998. A long pollen record from Lac du Bouchet, Massif Central, France: for the period ca. 325 to 100 ka BP (OIS 9c to OIS 5e). *Quaternary Science Reviews*, 17: 1107-1123.

ROBASZYNSKI, F., 1975. "Crétacé". In Marlière, R. & Robaszynski, F. (Eds.), Conseil géologique. Commissions nationales de Stratigraphie, Ministère des Affaires Economiques. 53.

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

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

RUTOT, A., 1881. Sur la position stratigraphique des restes de mammifères terrestres recueillis dans les couches de l'éocène de Belgique. *Bulletin de l'Académie royale des Sciences, des Lettres et des Beaux-Arts de Belgique*, 3ème série, I (4): 506-547.

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.

SPAGNA, P., VANDYCKE, S., YANS, J. & DUPUIS, C., 2007. Hydraulic and brittle extensional faulting in the Wealden facies of Hautrage (Mons Basin, Belgium). *Geologica Belgica* 10/3-4: 158-161.

STOCKMANS, F., 1946. Végétaux de l'Assise des Sables d'Aix-la-Chapelle récoltés en Belgique (Sénonien inférieur). *Mémoires du Musée Royal d'Histoire Naturelle de Belgique*, 105: 1-51.

STOCKMANS, F., 1968. Végétaux mésodévoniens récoltés aux confins du Massif du Brabant (Belgique). *Mémoires du Musée Royal d'Histoire Naturelle de Belgique,* 159: 1-49.

STOCKMANS, F. & WILLIÈRE, Y., 1943. Palmoxylons paniséliens de la Belgique. *Mémoires du Musée Royal d'Histoire Naturelle de Belgique*, 100: 1-75.

STOCKMANS, F. & WILLIÈRE, Y., 1953. Végétaux namuriens de la Belgique. *Association pour l'Etude de la Paléontologie et de la Stratigraphie Houillères*, 13: 1-382.

STOCKMANS, F. & WILLIÈRE, Y., 1961. Végétaux du Westphalien A de la Belgique. *Centre National de Géologie Houillère*, 4: 1-118.

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

TEXIER, J.-P., KERVAZO, B., LENOBLE, A. & NESPOULET, R. (éd.), 2004. Sédimentogenèse des sites préhistoriques du Périgord. Livret-guide de l'excursion AGSO-ASF, 23-24/04/2004. Association des sédimentologistes français, 63 p.

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., 2006. Neandertal Studies in Belgium: 2000-2005. *Periodicum Biologorum*, 108: 373-387.

TOUSSAINT, M. & PIRSON, S., 2007. Aperçu historique des recherches concernant l'homme préhistorique dans le karst belge aux XIXe et XXe siècles : archéologie, géologie, paléoanthropologie, paléontologie, datations. In: Evin, J. (ed.), Un siècle de construction du discours scientifique en préhistoire. Actes du XXVIe Congrès préhistorique de France. Avignon, 21-25 septembre 2004. Volume 3, Paris, 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., 2001. Evolution géodynamique de la partie orientale de l'allochtone de l'Ardenne. Observations structurales et modélisations numériques. Liège (Thèse de doctorat inédite, Université de Liège, Faculté des Sciences), 350 p.

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.

VANDYCKE, S. 2002. Paleostress records in Cretaceous formations in NW Europe: synsedimentary strike-slip and extensional tectonic events. Relationship with Cretaceous-Tertiary inversion tectonics. *Tectonophysics*, 357: 119-136.

VANDYCKE, S., BERGERAT, F. & DUPUIS, C., 1991. Meso-Cenozoic faulting and inferred palaeostress in the Mons Basin, Belgium. *Tectonophysics*, 192: 261-271.

VANHOORNE, R., 1951. Evolution d'une tourbière de plaine alluviale au Kruisschans (Anvers, Belgique). *Bulletin de l'Institut royal des Sciences naturelles de Belgique*, 27: 1-20.

VANHOORNE, R., 1963. La tourbe fin Eemien et début Würm du plateau d'Oevel (Belgique). *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre*, 39: 1-7.

VANHOORNE, R., 2003. A contribution to the palaeontological study of the Middle Pleistocene deposit at Lo (Belgium). *Quaternaire*, 14: 75-83.

VANHOORNE, R., 2005. Pollen assemblages, plant communities and biostratigraphy of the lower Pleistocene Campine clay in Belgium. *Geologica Belgica*, 8: 15-36.

VERBRUGGEN, C., 1999. Quaternary palaeobotanical evolution of northern Belgium. *Geologica Belgica*, 2: 99-110.

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

WATTS, W. A., ALLEN, J. R. M. & HUNTLEY, B., 2000. Palaeoecology of three interstadial events during oxygen-isotope Stages 3 and 4: a lacustrine record from Lago Grande di Monticchio, southern Italy. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 155: 83-93.

WELLMAN, C.H., OSTERLOFF, P.L. & MOHIUDDIN, U., 2003. Fragments of the earliest land plants. *Nature*, 425: 282-285.

WOILLARD, G., 1979. The last interglacial-glacial cycle at Grand Pile in northeastern France. *Bulletin de la Société belge de Géologie*, 88: 51-69.

YANS, J., 2007. Lithostratigraphie, minéralogie et diagenèse des sédiments à faciès wealdien du Bassin de Mons (Belgique). *Mémoire de la Classe des Sciences, Académie Royale de Belgique*, 3ème série, tome IX, n°2046, 179 p., Bruxelles.

YANS, J., DEJAX, J., PONS, D., DUPUIS, C. & TAQUET, P., 2005a. Paleontologic and geodynamic implications of the palynological dating of the Bernissart wealden facies sediments (Mons Basin, Belgium). *C.R. Palevol*, 4: 135-150.

YANS, J., DEJAX, J., PONS, D., TAVERNE, L. & BULTYNCK, P., 2006. The Iguanodons of Bernissart are middle Barremian to earliest Aptian in age. *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre*, 76: 91-95.

YANS, J., MASURE, E., DEJAX, J., PONS, D. & AMÉDRO, F., 2007. Influences boréales dans le bassin de Mons (Belgique) à l'Albien. In: Bulot, L.G., Ferry, S. & Grosheny, D. (eds), Relations entre les marges septentrionale et méridionale de la Téthys au Crétacé. *Notebooks on Geology*, Brest, Mémoire 2007/02, Résumé 06 (CG2007_M02/06).

YANS, J., SPAGNA, P., FOUCHER, J-C., PERRUCHOT, A., STREEL, M., BEAUNIER, P., ROBASZYNSKI, F. & DUPUIS, C., 2002. Multidisciplinary study of the wealden deposits of the Mons Basin (Belgium): a progress report. *Aardkundige Mededelingen*, 12: 39-42.

YANS, J., SPAGNA, P., VANNESTE, C., HENNEBERT, M., VANDYCKE, S., BAELE, J-M., TSHIBANGU, J-P., BULTYNCK, P., STREEL, M. & DUPUIS, C., 2005b. Description et implications géologiques préliminaires d’un forage carotté dans le "Cran aux Iguanodons" de Bernissart. *Geologica Belgica*, 8: 43-49.

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

130 YEARS AGO: THE DISCOVERY OF THE BERNISSART IGUANODONS

Pascal GODEFROIT

Institut royal des Sciences naturelles de Belgique, rue Vautier 29, 1 000 Bruxelles, Belgium; Pascal.Godefroit@naturalsciences.be

ABSTRACT. The discovery, in 1878, of more than twenty complete skeletons of the ornithopod dinosaur *Iguanodon*, is one of the most important discoveries in the history of palaeontology. Here we shortly describe the discovery, the excavation, the preparation, the exhibition and the study of these extraordinary skeletons.

KEYWORDS. *Iguanodon*, Bernissart, Lower Cretaceous, dinosaurs.

(5 figures, 1 table)

1. Introduction

Bernissart is a former coal-mining village in western Belgium, situated less than a km from the Franco-Belgian frontier. In 1878, the Sainte-Barbe Pit (Fig. 1) started to produce one of the greatest dinosaur discoveries of all times: more than 20 complete articulated skeletons and several incomplete specimens of *Iguanodon*. These were the first complete skeletons ever discovered and still remain one of the greatest accumulations of a single taxon of dinosaur. This discovery was a cornerstone in the history of palaeontology: for the first time, it was possible for the scientific community to realize how dinosaurs really looked like. Most of the specimens of *Iguanodon* are now on display in the renovated Janlet Wing of the Royal Belgian Institute of Naturals Sciences in Brussels. Nine of them are standing, mounted within an enormous glass cage. Many others have been left in their original position, lying on their sides as found entombed in the coal mine. This astonishing array of *Iguanodon* skeletons constitutes one of the most impressive displays of dinosaurs anywhere in the world.

2. Before Bernissart

Around 1822, Mary Ann Mantell discovered large fossilized teeth while strolling in the Sussex countryside in England. Her husband, the physician Dr. Gideon Mantell, was very intrigued by these fossils. He described them and named them *Iguanodon* ('Iguana tooth'), because of their superficial resemblance to those of living iguanas (Mantell, 1825). *Iguanodon*, the second representative of the group after *Megalosaurus* (Buckland, 1824), was one the few chart members of the 'Dinosauria', named by Richard Owen in 1842.

For 56 years, very little was known about *Iguanodon* and other dinosaurs. Mantell imagined these antediluvian animals to be some kind of giant lizards with elongated bodies and sprawling limbs. In 1854, the sculptor Waterhouse Hawkins erected a full-size reconstruction of *Iguanodon* for the Crystal Palace exhibition centre in London as a rhinoceros-like heavy quadruped with a large spike on its nose.

The first partial dinosaur skeleton, named *Hadrosaurus foulki* Leidy, 1858, was discovered in 1857 in New Jersey. This skeleton was reconstructed in a bipedal gait at the Academy of Natural Sciences of Philadelphia, but many questions were still left unanswered about the general appearance of dinosaurs.

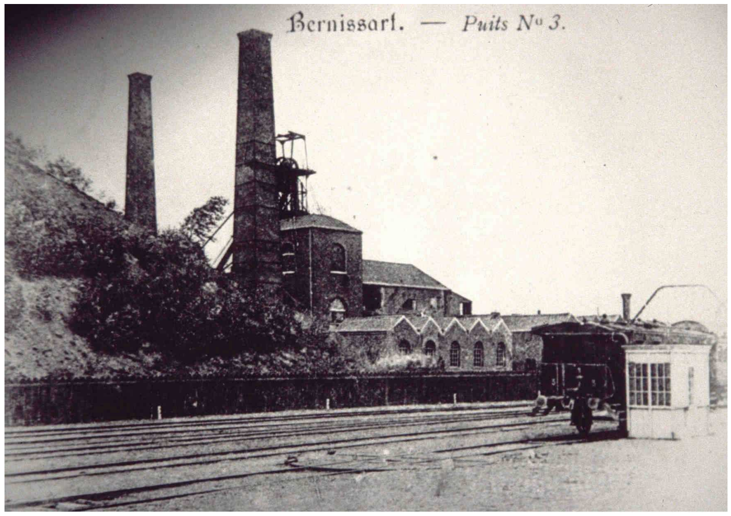

Figure 1. The Sainte-Barbe pit and mine buildings at the end of the 19th Century, at the time when the Bernissart Iguanodons were discovered.

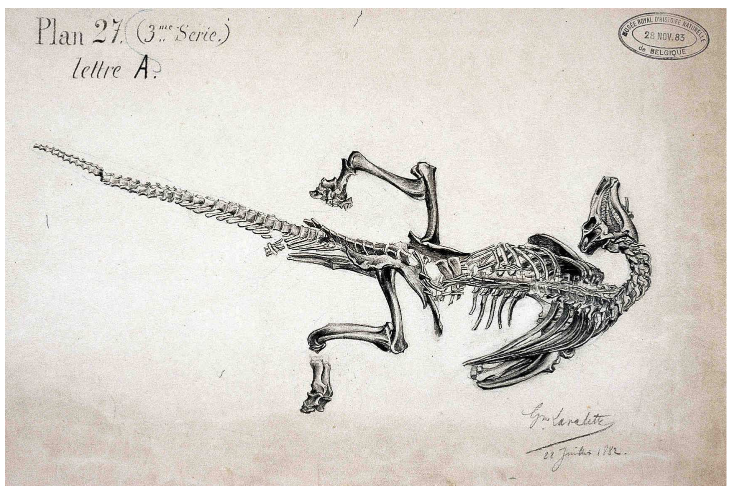

Figure 2. Drawing by G. Lavalette of a specimen of *Iguanodon bernissartensis* as discovered in the Sainte-Barbe pit at Bernissart.

3. The discovery of the Bernissart Iguanodons

In 1878, miners working in the the Sainte-Barbe Pit at Bernissart reported that the Luronne seam was cut out, at 322 m depth, by what they called a ‘cran’, a local name for pits formed by natural collapse through the coal seams and filled with Lower Cretaceous clayey deposits normally located above the Coal Measures. The miners had to traverse this ‘cran’ as quickly as possible in order to rejoin the Luronne seam.

On February 28, two miners, J. Créteur and A Blanchard, found in the clays of the ‘Cran’ what they believed to be a tree trunk filled with gold. Many other specimens were collected by the miners in March. On April 2, the local doctor L’Hoir and the mine manager G. Fagès concluded, that these strange objects were in fact fossil bones filled with pyrite, the ‘fool’s gold’. They rapidly sent fragments of fossil bones to several Belgian specialists. P.J. Van Beneden, a zoologist from Leuven University, was the first to recognize among the collected specimens teeth of the dinosaur *Iguanodon* (Van Beneden, 1878). On April 12, the management of the colliery sent a telegram to E. Dupont, director of the Royal Museum of Natural History in Brussels, asking for the services of L. De Pauw, a technician highly experienced in the restoration of fossils.

Insects		
	Order Hemiptera	
		Hylaeoneura lignei Lameere & Severin, 1897
Fishes		
	Order Palaeonisciformes	
		Coccolepis macropterus Traquair, 1911
	Order Pycnodontiformes	
		Lepidotes bernissartensis Traquair, 1911
		Lepidotes brevifulcratus Traquair, 1911
		Lepidotes arcuatus Traquair, 1911
		Turbomesodon bernissartensis (Traquair, 1911)
	Order Amiiformes	
		Callopterus insignis Traquair, 1911
		Amiopsis dolloi Traquair, 1911
		Amiopsis lata traquair, 1911
		Notagogus parvus traquair, 1911
	Order Pholidophoriformes	
		Pholidophorus obesus (Traquair, 1911)
		Pleuropholis sp.
	Order Gonorhynchiformes	
		Aethalionopsis robustus (Traquair, 1911)
	Order Salmoniformes	
		Pattersonella formosa (Traquair, 1911)
		Nybelinoides brevis (Traquair, 1911)
	Order Elopiformes	
		Arratiaelops vectensis (Woodward, 1890)
Amphibian		
	Caudata incertae sedis	
		Hylaeobatrachus croyii Dollo, 1885
Turtles		
		Chitracephalus dumonii Dollo, 1885
		Peltochelys duchasteli Dollo, 1885
Crocodiles		
		‘Goniopholis simus Owen, 1878’
		Bernissartia fagesiii Dollo, 1883
Dinosaurs		
		Iguanodon bernissartensis Boulenger, 1881
		Iguanodon atherfieldensis Hooley, 1924
		Theropoda indet.

Table 1. Faunal list of the ‘*Iguanodon* cran’ at Bernissart

4. The excavation of the Bernissart Iguanodons

During three years, L. De Pauw and his team, composed by one museum warder, one moulder and nine miners, actively excavated the ‘Iguanodon Cran’ at Bernissart. In August 1878, an important earthquake blocked the excavation team during two hours in the gallery 322 m below ground level. This gallery was subsequently flooded in autumn, forcing the team to abandon their researches during several months. The excavations restarted from May 1879 onwards. They were extended horizontally for 50m at the 322 m level. The miners also encountered fossiliferous clays at a depth of 356 m, but the diameter of the ‘cran’ was reduced at only 9m at this level and the skeletons were consequently completely dislocated (De Pauw, 1902).

It was the first time that palaeontologist had the opportunity to collect such a wealth of fossils within a single locality. More than twenty more or less complete skeletons of *Iguanodon* were found lying as they had fallen, little disturbed by their burial (Fig. 2). Besides these dinosaurs, hundreds of fragments of plants, hundreds of fishes, several crocodiles and tortoises, one amphibian, one fragment of insect, and one carnivorous dinosaur phalanx were also discovered (Table 1).

The excavation method elaborated by L. De Pauw was so efficient that it is still used at the present time during palaeontological excavations. Each *Iguanodon* skeleton was split into pieces that were coated with plaster of Paris. After being sketched and catalogued, the blocks were carried to the surface. After three years of excavations, about six hundred blocks, totalling more than 130 tonnes, were transported to Brussels in furniture removal vans.

The excavations were stopped in 1881, because the expenses involved by this enterprise were considered too high by the Belgian government. Members of the Parliament suggested that an Iguanodon skeleton should be sold abroad in order to collect supplementary subsidies, but public outcry prevented this transaction. From 1915, the German forces of occupation, under the initiative of the palaeontologist Otto Jaekel, planned to start new excavations at Bernissart in order to send new Iguanodon skeletons in German natural history museums. But the preliminary researches were interrupted in 1918 by the end of the First World War (Roolf, 2004). After the war, further initiatives to start new excavations at Bernissart were immediately stopped because of the absence of wish from the Belgian government to put up the money for such researches.

Figure 3. Mounting of the first Iguanodon specimen in the St. George Chapel of the Nassau Palace. Note, close to the Iguanodon's leg, the cassowary and wallaby skeletons used for comparison.

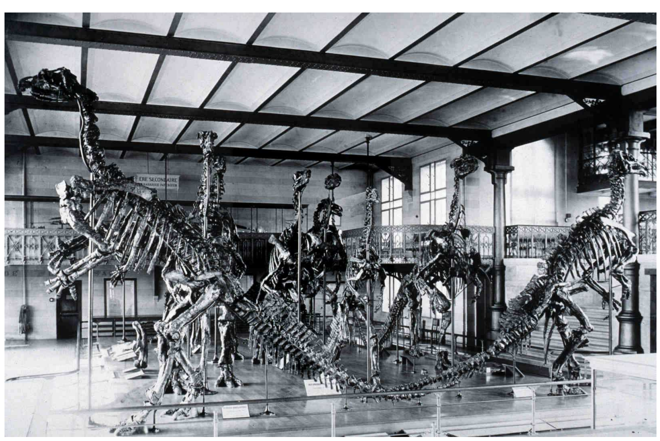

Figure 4. Exhibition, in the beginning of the 20th Century, of the mounted Iguanodon specimens in the Janlet Wing of the Royal Museum of Natural History.

5. Preparation and mounting of the Iguanodon skeletons

After death, the Iguanodon carcasses were covered by clayey sediments and their decomposition therefore developed in anoxic environment. In such conditions, sulphate-reducing bacteria were highly involved in the putrefaction processes. The hydrogen sulphide, produced during the hydrolysis of the organic matter by these bacteria, combined with the iron from the sediments and from the degradation of haemoglobin to form pyrite, which was deposited in cavities within the bones. In contact with damp air, the pyrite oxidised to form a salt, iron sulphate, or an iron oxide, limonite. Decomposition of both led to the disintegration of bone containing them (Leduc, 2004). For that reason, the *Iguanodon* bones became extremely fragile when they were extracted from the Bernissart pit.

Once they were arrived in Brussels, the *Iguanodon* blocks were stored in the Museum workshop, housed in the St George Chapel of the Nassau Palace, now preserved as an exhibition hall in the Albert I Royal Library. Between 1878 and 1905, the bones were impregnated with a carpenter's glue-based gelatine and the pyrite was systematically curetted from the bones. Some vertebrae contained more than 1 kg of pyrite. The remaining cavities were filled with 'carton-pierre', a stable mixture of paper, glue and talc (De Pauw, 1902).

It was decided to mount the best preserved *Iguanodon* specimens in a lifelike gait. In 1882, the first specimen was assembled and mounted by L. De Pauw and his team in the St. George Chapel. The bones were suspended from scaffolding by ropes that could be adjusted so as to obtain the most lifelike position for the complete skeleton, which was then supported by an iron framework (Fig. 3). This first mounted specimen was publicly exhibited in 1883 in a glass cage constructed in the interior court of the Nassau Palace. But the Nassau Palace Chapel quickly became too small for the storage, preparation, mounting and exhibition of these numerous and bulky skeletons. In 1891, the Iguanodons and the Royal Museum of Natural History were transported to a new home in the Leopold Park. In 1899, five specimens were mounted in a glass cage close to the entrance of the museum. From 1902 onwards, the whole Bernissart exhibition was permanently installed in the newly-constructed Janlet Wing of the Royal Museum of Natural History (Fig. 4).

Between 1933 and 1937, the *Iguanodon* skeletons were dismantled and treated, because thirty years of changes in temperature and humidity had produced important damages. The bones were soaked in a mixture of alcohol and shellac, a natural lacquer secreted by coccid insects. The specimens were installed into two large glass cages, in order to stabilize the temperature and humidity of their environment.

From 2004 till 2007, the Janlet Wing of the Royal Belgian Institute of Natural Sciences was entirely renovated. At this occasion, the Iguanodon skeletons were completely restored again. All the bones were reinforced by a solution in acetone and alcohol of synthetic polyvinyl acetate ('Mowilith'). New glass cages were constructed to protect the skeletons.

6. The study of the Bernissart Iguanodons

Just after the discovery of the Bernissart Iguanodons, E. Dupont, then director of the Royal Museum of Natural History, asked the young naturalist G. A. Boulenger to study these specimens. In 1881, Boulenger presented his first results to the Belgian Academy of Sciences, Letters and Fine Arts: he described the anatomy of the pelvis of these dinosaurs and proposed that the greater number of sacral vertebrae (six) in the Bernissart form, as opposed to the five sacral vertebrae in the English species *I. mantelli*, merited the establishment of a new species that he named *Iguanodon bernissartensis*. Unfortunately, this paper was refused publication, although a brief highly critical review of Boulenger's paper was published by Van Beneden (1881). The latter claimed that the Bernissart Iguanodons belonged to *Iguanodon mantelli*, already described from disarticulated specimens discovered in England. Shortly afterwards, in 1881, Boulenger accepted a post at the British Museum (Natural History) and in 1882 study of the Bernissart Iguanodons was entrusted to L. Dollo. Between 1882 and 1923, Dollo published many preliminary notes on the Bernissart fauna and, especially, on *Iguanodon* (see bibliographical list in Norman, 1980). He distinguished two species at Bernissart: most of the specimens belong to the larger form *I. bernissartensis*, the new species named by Boulenger, although a single complete individual represents the smaller and slender *I. mantelli*. While studying in detail several parts of the *Iguanodon* skeleton, Dollo was adopting a forensic approach to understanding these fossils. He developed a new style of palaeontology that became known as palaeobiology: palaeontology can be expanded to investigate the biology, and by implication the ecology and the behaviour of extinct creatures. Dollo's final contribution to the *Iguanodon* story was published in 1923 as a synthetic study, to honour the centenary of Mantell's original paper. He identified *Iguanodon* as an ecological equivalent of the giraffe. Its kangaroo-like posture enabled it to reach high into the trees to gather its fodder, which it was able to draw into its mouth by using a long, muscular tongue. The sharp beak was used to nip off tough stems, while the teeth served to pulp the food before it was swallowed. This image of *Iguanodon* as a gigantic kangaroo-style creature, as depicted by Dollo, has become iconic during more than 60 years and was reinforced by the distribution of full-sized replicas of mounted skeletons of *Iguanodon* from Brussels to many of the great museums around the world (Norman, 2005).

In 1980, the British palaeontologist D. Norman published a monographic study of *Iguanodon bernissartensis*. Functional analysis of the skeleton indicated that the vertebral column, stiffened by a network of ossified tendons, was held more or less horizontal while the animal was walking or running. Norman also believed that *I. bernissartensis* was mainly a quadrupedal animal. The structure of the pectoral girdle, the ratios of the fore-and hindlimb lengths, the strongly fused carpal bones, and the presence of hoof-like unguals on the middle three digits of the hand suggest that the adult of *I. bernissartensis* spent most of its time in a quadrupedal posture, though juveniles had a predominantly bipedal mode of life.

In 1986, Norman concluded that the small species from Bernissart belongs to *Iguanodon atherfieldensis* Hooley, 1925, a species previously described from the Wealden Beds of the Isle of Wight.

Although the Bernissart Iguanodons were discovered 130 years ago, these fantastic creatures have not revealed all their secrets yet. At the occasion of the last dismounting operation of the *Iguanodon* specimens, the best preserved skulls have been investigated by CT-scanning at Gasthuisberg Hospital in Leuven. It is now possible to study inaccessible areas inside the skull without damaging these fragile fossils. Fig. 5 is a reconstruction, after C-T scanning, of the brain cavity of these animals, dead some 130 million years ago.

Figure 5. Reconstruction by C-T scanning of the skull and brain of *Iguanodon bernissartensis*.

7. References

BUCKLAND, W., 1824. Notice on *Megalosaurus* or great fossil lizard of Stonesfield. *Transactions of the Geological Society of London*, 21: 390-397.

DE PAUW, L.F., 1902. *Notes sur les fouilles du charbonnage de Bernissart. Découverte, solidification et montage des Iguanodons*. Imprim. photo-litho, JH. & P. Jumpertz, 150 av. d'Auderghem, Bruxelles, Belgium.

LEDUC, T., 2004. *La diagenèse des ossements fossiles: étude bibliographique*. Mémoire de D.E.A. non publié, Université de Liège, Belgium.

LEIDY, J., 1858. *Hadrosaurus* and its discovery. *Proceedings of the Academy of Natural Sciences, Philadelphia*, 10: 213-218.

MANTELL, G.A., 1825. Notice on the *Iguanodon*, a newly discovered fossil reptile, from the sandstone of Tilgate Forest, in Sussex. *Philosophical Transactions of the Royal Society*, 115: 179-186.

MARTIN, F. & BULTYNCK, P., 1990. *The Iguanodons of Bernissart*. Institut royal des Sciences naturelles de Belgique, Bruxelles, Belgium.

NORMAN, D.B., 1980. On the ornithischian dinosaur *Iguanodon bernissartensis* of Bernissart (Belgium). *Mémoires de l'Institut royal des Sciences naturelles de Belgique*, 178: 1-103.

NORMAN, D.B., 1986. On the anatomy of *Iguanodon atherfieldensis* (Ornithischia, Ornithopoda). *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre*, 56: 281-372.

NORMAN, D.B., 2005. *Dinosaurs. A very short introduction*. Oxford University Press, Oxford, U.K.

OWEN, R., 1842. Report on British fossil reptiles, part II. *Report of the Eleventh Meeting of the British Association for the Advancement of Science, held at Plymouth, July 1841*, 66-204. London.

ROOLF, C., 2004. Dinosaurier-Skelette als Kriegziel: Kulturgutraubplanungen, Besatzungpolitik und die deutsche Paläontologie im Ersten Weltkrieg. *Berichte zur Wissenschaftgeschichte*, 27: 5-26.

VAN BENEDEN, P.-J., 1878. Découverte de reptiles gigantesques dans le charbonnage de Bernissart, près de Péruwelz. *Bulletin de l'Académie royale de Belgique*, 2ème série, 45: 578.

VAN BENEDEN, P.-J., 1881. Sur l'arc pelvien chez les dinosauriens de Bernissart. *Bulletin de l'Académie royale belge, classe des Sciences*, 3 : 600-608.

SEDIMENTOLOGY OF THE WEALDEN CLAYS IN THE HAUTRAGE QUARRY

Paul SPAGNA[1], Christian DUPUIS[1] & Johan YANS[2]

1. Service de Géologie Fondamentale et Appliquée, Faculté Polytechnique de Mons, 9 rue de Houdain, 7000 Mons. Paul.Spagna@fpms.ac.be; Christian.Dupuis@fpms.ac.be
2. Département de Géologie, Faculté Universitaire Notre Dame de la Paix, 61 Rue de Bruxelles, 5000 Namur. Johan.Yans@fundp.ac.be

(7 figures and 1 plate)

ABSTRACT. The wealden facies of Hautrage are here approached through their depositional environment characteristics. Lithological, textural and mineralogical data are used in order to precise the sedimentological and geodynamic conditions of the middle Barremian to earliest Aptian interval in Hautrage. The results suggest the deposition of the wealden facies in a floodplain crossed by east-west oriented channels (flowing westward). Clayey sediments settled during high flood events. Conditions of stability and exundation allowed the development of poor maturation soils, especially in the lowermost sediments. The pebbles within the sandy channels at the top of the series and the size of the channels (southern front of the quarry) reflect an increase of the hydrological energy.

KEYWORDS. Hautrage, wealden facies, sedimentology, continental, palaeosoils, channels, floodplain.

1. Introduction

Since a few decades, the Geological Service of the Faculté Polytechnique de Mons studied the wealden deposits of the Hautrage quarry, thanks to a constructive collaboration with the CBR-Heidelbergcement industry that uses those clays for their high aluminate and silicate contents. During prospective campaigns several boreholes have been realized, sampled and analyzed, in order to decipher the clays and sands qualities for their future applications. To complete the data sets, many cross sections have been described and analyzed during and/or after the successive annual exploitation campaigns.

We present here the sedimentological context of those deposits, based on lithological, textural and mineralogical data (Spagna, PhD thesis in progress).

2. Geological setting

The wealden clays of the Mons Basin (MB) are mainly outcropping in several plurikilometric “pockets” dispatched along the northern edge of the basin (see Pirson *et al*., this volume). The Danube-Bouchon quarry is localized in one of those pockets, called the “Hautrage pocket” (Saint-Ghislain entity) at about 20 kilometers north-west of Mons. The wealden clays and sands trapped in this pocket overlie the Namurian weathered basement, and are recovered by Cenomanian-Turonian marine sediments. Due to their palynological contents, the age of the wealden sediments of Hautrage has been included in the middle Barremian to earliest Aptian interval (Yans, 2003; Dejax *et al*., this volume). This age is representative of the Mons basin’s western wealden sediments (St-Barbe Fm, Hautrage Fm and Baudour Fm). On the other hand, the wealden facies of the eastern part of the Mons basin are dated Late Albian (Thieu Fm.), and even Turonian for the Strepy Fm. (Yans, 2003; Pirson *et al*. this volume).
In the Hautrage area, the wealden facies (actually the oldest sediments of the Mons Basin) are deposited in a continental system. It can be linked to a major gully that exists during the middle Barremian-earliest Aptian interval, between the south-east English area and the future Basin of Paris (Ziegler 1990; Thiry *et al*., 2006). The relative low sea-level of this period probably allows this gully to collect the products of the surrounding Armorican Massif in the south west, and London-Brabant Massif in the north east.

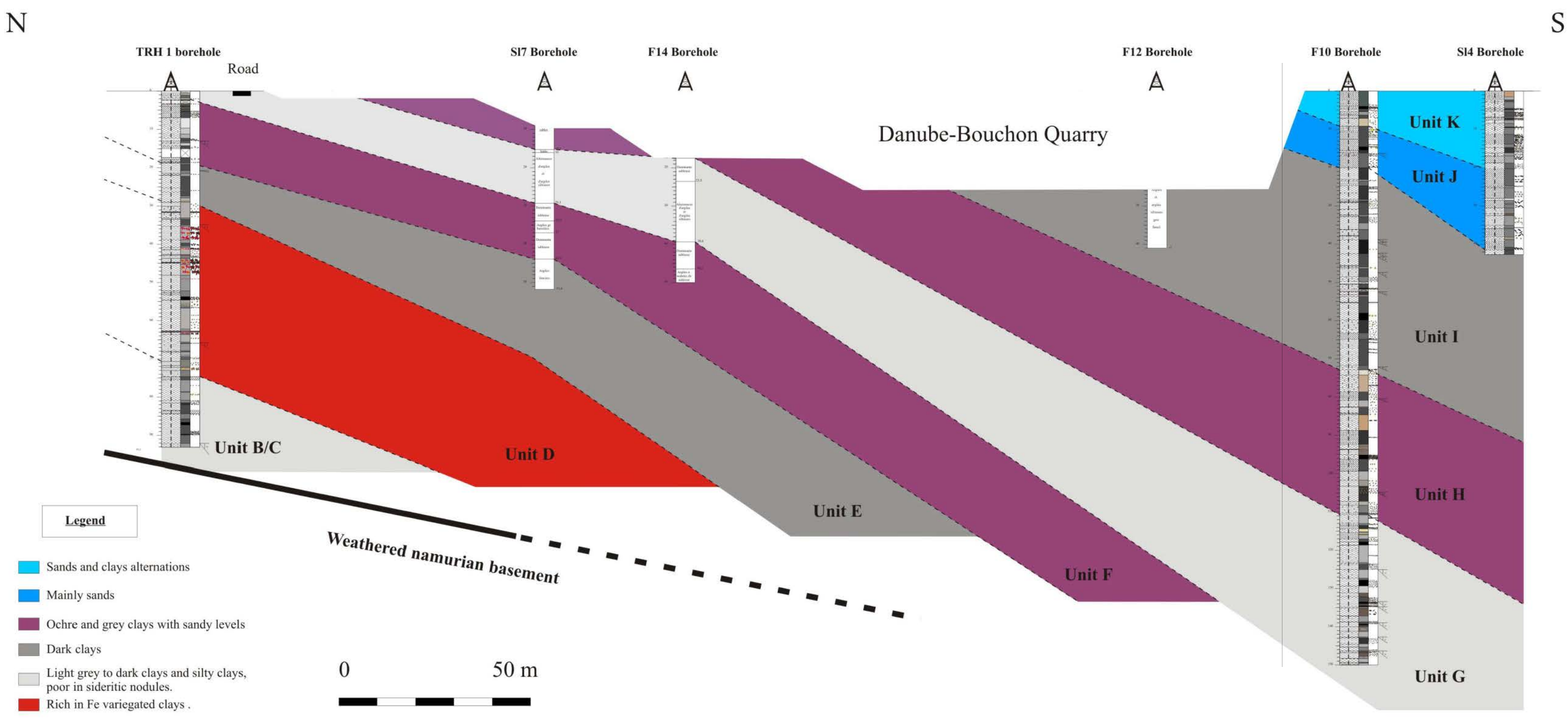

Figure 1. North-South lithological cross-section through the Danube-Bouchon quarry of Hautrage (from Spagna 2005).

3. Lithological, granulometric and mineralogical data

3.1. Lithological data

The Danube-Bouchon quarry cuts clayey and sandy sediments. Those loose deposits frequently contain organic matters (root traces, millimetric to plurimetric lignite and wood fragments, ...), sideritic nodules and pyrites. The sediments are clearly stratified and east-west oriented, dipping south with 15 to 25° dip, as shown by different key beds all along the series (Fig. 1).

As shown in the synthetic log at Fig. 2, the Hautrage succession of 235 meters of wealden sediments can be divided in 3 parts (Yans, 2003; Spagna, 2005):

a) dominance of red ‘clays’ (actually, all the analyzed samples contained around 60-70% of micrometric to millimetric grains of quartz, making them belong to the ‘clayey silt and sands’ or ‘silty and sandy clays’ categories, but we will use the “clays” term for more usability) rich in weathered siderite at the bottom (Units A to D)
b) alternations of black, grey, white and bluish clays containing various quantities of sands, wood fragments, pyritic and sideritic nodules (Units E to I)
c) dominance of sandy (to conglomeratic) sediments rich in pyrite and wood fragments at the top (J and K Units).

3.2. Granulometric data

The granulometric evolution of the series is in relation with the lithologies, and can roughly be defined as “coarsening upwards” (clays → alternations of clays and sands → sands and pebbles). The D95 values (here measured from wet sieving analysis, this parameter calculates the grain size corresponding to the 95th percentile) ranges from smaller than 20 μm for the finest plastic clay beds to a few centimeters for the pebble beds. Most of the clayey sediments turns around 50 to 100 μm (D95) while the same parameter is commonly measured around 250-300 μm in the sandy levels (Spagna, *in progress*).

3.3. Mineralogical data

Quartz-α is the predominant mineralogical phase of the whole series. The clayey fraction (< 2 µm) is divided in three main compounds: kaolinite, smectite (I-S mixed-layers) and illite. The mineralogical log of Fig. 2 shows the ratio of the other mixed-layers minerals, and illustrates a very clear trend of raising contain of the chlorite-smectite mixed-layer phase to the base of the succession. Seven mineralogical units can be defined in the whole series, rather unlinked to the lithological one (Yans, 2003; Spagna, 2005).

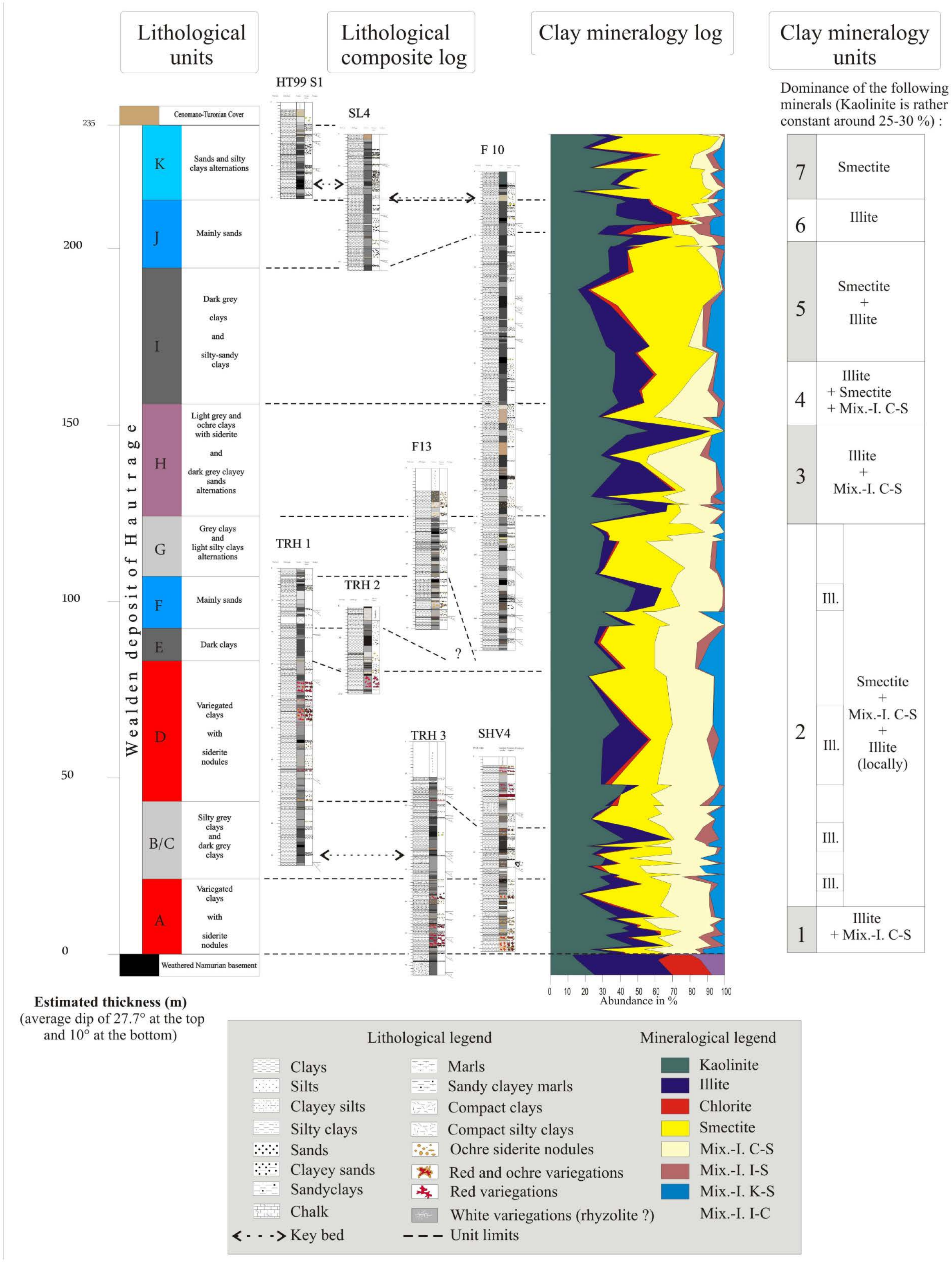

Figure 2. General succession of the Hautrage Clays Formation (from Yans 2003 and Spagna 2005).

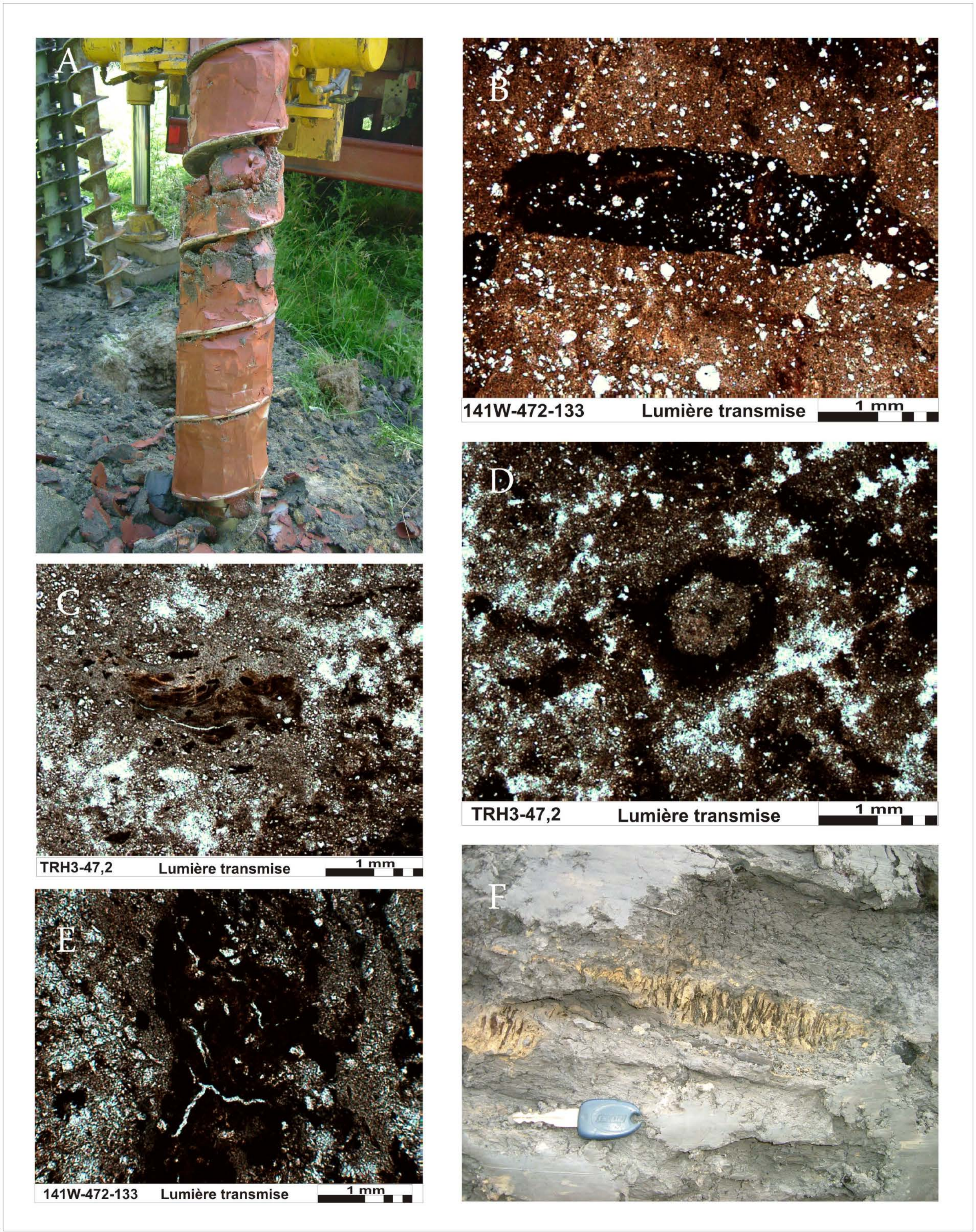

Plate 1. Traces of palaeosoils : A) red color and variegations of clayey bed; B) “Black pebble”; C) Illuviation figure; D) Rhizolite; E) Cracking figures and F) Sideritic nodules trapping parallel traces of roots (?) (from Yans 2003 and Spagna *in progress*).

4. Sedimentological structures and palaeoenvironmental interpretation

4.1. Palaeosoils

Many traces of palaeosoils can be found in the Hautrage wealden facies, especially in the lower part of the deposit:

- The red color (and marmorosis) of the clays found at the bottom of the series is related to a weathering (pedogenic oxidizing) of their primitive sideritic contain (Plate 1, A);
- "Black pebble" have been observed (Plate 1, B) together with illuviation figures (Plate 1, C), rhizolite (Plate 1, D) and crackings (Plate 1, E), all of which indicate a poor maturation of the soil (Machette, 1985);
- Traces of roots are common, sometimes trapped in sideritic nodules (Plate 1, F) what would induced a secondary phase of sideritization (after the development of the soil).

All those elements indicate the exundation and stability of the sediments during relatively long periods. An in situ tree stump has also been found within lightly variegated clays (Fig. 3).

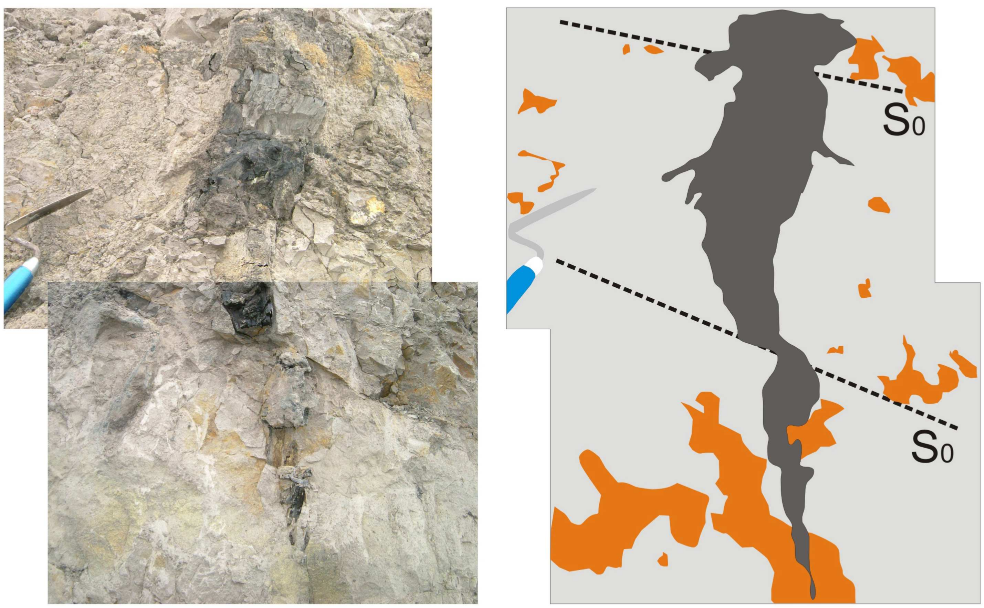

Figure 3. In situ tree stump in a slightly variegated clay bed.

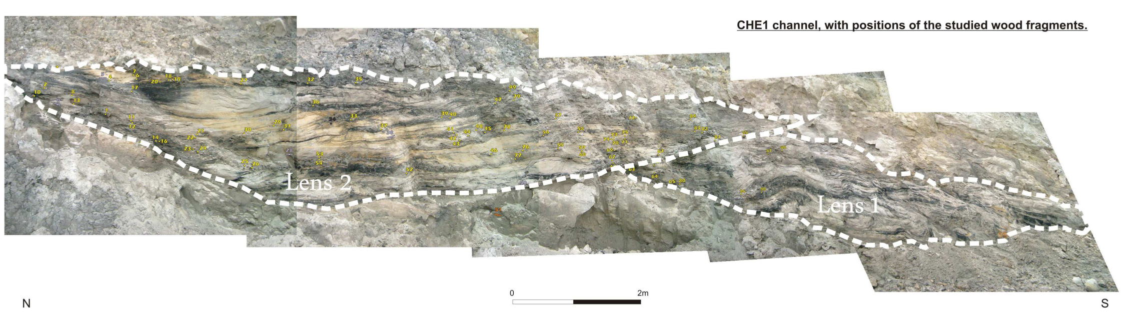

Figure 4. Outcropping CHE1 channel in the northern part of the quarry, with the positions of the measured wood fragments.

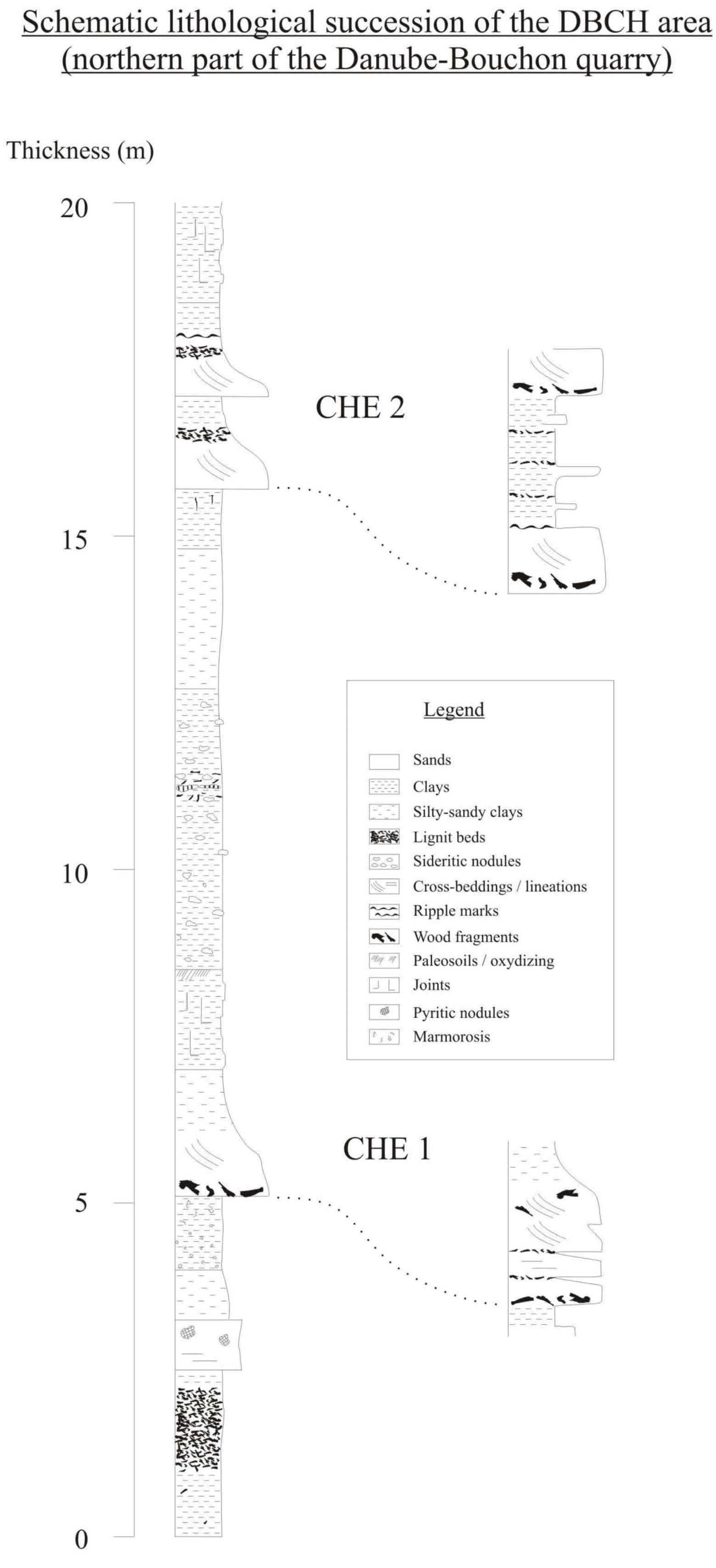

Figure 5. Lithological succession of the DBCH area, northern part of the Danube-Bouchon quarry.

4.2. Channels

Channels are present at different levels in the quarry. The massive sandy outcrop of the southern quarry front (J Unit) is of fluvial origin. Its pebble contain gives an idea of the level of energy that could have been developed at that time. Some other smaller scale channels are found in the northern part of the quarry (called DBCH area), as the "CHE1" (Fig. 4 and replaced in a lithological succession in Fig. 5). Two major plurimetric sandy lenses prograding northward compose this outcrop. Their fillings are quite complex, containing lots of smaller scale fining upwards units. Some coal pieces have also been found herein (Fig. 6), probably eroded from the underlying Namurian basement.

Wood fragment sizes and orientations have been measured inside the "CHE1" channel (around 80 wood samples). The results of this investigation clearly demonstrate an east-west preferential orientation (Spagna, *in progress*) which can be used to extrapolate the direction of the main palaeocurrents (Fig. 7). This result is rather inconsistent with the deltaic environment interpretation that was previously used to explain the position and geometry of the wealden deposits on the northern edge of the MB (Marlière, 1946).

4.3. Flood plain, lignite beds, ...

During intense rising events, channels were overflowed, and clayey sediments, due to the lost of energy, could then settling the plain out. The result of those floods may have been a relatively humid environment adapted for the development of a swampy vegetal cover.

Those deposits represent the major part of the sediments. Depending on their mineralogical content, it will be variably colored: black when rich in organic matter, red when presenting a high Fe content, lighter (grey to white) when richer in silt and sand, and so on.

Some pure lignite beds (and/or charcoal) are also trapped in the wealden series of Hautrage (e.g. at the bottom of the DBCH log of Fig. 6). Together with the carbonized aspect of most of the wood fragment it would indicate some big wood fire events at that period (Gomez *et al.*, this volume).

Figure 6. Piece of coal found in the CHE1 filling.

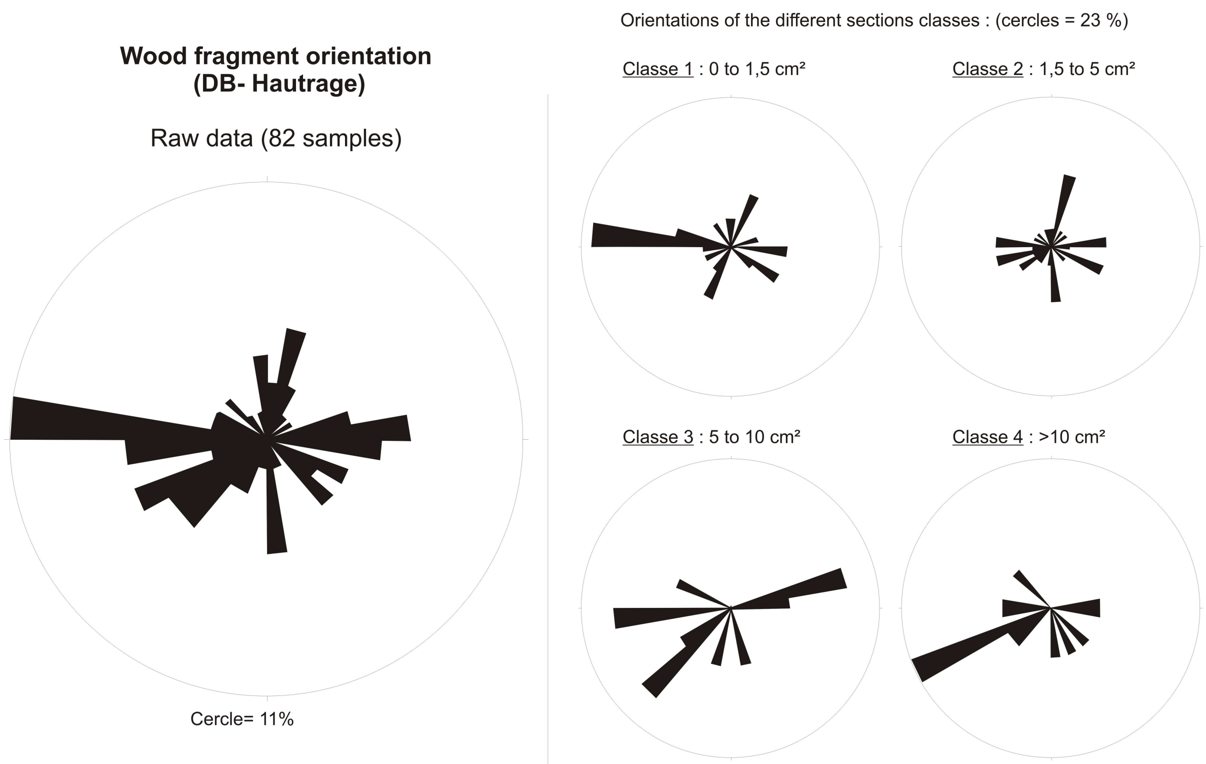

Figure 7. Orientation of the wood fragments found in the CHE1 filling. Based on more than 80 samples it shows a clear preferential east to west trend (Spagna, in progress).

5. Conclusions

The fluvial origin of the deposit is clearly established. The palaeoenvironment of the Hautrage area is defined as a flooding plain crossed by east-west oriented channels (flowing westward) in which clayey sediments had the opportunity to settle out during intense rising events. The conditions of stability and exundation allowed the frequent development of poor maturation soils, especially at the bottom of the series. The pebbles contained in the upper Hautrage wealden sediments and the sizes of the channels reflect an increase of the hydrological energy at the end of the series.

Those results based on sedimentological studies, combined with the ones obtained on other regional wealden deposits (i. e. Thieu, Bernissart and Baudour) contribute to the reconstruction of the regional palaeoenvironment at the period, the one in which lived the famous Iguanodons of Bernissart.

6. Bibliography

DEJAX, J., PONS, D. & YANS, J., 2008. Palynology of the Wealden facies from Hautrage quarry (Mons Basin, Belgium). This volume.

GOMEZ, B., GILLOT, T., DAVIERO-GOMEZ, V., SPAGNA, P. and YANS, J. 2008. Palaeoflora from the wealden facies strata of Belgium -2. Mega- and meso-fossils of Hautrage. This volume.

MACHETTE, M.N., 1985. Calcic soils of the south-western United States. *Geological Society of America, Special Pap*ers, 203: *1-21.*

MARLIERE, R. 1946. Deltas wealdiens du Hainaut ; sables et graviers de Thieu ; argiles réfractaires d'Hautrage. *Bulletin de la Société belge de Géologie*, 55: *69-100.*

PIRSON, S., SPAGNA, P., BAELE, J.-M., VANBRABANT, Y. AND YANS, J. 2008 An overview of the Geology of Belgium. This volume.

SPAGNA, P. 2005. Les argiles wealdiennes d'Hautrage : synthèse du gisement, minéralogie et géochimie. Contribution à l'étude de leur comportement dans le processus de fabrication du ciment blanc chez CBR-

Heidelbergcement Harmignies. TFE de DEA en Sciences Appliquées, Faculté Polytechnique de Mons, 44 p. + annexes.

SPAGNA, P. *in progress*, Les sédiments à faciès wealdien du Bassin de Mons (Belgique) : étude géodynamique, paléoenvironnementale et valorisation industrielle. Thèse de doctorat, Faculté Polytechnique de Mons.

THIRY, M., QUESNEL, F., YANS, J., WYNS, R., VERGARI, A., THEVENAUT, H., SIMON-COINÇON, R., RICORDEL, C., MOREAU, M-G., GIOT, D., DUPUIS, C., BRUXELLES, L., BARBARAND, J. & BAELE, J-M., 2006. Continental France and Belgium during the Early Cretaceous: paleoweatherings and paleolandforms. *Bulletin de la Société Géologique de France* 177: 155-175.

YANS, J., 2003. Chronologie des sédiments kaoliniques à faciès wealdiens (Barrémien moyen à Albien supérieur ; Bassin de Mons) et de la saprolite polyphasée (Crétacé inférieur et Miocène inférieur) de la Haute-Lesse (Belgique). Implications géodynamiques et paléoclimatiques. Thèse de doctorat, Faculté Polytechnique de Mons et Université de Paris-Sud Orsay, 316 p.

ZIEGLER, P.A., 1990. Geological Atlas of Western and Central Europe, 2nd and completely revised edition, Shell Internationale Petroleum Maatschappi B.V., Geological Society Publishing House, Bath.

PALYNOLOGY OF THE WEALDEN FACIES FROM HAUTRAGE QUARRY (MONS BASIN, BELGIUM)

J. DEJAX[1], D. PONS[2] & J. YANS[3]

1. Muséum national d'Histoire naturelle, USM 0203, CNRS UMR 5143 (Paléobiodiversité et paléoenvironnements), Département "Histoire de la Terre", Case postale 38, 57 rue Cuvier, 75231 Paris Cedex 05, France. dejax@mnhn.fr.
2. Université Paris VI, CNRS UMR 5143 (Paléobiodiversité et paléoenvironnements), Muséum national d'Histoire naturelle, Case postale 48, 57 rue Cuvier, 75231 Paris Cedex 05, France. denise.pons@snv.jussieu.fr.
3. Facultés Universitaires Notre Dame de la Paix (FUNDP), rue de Bruxelles 61, 5000 Namur, Belgium. johan.yans@fundp.ac.be.

(3 plates)

ABSTRACT. This article focuses on a palynological study of samples from the Wealden facies sediments filling the Hautrage "pocket" (Mons Basin, Belgium). The microflora is compared to that found at Bernissart and Baudour (Mons Basin). The palynomorphs are of continental origin only. The botanical affinities of the palynological taxa are mainly ferns, gymnosperms and freshwater "algae". Also encountered are stratigraphically important angiospermous pollen grains, allowing us to date the Hautrage Clays Formation as middle Barremian to earliest Aptian.

RÉSUMÉ. Cet article traite de la palynologie des sédiments à faciès wealdien constituant la "poche" de Hautrage (Belgique). La microflore est comparée à celle de Bernissart et de Baudour. Les palynomorphes sont d'origine continentale. L'affinité botanique des principaux taxons se situe chez les fougères, les gymnospermes et les "algues" d'eau douce. La présence de grains de pollen d'affinité angiospermienne s'avère importante sur le plan stratigraphique, permettant une datation du Barrémien moyen à l'Aptien le plus inférieur.

KEYWORDS: Biostratigraphy, Lower Cretaceous.

1. Introduction

Recently, Yans et al. (2005, 2006) and Dejax et al. (2007b) analyzed the palynological assemblage of the 322 meter level at Bernissart (Sainte-Barbe Clays Formation) and focused their study on angiospermous pollen, found for the first time in the Belgian Wealden facies. Dejax et al. (2007a) emphasized this focus, highlighting angiospermous pollen and describing "variant forms" from Baudour quarry clay samples (Baudour Clays Formation). We offer here the first palynological study of the Wealden facies of the Hautrage site (Hautrage Clays Formation), and we compare its palynological assemblage with those already mentioned in the Mons Basin.

2. Geological setting

The Danube-Bouchon quarry of the Hautrage "pocket" is situated in the Mons Basin (Belgium), which can be regarded as a part of the Paris Basin (Marlière, 1970). The sedimentary succession of the Mons Basin begins with the Wealden facies (Hautrage Clays Formation) and continues with Middle-Upper Albian, Upper Cretaceous and Cenozoic deposits (Marlière, 1970; Pirson et al., 2008). Several boreholes have been recently drilled in the quarry and adjacent areas, allowing us to have a complete succession of the Wealden facies (Spagna *et al*., 2008). We here especially studied the TRH 3 borehole, at a depth of 23,90 metres which corresponds to the B/C unit (Spagna *et al*., 2008).

3. Methods

For the purpose of palynological analysis, we processed several samples of black clay and silt from the TRH3 borehole. The treatment involves mainly the destruction of minerals with hydrofluoric acid (70%), followed by a filtration using a 9 µm-mesh sieve. The slides will be housed in the Royal Belgian Institute of Natural Sciences (Brussels).

The morphological classification and nomenclature of Potonié & Kremp (1954 and subsequent papers), as improved by Dettmann (1963), are followed herein; for the purpose in hand, another nomenclature *sensu* Hughes and collaborators (see complete reference list in Hughes, 1994) was also used for three peculiar taxa, which were defined as "biorecords" in the English Wealden. It must be reminded that morphological taxa and biorecords are not true Linnean taxa, but para-taxa or morphotypes which are *sporae dispersae* with no specific relationship to a mother-plant. A biorecord is considered here as a fundamental reference taxon, equivalent to the taxa defined through the use of the conventional morphological scheme (Hughes, 1976, p. 26; Hughes et al., 1979, p. 515); see a commentary about "palynological languages" in Dejax et al. (2007a).

4. Palynological content

The palynological assemblage of Hautrage quarry is very well preserved, suggesting that most of the mother-plants grew close to the place where the palynomorphs were buried and that diagenesis was minor, as the palynological analysis of Bernissart and Baudour clay samples already pointed out. This assemblage is entirely continental in origin, quite similar to those of these neighbouring localities but somewhat less diversified (work in progress). Fern spores (e.g. *Concavissimisporites verrucosus*, *Deltoidospora minor*, *Dictyophyllidites harrisii*) and bisaccate pollen grains (*Parvisaccites radiatus*) are a main feature of these three assemblages, including macrospores (*Dijkstraisporites helios*). Ephedroid pollen grains (*Ephedripites montanaensis*) are abundant, Sciadopityaceae (biorecord Hauterivian-*cactisulc*, alias *Cerebropollenites* sp.) pollen grains are less numerous and Araucariaceae pollen grains are quite scarce. The angiospermous biorecord Superret-*croton* is noticeable as among Bernissart and Baudour assemblages, somewhat less abundant than among the latter one; another angiospermous biorecord, the probable Retisulc-*dentat*, is extremely rare as among Baudour assemblage [these biorecords *sensu* Hughes et al. (1979) and Hughes (1994)]. Freshwater "algae" as zygospores (*Ovoidites parvus* and *Schizosporis reticulatus*) and *Botryococcus* are present.

5. Discussion

The palynological assemblage of the Hautrage quarry is typically "Wealden" in aspect: many of the palynomorphs identified have been reported elsewhere since the pioneering work of Delcourt & Sprumont (1955) dealing with the Wealden facies sediments of the same province of Hainaut; for an exhaustive list of the studies related to the palynology of the Wealden facies of northern Europe, see Dejax et al. (2007a). Worthy of interest is the occurrence of continental guide-forms already defined in the Wealden facies sediments from southern and eastern England.

6. Stratigraphic implications

Biorecord Superret-*croton* was defined by Hughes et al. (1979); in the description of the species *Stellatopollis hughesii*, from the Upper Barremian (?) of Egypt, Penny (1986) regarded it equivalent to this biorecord. In the "stratotypic" Wealden facies of the Weald and Wessex sub-basins, which is dated by marine interbeds with ammonites and dinoflagellate cysts (Harding, 1986, 1990), the stratigraphic distribution of biorecord Superret-*croton* is attributed to MCT (Monosulcate Columellate Tectate) phases 3 to 5, ranging from the middle Barremian to the earliest Aptian (Hughes, 1994). Yans et al. (2004, 2005) and Dejax et al. (2007a, 2007b) therefore suggested a middle Barremian to earliest Aptian age for the sediments of Bernissart (at a depth of 322 m) and for the Baudour Clays Formation, and the same dating is proposed here for the Hautrage clay (at least for the B/C unit).

7. Conclusions

The Hautrage Clays Formation contains many continental palynomorphs including fern spores, gymnospermous bisaccate pollen grains and angiospermous pollen grains. The occurrence of pollen grains of the angiospermous biorecord Superret-*croton* and probable biorecord Retisulc-*dentat* [*sensu* Hughes et al. (1979) and Hughes (1994)] denotes a middle Barremian to earliest Aptian age for these sediments, and so they are confirmed to be of the same age as the Wealden facies sediments in the natural pit of Bernissart and the "pocket" of Baudour. This identity in age suggests that the natural pit of Bernissart and the "pockets" of Baudour and Hautrage may be the result of the same mechanisms of subsidence, probably demonstrating a genetic relationship between natural pits and relatively large "pockets" in the Mons Basin. So natural pits (as the famous "cran de Bernissart") and "pockets" may be the surface expression of the dissolution of deeply buried anhydrites (Delmer et al., 1982) and/or regional crustal activity (Vandycke et al., 1991; Spagna et al., 2007).

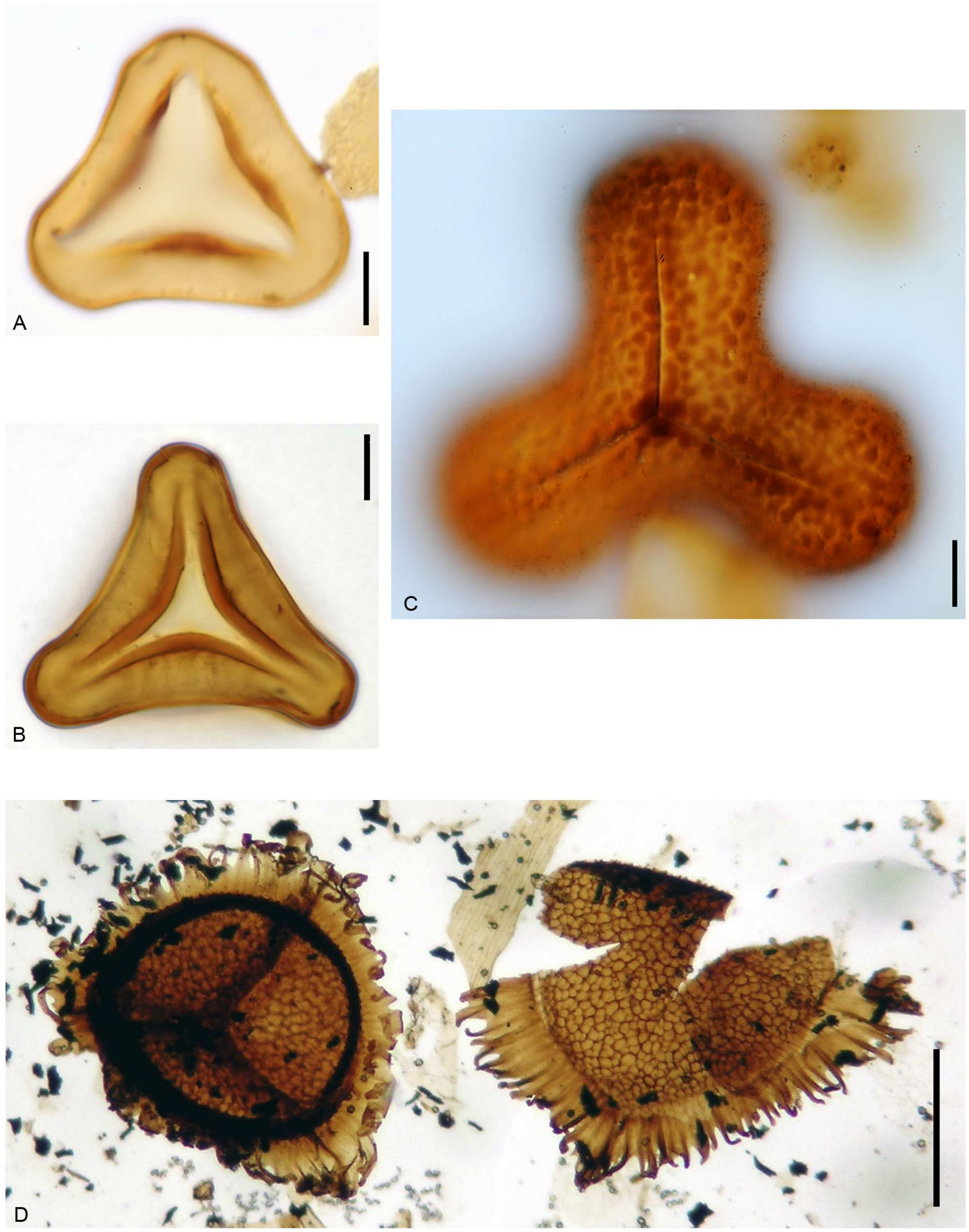

Plate 1

Mentions between brackets mean: slide number / coordinates after the "England Finder"; scale bar is 10 µm, except (D) which is 50 µm.

(A) *Deltoidospora minor* (TRH3-23,90-1 / R42-4)
(B) *Dictyophyllidites harrisii* (TRH3-23,90-2 / U33-1)
(C) *Concavissimisporites verrucosus* (TRH3-23,90-1 / T33-2)
(D) *Dijkstraisporites helios* (TRH3-23,90-4 / Q62-1)

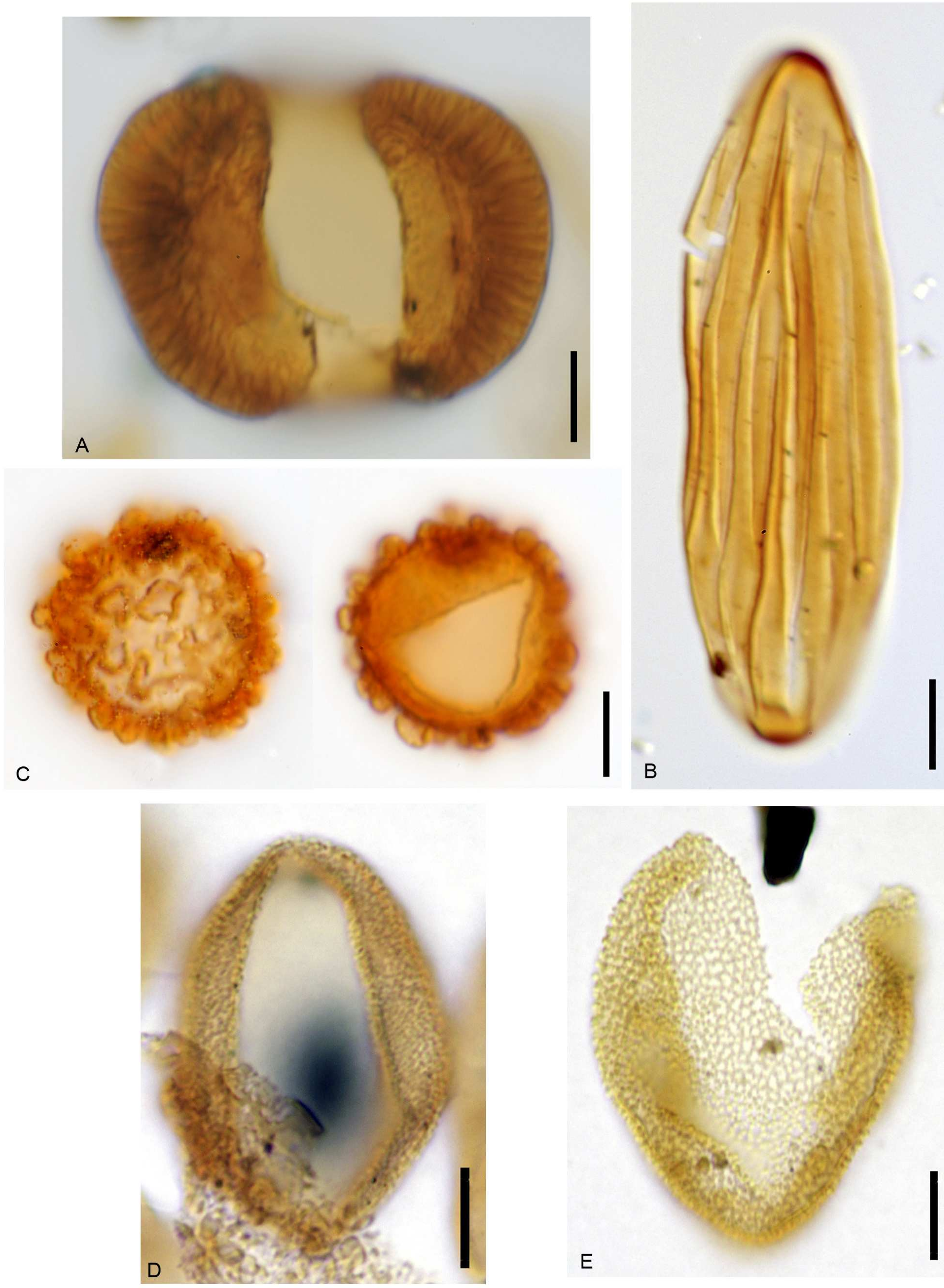

Plate 2
Mentions between brackets mean: slide number / coordinates after the "England Finder"; scale bar is 10 µm.

(A) *Parvisaccites radiatus* (TRH3-23,90-1 / Q58-4)
(B) *Ephedripites montanaensis* (TRH3-23,90-1 / Q62-4)
(C) Biorecord Hauterivian-*cactisulc* (TRH3-23,90-1 / K33-3/L33-1) [left and right : focus on presumed proximal and distal faces]
(D) Biorecord Superret-*croton* (TRH3-23,90-2 / P46) [focus on presumed distal face]
(E) Biorecord Superret-*croton* (TRH3-23,90-2 / R47-3) [torn specimen showing the reticulate pattern of the tectum]

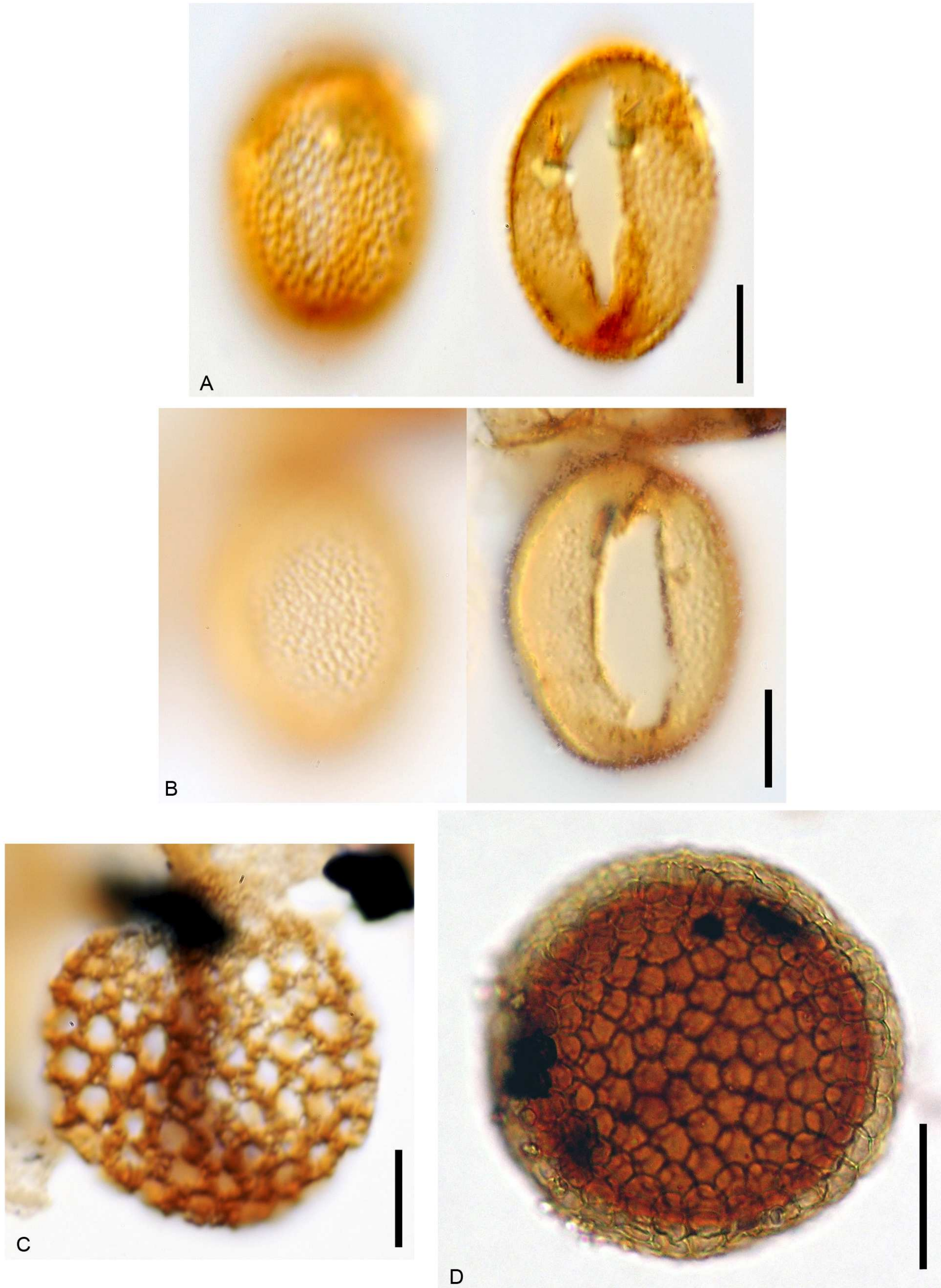

Plate 3

Mentions between brackets mean: slide number / coordinates after the "England Finder"; scale bar is 10 µm, except (D) which is 50 µm.

(A) Biorecord Superret-*croton* (TRH3-23,90-3 / J55-K55) [left and right : focus on presumed proximal and distal faces]

(B) Biorecord Superret-*croton* (TRH3-23,90-1 / X33) [left and right : focus on presumed proximal and distal faces]

(C) Probable biorecord Retisulc-*dentat* (TRH3-23,90-3 / H52-3)

(D) *Schizosporis reticulatus* (TRH3-23,90-4 / K57-L58)

8. References

DEJAX, J., DUMAX, E., DAMBLON, F. & YANS, J., 2007a. Palynology of Baudour Clays Formation (Mons Basin, Belgium): correlation within the "stratotypic" Wealden. *In*: Steemans P. & Javaux E. (eds.), Recent Advances in Palynology. *Carnets de Géologie / Notebooks on Geology*, Memoir 2007/01: 16-28. http://paleopolis.rediris.es/cg/CG2007_M01/CG2007_M01_Abstract03.html

DEJAX, J., PONS, D. & YANS, J., 2007b. Palynology of the dinosaur-bearing Wealden facies in the natural pit of Bernissart (Belgium). *Review of Palaeobotany and Palynology*, 144: 25-38.

DELCOURT, A. & SPRUMONT, G., 1955. Les spores et grains de pollen du Wealdien du Hainaut. *Mémoires de la Société belge de Géologie, de Paléontologie et d'Hydrologie*, 5: 1-73.

DELMER, A., LECLERCQ, V., MARLIÈRE, R. & ROBASZYNSKI, F., 1982. La géothermie en Hainaut et le sondage de Ghlin (Mons, Belgique). *Annales de la Société géologique du Nord*, 101: 189-206.

DETTMANN, M.E., 1963. Upper Mesozoic microfloras from south-eastern Australia. *Proceedings of the Royal Society of Victoria*, 77: 1-148.

HARDING, I.C., 1986. An Early Cretaceous dinocyst assemblage from the Wealden of Southern England. *Special Papers in Palaeontology*, 35: 95-109.

HARDING, I.C., 1990. A dinocyst calibration of the European Boreal Barremian. *Palaeontographica B*, 218: 1-76.

HUGHES, N.F., 1976. Palaeobiology of angiosperm origins. Cambridge University Press, Cambridge.

HUGHES, N.F., 1994. The enigma of angiosperm origins. Cambridge University Press, Cambridge.

HUGHES, N.F., DREWRY, G.E., & LAING, J.F., 1979. Barremian earliest angiosperm pollen. *Palaeontology*, 22: 513-535.

MARLIÈRE, R., 1970. Géologie du Bassin de Mons. *Annales de la Société géologique du Nord*, 40: 171-189.

PENNY, J.H.J., 1986. An Early Cretaceous angiosperm pollen assemblage from Egypt. *Special Papers in Palaeontology*, 35: 121-134.

PIRSON, S., SPAGNA, P., BAELE, J.-M., VANBRABANT, Y. & YANS, J. 2008. An overview of the Geology of Belgium. This volume.

POTONIÉ, R. & KREMP, G., 1954. Die Gattungen der paläozoischen Sporae dispersae und ihre Stratigraphie. *Geologisches Jahrbuch*, 69; 111-194.

SPAGNA, P., DUPUIS, C. & YANS, J., 2008. Sedimentology of the Hautrage wealden clays quarry. This volume.

SPAGNA, P., VANDYCKE, S., YANS, J. & DUPUIS, C., 2007. Hydraulic and brittle extensional faulting in the Wealden facies of Hautrage (Mons Basin, Belgium). *Geologica Belgica*, 10: 158-161.

VANDYCKE, S., BERGERAT, F. & DUPUIS, C. 1991. Meso-Cenozoic faulting and inferred palaeostress in the Mons Basin, Belgium. *Tectonophysics*, 192: 261-271.

YANS, J., DEJAX, J., PONS, D., DUPUIS, C. & TAQUET, P., 2005. Implications paléontologiques et géodynamiques de la datation palynologique des sédiments à faciès wealdien de Bernissart (bassin de Mons, Belgique). *Comptes Rendus Palevol*, 4: 135-150.

YANS, J., DEJAX, J., PONS, D., TAVERNE, L. & BULTYNCK, P., 2006. The iguanodons of Bernissart (Belgium) are middle Barremian to earliest Aptian in age. *Bulletin de l'Institut des Sciences Naturelles de Belgique*, 76: 91-95.

YANS, J., PONS, D. & DEJAX, J., 2004. Palynological study of the dinosaurs-bearing Wealden facies sediments of Bernissart (Belgium). XI Palynological International Congress, Granada. *Pollen*, 14: 177-178.

PALAEOFLORA FROM THE WEALDEN FACIES STRATA OF BELGIUM - MEGA- AND MESO-FOSSILS OF HAUTRAGE

Bernard GOMEZ[1], Thomas GILLOT[1], Véronique DAVIERO-GOMEZ[1], Paul SPAGNA[2] & Johan YANS[3]

[1] *Université Lyon 1 (Claude Bernard), CNRS-UMR 5125 Paléoenvironnements et Paléobiosphère (PEPS), 43 Boulevard du 11 Novembre 1918, 69622 Villeurbanne cedex, France; e-mails:* bernard.gomez@univ-lyon1.fr; tom6446@hotmail.fr; daviero@univ-lyon1.fr.
[2] *Faculté Polytechnique de Mons, Service de Géologie Fondamentale et appliqué, 9 rue de Houdain, 7000 Mons, Belgium;* Paul.Spagna@fpms.ac.be.
[3] *Facultés Universitaires Notre-Dame de la Paix, Département de Géologie, 61 rue de Bruxelles, 5000 Namur, Belgium; e-mail:* johan.yans@fundp.ac.be.

(2 figures and 3 plates)

ABSTRACT. Seven beds were collected from the Barremian-Aptian clay pit of Danube-Bouchon's Hautrage quarry (Mons Basin, Belgium) for bearing abundant fossil plant mesoremains. Two of those beds were bulk macerated in hydrogen peroxide and sorted with the naked eye. The clay bed studied contains wood preserved as fusains (charcoals), conifer leafy axes (Cheirolepidiaceae *Frenelopsis* and Taxodiaceae cf. *Sphenolepis*) bearing cuticles as well as inner anatomy, female cone scales (Cheirolepidiaceae *Alvinia*) and cones. The lignite bed includes a much dissimilar assemblage consisting of amber, more abundant fusain fragments, sterile and fertile fern pinnules and pinnae (Osmundaceae *Cladophlebis*, Weichseliaceae *Weichselia*, Matoniaceae *Phlebopteris*), conifer leaves and twigs (Miroviaceae *Mirovia* and Taxodiaceae cf. *Sphenolepis*), reproductive organs and seeds. They are preliminary inventoried, but identifications and descriptions at the species level require further microscopic studies. The plant associations and their states of preservation (especially the exquisite anatomical preservations of ferns and conifers) clearly suggest that wild fires not only occurred frequently at that time but also that these plants were adapted to grow in such strongly constrained environments.

KEYWORDS: Amber, fusain (charcoal), cuticles, ferns, conifers, Lower Cretaceous, Hautrage, Belgium.

1. Introduction

Fossil plant megaremains, and especially impressively fresh-looking *Pinus*-like conifer cones, were first reported from the clays of La Louvière in the hamlet of Baume (Coemans, 1867). Nevertheless, the Wealden flora of Belgium was most famously known by the detailed descriptions of fern and conifer assemblage associated with the discovery of 28 complete Iguanodon skeletons from the coal mine Sainte-Barbe of Bernissart (Dupont 1878; Seward, 1900; Bommer, 1911). Somewhat similar fern and conifer assemblage was also mentioned in the literature from the Wealden clay of Bracquegnies at Houdeng (Bommer, 1892). In fact, materials from more localities (Puits Négresse at Bernissart, at Hautrage, Aimeries at Houdeng, Culot at Villerot, and Perlonjour quarry at Soignies) were collected during decades and stored in the collections of the Royal Belgian Institute of Natural Sciences, but they remained unstudied for a long while. By the fifties, many conifer cones and foliages (*Pinus belgica* Alvin, *Pityostrobus andraei* (Coemans) Alvin, *Pi. bernissartensis* Alvin, *Pi. corneti* (Coemans) Alvin, *Pi. hautrageanus* Alvin, *Pi. soigniesiensis* Alvin, *Pi. villerotensis* Alvin, *Pseudoaraucaria gibbosa* (Coemans) Alvin, *Ps. heeri* (Coemans) Alvin, *Prepinus sclerophylla* Alvin, *Abiocaulis verticillatus* Alvin, *Elatocladus bommeri* Harris, *Sphenolepis kurriana* (Dunker) Schenk) and the fertile and sterile fern parts of *Weichselia reticulata* (Stokes et Webb) Fontaine were revised in much details (Alvin, 1953, 1957, 1960, 1968, 1971; Harris, 1953; Hill, 1990). However, as far as ferns are concerned, one may be surprised that most taxa listed by Bommer (1892) and Seward (1900) are still misidentified, invalid or poorly studied genera or species ('morphotaxa'). Similarly, but in contrast with the conclusion by Alvin (1960), one may questioned whether the conifers are actually exhaustively listed, and especially whether it is the case for each bed in each locality, which is of tremendous consequence for taphonomic and palaeoecological interpretations. As a matter of fact, only three species corresponding to three conifer cones were described from the clay of Hautrage: *Pityostrobus corneti* (Coemans) Alvin (Alvin, 1953), *Pi*. *villerotensis* Alvin (Alvin, 1957) and *Pi*. *hautrageanus* Alvin (Alvin, 1960). Our preliminary taxonomical study below of fossil plant mega- and meso-remains is pointing out whether much diversified plants assemblages existed and whether difference in composition occurred between beds.

2. Material and Methods

Seven beds were sampled in the Danube-Bouchon's Hautrage clay pit quarry (Mons Basin, Belgium) by three of us (BG, PS, JY) on August 2007 (Fig. 1; Pl. 1, Figs A-H). The sediments studied belong to the Hautrage Clay Formation consisting of continental clays, silts and sands, containing lignite remains, pyrite and siderite nodules in variable proportions (Spagna et al., 2007). The Hautrage Clay Fm is middle Barremian to earliest Aptian in age (Yans, 2003). The depositional environment of Hautrage is currently interpreted as a floodplain traversed by numerous channels (Yans et al., 2002; Yans, 2003).

The fossil plant assemblages from two of them were extracted after bulk maceration in hydrogen peroxide (H_2O_2), followed by sieving with tap water with 1-mm-, 500-µm-, and 100-µm-fine mesh sieves. The organic matter has been subsequently left to dry on air. Sorting, still in progress, has been done with the naked eye; it has concern the fraction over 1 mm.

Figure 1. Topographic map of the Danube-Bouchon's Hautrage clay pit quarry (Mons Basin, Belgium) showing sampling locations and numbered from no 1 to no 7.

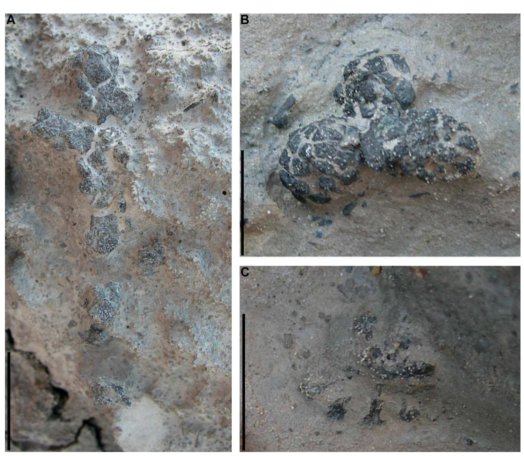

Figure 2. Conifers photographed *in situ* in the sampling level no 3. A, branched leafy axes (cf. *Sphenolepis*); B, three entire, taxodiaceous female cones (*Sphenolepis*) in connection; C, longitudinal section of one taxodiaceous female cones (*Sphenolepis*).

3. Systematic Palaeontology

The sampling level no 1 contains millimetric to centimetric wood debris preserved as fusains (charcoals) (Pl. 2, Fig. A). Apart from those, the most abundant plant mega- and meso-fossils are constituted by sterile conifer leafy axes of two kinds (Pl. 2, Figs B & J): (1) The genus *Frenelopsis* of the fossil family Cheirolepidiaceae shows typical cylindrical axes, whorls of three tiny leaf tips arranged at about 120° one to each other, and alternating at about 60° one node to the next (Pl. 2, Figs. C-F); (2) The axes bearing more or less adpressed, helically arranged leaves (Pl. 2, Figs K-O) are temporarily ascribed to the genus *Sphenolepis* (cf. *Sphenolepis*) because of the difficulties in identifying conifer foliages based on the morphology only and the resemblances with the specimens of *Sphenolepis kurriana* published by Harris (1953). It is noteworthy that both conifer leafy axes exhibit apparently preserved anatomy and especially a central solid vascular bundle (Pl. 2, Figs G-I & M-O). In addition the cone scale as illustrated in Plate 2 Figs S-T showing several layers of very fine cuticles correspond to the genus *Alvinia* associated with *Frenelopsis*. The two types of cones (Pl. 2, Figs P-R) and the second type of cone scales (Pl. 2, Figs U-V) are of uncertain affinities.

The sampling level no 2 differs by many components. Although the wood fragments are also preserved as fusains, they consist of a larger proportion of the specimens (Pl. 3, Fig. A). Similar helically arranged leafy axes of cf. *Sphenolepis* occur, but there are fewer in number (Pl. 3, Figs N & O-S). No *Frenelopsis* leafy axes and no *Alvinia* cone scales have been sorted out. Quite frequent, yellow to orange pieces of amber exist (Pl. 3, Fig. B). Different sterile and fertile fern parts are anatomically preserved as charcoals: sterile pinnules of the Osmundaceae *Cladophlebis* sp. (Pl. 3, Figs E-I) and the Weichseliaceae *Weichselia reticulata* (Pl. 3, Figs C-D), tiny circinate fronds of uncertain affinities (Pl. 3, Figs J-K), fertile pinnules of the Matoniaceae *Phlebopteris dunkeri* showing rounded sori (Pl. 3, Figs L-L'), rachis fragment of secondary fertile pinna of *W. reticulata* showing the scars where the sori are attached (Pl. 3, Figs. M-M'). The genus *Mirovia* of the family Miroviaceae is mostly represented by fragments of the mid laminas (Pl. 3, Fig. V) and a very few apices (Pl. 3, Fig. T) and bases (Pl. 3, Fig. U). The leaves when entire are needle-like, and are well characterized by the stomatal groove running through the leaf on a single surface (considered as the lower surface). Reproductive organs include a strobilus or cone (Pl. 3, Figs W-W') and related isolated scales (Pl. 3, Figs X-Y'), and seeds (Pl. 3, Fig. Z), all being of uncertain affinities.

At that stage of the study the sampling level no 3 is only know by taxodiaceous leafy axes and cones of *Sphenolepis* observed *in situ* during field collections (Fig. 2, A-C).

4. Discussion

Although our study is still at a preliminary stage, several results can be pointed out. Most beds, if not all, from the middle Barremian – lowermost Aptian of the Danube-Bouchon's Hautrage clay pit quarry contain fossil plant mega- and meso-remains. The diversity at Hautrage is much higher than only the three female cones described by Alvin (1953, 1957, 1960) under the species names *Pityostrobus corneti* (Coemans) Alvin, *Pi. hautrageanus* Alvin and *Pi. villerotensis* Alvin. Some taxa, especially the ferns *Cladophlebis* sp., *Phlebopteris dunkeri* and *Weichselia reticulata* were already known from coeval clay sediments of Bernissart, but others such as *Frenelopsis* and *Mirovia* are reported for the first time (note that small cuticles fragments of *Mirovia* have been recently identified from Bernissart sediments stored in the RBINS collections, BG unpublished data). Similarly amber was reported in the literature and occurs in the RBINS collections, but it is for the first related to a stratum and a fossil plant assemblage. Notable differences in abundance and composition do exist between sampling beds no 1 and no 2. They probably represented ecological changes through time and space. Wild fires definitively played a major role in the ecosystem dynamic. However further taxonomic, systematic, taphonomic and sedimentological investigations are needed to clarify whether wild fires resulted in ecological changes from one to another plant association or they favoured the transport over long distance of extra-local vegetation.

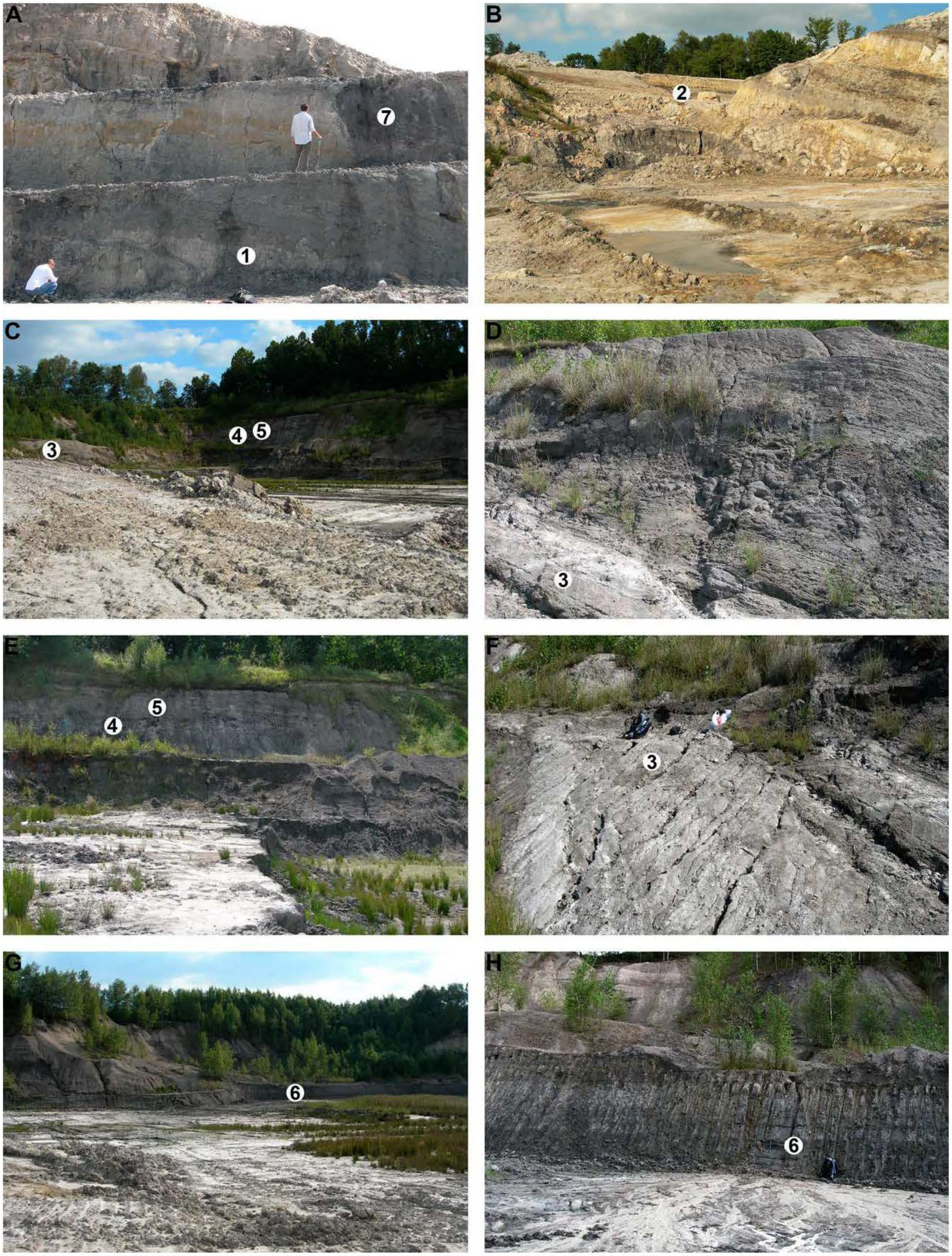

Plate 1. A-H, Photographs of the sampling levels in the Danube-Bouchon's Hautrage clay pit quarry (Mons Basin, Belgium) and numbered from no 1 to no 7. 1, blue clays with siderite nodules; 2, lignite; 3, white sands; 4-5, dark clays with fine sandy beds; 6, sandy clays; 7, dark sandy clays.

Plate 2. Plant mega- and meso-fossils from the sampling level no 1 in the Danube-Bouchon's Hautrage clay pit quarry (Mons Basin, Belgium). A, wood preserved as fusains (charcoals); B-I, conifer leafy axes showing whorls of three leaves and a central solid vascular tissue (*Frenelopsis*); J-O, conifer leafy twigs showing more or less adpressed, tiny leaves (cf. *Sphenolepis*); P-R, cone-like structure of uncertain affinities; S-T, conifer cheirolepidiaceous female cone scale (*Alvinia*); U-V, conifer female cone scale of uncertain affinity. Scale bars: 10 mm (A, B and J) and 1 mm (other pictures)

Plate 3. Plant mega- and meso-fossils from the sampling level no 2 in the Danube-Bouchon's Hautrage clay pit quarry (Mons Basin, Belgium). A, wood preserved as fusains (charcoals); B, yellow to orange pieces of amber; C-I, sterile fern pinnules (*Cladophlebis* and *Weichselia*); J-K, circinate fern fronds; L-L', fertile fern pinnule (*Phlebopteris*) showing rounded sori; M-M', pinna fragment showing insertion scars of sori (*Weichselia reticulata*); N-S, conifer leafy twigs showing more or less adpressed, tiny leaves (cf. *Sphenolepis*); T-V, leaf fragments of *Mirovia* (T, apex; U, base; V several middle laminas); W-Y, cone and scales of uncertain affinities; Z, seeds of uncertain affinities. Scale bars: 10 mm (A, B, N) and 1 mm (other pictures).

5. References

ALVIN, K.L., 1953. Three Abietaceous cones from the Wealden of Belgium. *Mémoires de l'Institut royal des Sciences naturelles de Belgique,* 125: 3-42.
ALVIN, K.L., 1957. On the two cones *Pseudoaraucaria heeri* (Coemans) n. comb. and *Pityostrobus villerotensis* n.sp. from the Wealden of Belgium. *Mémoires de l'Institut royal des Sciences naturelles de Belgique,* 135: 3-27.
ALVIN, K.L., 1960. Further conifers of the Pinaceae from the Wealden Formation of Belgium. *Mémoires de l'Institut royal des Sciences naturelles de Belgique,* 146: 3-39.
ALVIN, K.L., 1968. The spore-bearing organs of the Cretaceous fern *Weichselia* Stiehler. *Journal of the Linnean Society (Botany),* 61: 87-92.
ALVIN, K.L., 1971. *Weichselia reticulata* (Stokes et Webb) Fontaine from the Wealden of Belgium. *Mémoires de l'Institut royal des Sciences naturelles de Belgique* 166: 1-33.
BOMMER, C., 1892. Nouveau gite de végétaux découvert dans l'argile wealdienne de Bracquegnies (Hainaut). *Bulletin de la Société belge de Géologie,* 6: 160-161.
BOMMER, C. 1911. Contribution à l'étude du genre *Weichselia* (note préliminaire). *Bulletin de la Société royale de Botanique de Belgique,* 47: 296-304.
COEMANS, E., 1867. Description de la flore fossile du premier étage du terrain crétacé du Hainaut. *Mémoires de l'Académie Royale de Belgique,* 36: 1-21.
DUPONT, E., 1878. Sur la découverte d'ossements d'Iguanodons, de poissons et de végétaux dans la fosse Sainte-Barbe du charbonnage de Bernissart. *Bulletin de l'Académie Royale de Belgique,* 46: 387-408.
HARRIS, T.M., 1953. Conifers of the Taxodiaceae from the Wealden Formation of Belgium. *Mémoires de l'Institut royal des Sciences naturelles de Belgique,* 126: 3-43.
HILL, C.R., 1990. Scanning electron microscopy in palaeobotany. *In:* Claugher, D. (ed.) *Scanning Electron Microscopy in Taxonomy and Functional Morphology,* Clarendon Press, Oxford, *Systematics Association Special Volume,* 41: 193-234,
SEWARD, A.C., 1900. La flore wealdienne de Bernissart. *Mémoires du Musée royal d'Histoire naturelle de Belgique,* 1: 1-39.
SPAGNA, P., VANDYCKE, S., YANS, Y. & DUPUIS, C., 2007. Hydraulic and brittle extensional faulting in the Wealden facies of Hautrage (Mons Basin, Belgium). *Geologica Belgica,* 10: 158-161.
YANS, J. 2003. Chronologie des sediments kaoliniques à faciès wealdiens (Barrémien moyen à Albien supérieur; Bassin de Mons) et de la saprolite polyphasée (Crétacé inférieur et Miocène inférieur) de la Haute-Lesse (Belgique). Implications géodynamiques et paléoclimatiques. Thèse de doctorat, Faculté Polytechnique de Mons et Université de Paris-Sud Orsay.
YANS, J., SPAGNA, P., FOUCHER, J.-C., PERRUCHOT, A., STREEL, M., BEAUMIER, P., ROBASZYNSKI, F., et DUPUIS, C., 2002. Multidisciplinary study of the Wealden deposits in the Mons Basin (Belgium): a progress report. *Aardkundige Mededelingen,* 12: 39-42.

6. Acknowledgements

This research received support from the FP-VI European-funded Integrated Infrastructure Initiative grant SYNTHESIS Project http://www.synthesys.info/ which is financed by European Community Research Infrastructure Action under the FP6 Structuring the European Research Area" Programme. This article is a contribution to projects ANR AMBRACE (No BLAN07-1-184190) of the French 'Agence nationale de la recherche'. The research of B.G. and V.D.-G. was supported by CNRS-UMR 5125 PEPS, projects CGL2005-00046/BTE and CGL2005-01121/BTE of the 'Ministerio de Educación y Ciencia' of the Spanish government and project 2005SGR-00890 of the Catalan government.

WOOD REMAINS AND SPOROMORPHS FROM THE WEALDEN FACIES OF HAUTRAGE (MONS BASIN, BELGIUM): PALAEOCLIMATIC AND PALAEOENVIRONMENTAL IMPLICATIONS

Thomas GERARDS[1, 2], Johan YANS[3], Paul SPAGNA[4] & Philippe GERRIENNE[1]

1. Paléobotanique, Paléopalynologie et Micropaléontologie. Département de Géologie, Université de Liège, B18, Sart Tilman, 4000 Liège1. tgerards@hotmail.com
2. Service de chimie organique de synthèse – Centre de Recherche du Cyclotron. Université de Liège, B30, Sart Tilman, 4000 Liège1. johan.yans@fundp.ac.be
3. Département de Géologie. Faculté Universitaire Notre Dame de la Paix. Rue de Bruxelles 61, 5000 Namur. Paul.Spagna@fpms.ac.be.
4. Service de Géologie Fondamentale et Appliquée. Faculté Polytechnique de Mons. Rue de Houdain 9, 7000 Mons. P.Gerrienne@ulg.ac.be.

(2 figures, 1 table, 2 plates)

ABSTRACT. Wood remains and palynomorphs from the Wealden facies of the Danube-Bouchon quarry at Hautrage (Mons Basin, Belgium) have been studied. Their palaeofloristic, palaeoenvironnemental and palaeoclimatic implications are discussed. The palynological study indicates a middle Barremian to earliest Aptian age. The wood assemblage includes specimens of *Podocarpoxylon*, *Taxodioxylon*, *Thujoxylon*, cf. *Sequoioxylon*, *Brachyoxylon*; 3 different Pinaceae, and 2 new genera. Tree ring analysis confirms the palaeogeographical position (around 35°N) of the Mons Basin during the Early Cretaceous. The composition of the wood assemblage and the tree ring analysis suggest a humid warm-temperate climate. The compared analysis of the wood and sporomorph assemblages suggests that the Hautrage locality was located in an alluvial or deltaic floodplain, not far from the seashore. Taxodiaceae, Podocarpaceae and various ferns thrived in the floodplain, probably in swampy environments. Mangroves with Cheirolepidiaceae possibly existed downstream. Pinaceae and Cupressaceae lived in the surroundings.

KEYWORDS: Aptian, Barremian, Charcoal, Fusain, Vitrinite, Climate.

1. Introduction

This paper is mainly concerned with the interpretation of the wood remains from the Wealden facies of the Danube-Bouchon quarry at Hautrage (Mons Basin, Belgium). Wood remains are preserved as “fusain” or “charcoal” and are present in large quantities at the locality. The palaeoclimatic implications of their growth rings have already been discussed (Gerards et al., 2007).

The wood assemblage was first described and identified, and then compared with coeval and modern localities. The anatomical features (mainly the growth rings) of the wood were also analysed. All this information is discussed from the palaeoecological and palaeoclimatic points of views, and according to the Nearest Living Relative method (Mosbrugger, 1999).

The systematics of the palymorphs from 5 palynological samples were also studied and compared with coeval localities.

The palaeofloristic, palaeoenvironmental and palaeoclimatic implications of the sporomorph and the wood remain assemblages are discussed.

2. Locality, geology and age

In Belgium, Wealden facies deposits mainly occur on the northern edge of the Mons Basin (Pirson et al.; 2008). The Mons Basin is situated along the Haine and northwestern Sambre valley and is generally considered as a lateral extension the Paris Basin (Marlière, 1970).

Plant fossils studied were collected in the Danube-Bouchon quarry (Hautrage locality), from sediments belonging to the Hautrage Clays Formation. This quarry is located at the northern margin of the Mons Basin (Robaszynski et al., 2001; Yans et al., 2002, 2005). The age of this formation has been discussed at length (Dejax et al., 2008). Recent data indicate that the Wealden facies at Hautrage are Early Cretaceous in age ("Wealden" *sensu stricto*, pre-Albian in age; Yans et al., 2005).

A palynological study of the dinosaur-bearing Wealden facies in the "natural pit with Iguanodons" of Bernissart (Belgium) indicated a middle Barremian to earliest Aptian age for the Wealden facies (Dejax et al., 2007).

The fossils were collected from two outcrops in the Danube-Bouchon quarry. The outcrop noted CHE in Fig. 1 is located in the northern part of the quarry. It consists of sandy palaeochannels alternating with white-grey to white variegated plastic clay, often rich in wood fragments, pyrite and sideritic nodules. The CHE-1, CHE-2 and CHE+1 levels are respectively 1 meter below, 2 meters below and 1 meter above the CHE channel level. Variegations clearly indicate the presence of palaeosoils. They are quite common in the CHE area where the oldest Wealden sediments of the Hautrage series outcrop (Spagna et al., 2008). One has been sampled around the CHE level.

The levels DB1-5.18 and DB1-6.60 are located in the southern part of the quarry (Fig. 1); they occur respectively 5.18 and 6.60 meters below the overlying Cenomanian sediments. They both consist of sandy and pebble-gravel beds.

Additional material coming from the core of a borehole drilled through the complete succession in 2001 (Dejax et al., 2008) has also been studied.

3. Material and methods

189 wood samples have been collected. Wood anatomy was examined with a scanning electron microscope (SEM Jeol-5800), in longitudinal radial, longitudinal tangential and transverse sections. The specimens are described according to the characters defined and codified by the IAWA (IAWA Committee, 2004).

Growth ring width has been measured on 42 specimens in the « Centre Européen d'Archéométrie » of the University of Liege, under a dissecting stereomicroscope coupled with a mobile stage and a micrometer. Mean width and mean sensitivity (MS) have been calculated for 10 specimens.

Palynological slides from levels CHE, CHE+1, DB1-6.60, DB1-5.18 and from the palaeosoil were prepared using the standard palynological methods. They were studied under a light microscope. Spore and pollen assemblages have been compared with modern and coeval assemblages, as well as with the wood assemblage.

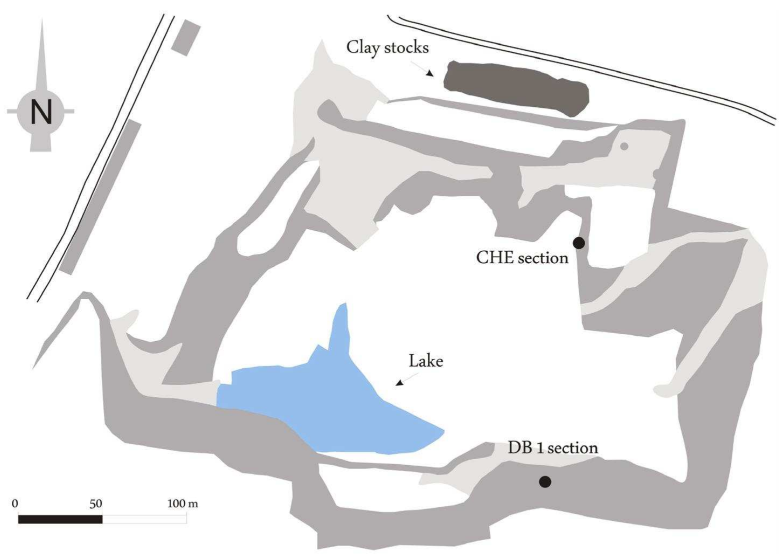

Figure 1. Simplified topographic map of the Danube Bouchon quarry at Hautrage, showing the location of the two studied fossiliferous outcrops.

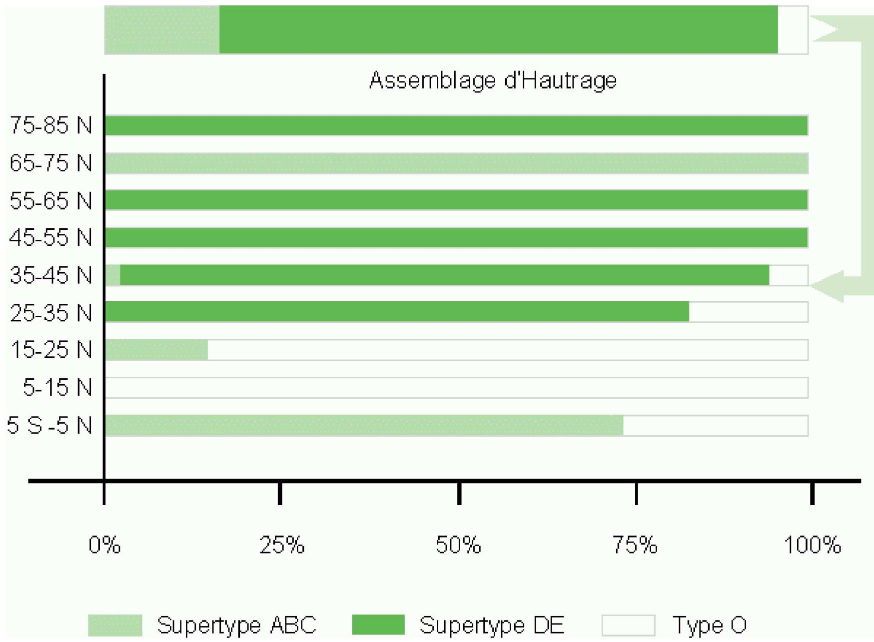

Figure 2. (from Gerards et al., 2007 ; modified from Brison et al., 2001). Latitudinal distribution of the ABC, DE, and O ring supertypes during the Early Cretaceous. The upper part of the diagram shows the proportion of the 3 ring supertypes in the Hautrage assemblage.

4. Results and discussion

4.1. The wood assemblage

Only 39 out of the 189 collected specimens could be identified. All the others were preserved as vitrinite, which does not allow any identification. Vitrinite was presumably formed by the action of sulphur bacteria, thriving in wet and anoxic environment and excrete sulphuric acid (work in progress at Liege University).

The following taxa have been collected from Hautrage: *Taxodioxylon* Hartig (Pl. 1A-D); *Thujoxylon* (Unger) Hartig emend. Süss & Velitzelos (Pl. 1E-H);; *Brachyoxylon* Hollick & Jeffrey (Pl. 2A-D); *Podocarpoxylon* Gothan (Pl. 2E-H); cf. *Sequoioxylon* Torrey ; 3 different undetermined *Pinaceae*; and 2 new genera. The number of specimens for each taxon found at the different levels is given in Table 1.

Taxon	DB1 5.18	DB1 6.6	CHE	CHE-1	CHE-2	CHE+1	Core
Podocarpoxylon	3	5	2				3
Taxodioxylon	2	5	1	2			3
Thujoxylon	4	1					
Cf. *Sequoioxylon*		2					
Brachyoxylon	1						
Pinaceae	1	1					1
Gen. nov. 1							1
Gen. nov. 2					1		

Table 1. The wood assemblage from Hautrage. DB and CHE are the two studied fossiliferous outcrops.

4.2. Other occurrences of the collected taxa

The presence of one specimen of *Brachyoxylon* at Hautrage has important palaeoenvironmental implications. This taxon is indeed known to be characteristic of coastal zones or mangroves, under warm, globally wet, climates, with alternating dry and wet seasons. This type of climate corresponds to tropical or warm-temperate climates (Greguss 1967, Vozenin-Serra & Pons 1990, Philippe 1995, Garcia et al., 1998, Néraudeau et al., 2003, Philippe et al., 2004).

The genus *Taxodioxylon* is known worldwide, and is especially abundant in Europe (Meijer, 2000). The genus is found in a wide range of palaeoenvironments and palaeoclimates, and is not useful as a past climate indicator. A survey of the literature indicates that the genus *Podocarpoxylon* is also ubiquitous and found in various palaeoclimates. It is therefore not a good past climate indicator either.

The Hautrage charcoal assemblage includes 5 specimens of *Thujoxylon*. This genus is not often recorded: only 3 other occurrences are known. All 3 indicate consistently that *Thujoxylon* can be associated with a warm-temperate climate. *Thujoxylon* occurs together with *Brachyoxylon* and *Brachyphyllum* in the Late Cretaceous Magothy flora (Masschusetts and Maryland, USA; Penny, 1947). At that time, the climate over Masschusetts and Maryland was warm-temperate (Scotese, 2000). The second occurrence is located in Tertiary deposits from the Yellowstone National Park area (Montana; Beyer, 1954), which also experienced a warm-temperate climate during the Tertiary (Scotese, 2000). Finally, Iamandei and Iamandei (2001) report the presence of *Thujoxylon* in the Miocene of Rumania. On the basis of the plant assemblage, the authors suggest a warm-temperate climate.

From the analysis of the Appendix A of Philippe et al., (2004), it appears that the association of *Brachyoxylon*/*Podocarpoxylon(Mesembrioxylon)*/*Taxodioxylon* (*Taxaceoxylon*) is indicative of a warm-temperate climate.

To summarize, the wood assemblage from Hautrage most probably indicates that, during the middle Barremian - earliest Aptian interval, the Mons Basin experienced a warm-temperate climate, with some humid tropical characteristics.

Today, two types of warm-temperate climate exist: the Mediterranean type (Zonobiome IV *sensu* Breckle 2002) and the “Laurel Forest” type (Zonobiome V *sensu* Breckle 2002). The Zonobiome IV, Mediterranean type, climates are located between 30 and 40°N; they include a long dry summer. As deduced from the tree ring analysis (see 4.5), this was probably not the case at Hautrage. The Zonobiome V, “Laurel Forest” type, climates are transitional between subtropical/tropical climates and temperate climates. They are divided into 2 subzonobiomes: the subzonobiome V (sr) (30-35°N; on the eastern border of the continents; rainfall all year long, with a minimum during winter), and the subzonobiome V (w) (more to the North than the (sr) ; on the western border of the continents ; rainfall all year long, winter rains predominant) (Breckle, 2002). During the Early Cretaceous, Hautrage was located between 30-35°N, on the eastern border of the continent. This is the reason why we believe that the climate type at Hautrage at that time was that of the subzonobiome V sr. This type of climate is presumably equivalent to the “Paratropical Climate” of Scotese, 2000.

4.4. Nearest living relative

The two new genera as well as *Brachyoxylon* will not be considered, as they are not comparable with any extant taxa.

Podocarpoxylon closely compares with *Podocarpus*. *Podocarpus* is common in warm- temperate, subtropical and tropical regions, most from southern hemisphere (Farjon, 1998). Its distribution matches almost exactly the subzonobiome V (sr) of Breckle (2002).

The *Taxodioxylon* wood type can be found in two extant genera: *Taxodium* and *Cryptomeria*. The genus *Taxodium* is found in Guatemala, Mexico and Florida (Farjon, 1988), mainly on permanently wet soils. *Cryptomeria* occurs in Japan and in south-eastern China (Farjon, 1988). Both genera appear to be characteristic of the subzonobiome V (sr) of Breckle (2002).

The genus *Thujoxylon* has close affinities with the extant genus *Thuja*. The genus is found under various climates, ranging from humid cold-temperate to tropical (Farjon, 1988), and therefore does not help much to reconstruct the climate at Hautrage.

Nevertheless, the Nearest Living Relative method (Mossbrugger, 1999) as applied to wood assemblage of Hautrage is globally consistent with the subzonobiome V (sr) climate type deduced from the fossils themselves.

4.5. Tree ring analysis

Creber and Chaloner (1985) established 6 categories of tree rings, according to the type of earlywood/latewood transitions and the earlywood/latewood quantities. Those 6 types were redefined by Brison et al. (2001) as follows:

- Type A: tree rings with little earlywood; sharp earlywood/latewood transition.
- Type B: tree rings with a wide band of latewood; more gradual earlywood/latewood transition than in type A.
- Type C: tree rings with a very gradual earlywood/latewood transition.
- Type D: tree rings with a thin band of latewood; well-marked earlywood/latewood transition.
- Type E: tree rings similar to type D, but with a more gradual earlywood/latewood transition.
- Type O: no growth rings.

On the basis of those 6 types, we have defined 3 supertypes: ABC, DE and O. Indeed, the distinction between A, B, C types and D, E types respectively is often difficult and does not bring any substantial palaeoclimatic information (Brison et al., 2001).

Tree ring type could be observed on 42 specimens: 5 % (2 specimens) have ABC type rings, 81 % (34 specimens) have DE type rings, and 14 % (6 specimens) have O type rings. Brison et al. (2001, fig. 5) have recorded the various latitudinal occurrence of the ABC, DE and O types of tree rings during the Early Cretaceous. The proportion found in the Hautrage assemblage is intermediate between that of the 25-35°N and 35-45°N. This suggests that the palaeolatitude of the Mons Basin during the Early Cretaceous was approximately 35°N, which is consistent with the latest palaeogeographical reconstructions (Scotese, 2000, Thiry et al., 2006).

It is generally admitted that rings over 2 mm in width indicate that the growth conditions were good (Fritts 1976; Morgans 1999). The mean width of the Hautrage wood rings is 1.46 mm. As those woods have been charcoalified, they have undergone a retraction that has been estimated at more or less 30% of the diameter (Gerards & Gerrienne, 2003). Consequently, the mean width of the tree rings at Hautrage was around 1.9 mm before charcoalifcation. It should also be taken into account that most of the wood remains were branch wood. This means that the mean width of the trunk wood rings was larger (Gerards et al., 2007), above 2 mm, clearly indicating that the growth conditions were generally good, with high water availability.

The Mean Sensitivity (MS) was calculated for the 10 specimens showing more than 15 rings. Their MS is 0 .42 (ranging from 0.32 to 0.55), which is rather high. This indicates that the ring width is much variable, and that the environmental conditions were somewhat instable.

False rings are frequently observed, which again shows that the growth conditions were somewhat instable or variable.

Rings have been observed in more than 85% of the studied specimens. In most cases, those rings are of the DE type (with large amount of earlywood and little latewood). This suggests that the trees lived in a climate with two well-marked seasons (one growing season, and a season of unknown length with no growth at all). This again is consistent with a warm-temperate or a tropical climate.

4.6. Palynological study

The sporomorphs identified at Hautrage, although less diversified, are globally the same as those described from Bernissart (Dejax et al., 2007). The presence of *Stellatopolis huguesii* at Bernissart and at Hautrage indicates that the two localities are probably more or less coeval, of middle Barremian to earliest Aptian age (Dejax et al., 2008).

The following sporomorph taxa have been identified:

-Spores:
Aequitriradites Delcourt & Sprumont, *Appendicisporites* Weyland & Krieger, *Camarozonosporites* Pant ex Potonié, *Cicatricosisporites* Potonié & Gelletich. *Concavissimisporites* Delcourt & Sprumont, *Deltoidospora* Miner, *Dictyophyllidites* Couper emend. Dettman, *Gleicheniidites* Ross, *Klukisporites* Couper, *Leptolepidites* Couper, *Matonisporites* Couper, *Trilobosporites* Pant ex Potonié, *Verucosisporites* Ibrahim.

-Pollen grains:
Araucariacites Cookson ex Couper, *Cerebropollenites* Nilsson, *Classopollis* Pflug, *Eucommiidites* Erdtman ex Potonié, *Stellatopolis huguesii* Penny, *cf. Pinuspollenites* Raatz ex Potonié, *cf. Podocarpidites* Cookson ex Couper.

-Algae:
Ovoidites Cookson & Dettman.

On the whole, the sporomorph assemblage indicates either a humid warm-temperate climate or a tropical climate.

The presence of *Ovoidites* demonstrates that the sedimentation occurred in a freshwater environment (Grenfell, 1995, Dejax et al., 2007), probably in an alluvial or deltaic floodplain as suggested by the presence of *Eucomiidites* (Kvaceck & Pacltova, 2001). The joint presence of *Ovoidites* and *Taxodium* indicates the existence of swamps, probably peripheral to the river. The presence of Zignemataceae and of a high proportion of vitrinised woods is consistent with the hypothesis of acid swamps.

The presence of the genus *Classopollis* is consistent with the presence of *Brachyoxylon*, as both are known to be produced by Cheirolepidiaceae (Alvin, 1982, Yi et al., 2003). Cheirolepidiaceae are generally considered as indicative of coastal environments or even mangroves (Garcia et al., 1998, Iamandei & Iamandei, 2005). At Hautrage, *Classopollis* and *Brachyoxylon* are rare, which suggests that the locality was not immediately close to the sea-shore.

The sporomorph *Pinuspollenites* is abundant, whereas Pinaceae woods are rare. This suggests that the trees of the Pincaeace lived at some distance from the sedimentary basin, and that only their anemophilous pollen could reach the latter.

No Cupressaceae pollen was found, whereas Cupressaceae wood (*Thujoxylon*) is abundant. This probably means that the wood was brought by the river system, and the Cupressaceae lived (far away?) upstream. Woods of the *Podocarpoxylon* and the *Taxodioxylon/Sequoioxylon* types on the one hand, and the pollen that they produced (*Podocarpidites, Cerebropollenites*) on the other hand, are roughly equally abundant. This strongly suggests that *Podocarpoxylon* and *Taxodioxylon/Sequoioxylon* were living in the sedimentary basin.

In the sample coming from the palaeosoil level, the spores of ferns are extremely abundant, which indicates that they were most probably living in a close proximity.

5. Conclusions

The analysis of the sporomorph and the wood assemblages from the Danube-Bouchon quarry has yielded the following information.

- The palynological study confirms the middle Barremian to earliest Aptian age of the sediments.
- The wood assemblage is comprised of specimens of *Podocarpoxylon, Taxodioxylon, Thujoxylon*, cf. *Sequoioxylon, Brachyoxylon*; 3 different Pinaceae, and 2 new genera.
- The composition of the wood assemblage and the tree ring analysis suggest a humid warm-temperate climate. Ring analysis also confirms the 35°N palaeogeographic position of the Mons Basin during this period.
- The composition of the wood assemblage and its detailed comparison of the sporomorphs suggest that the Hautrage locality was located in an alluvial or deltaic floodplain. The locality itself was not far from the sea-shore, but not directly close to it. Taxodiaceae and Podocarpaceae thrived in the floodplain, probably in swampy environments. Mangroves with Cheirolepidiaceae possibly existed downstream.
- The sedimentary basin was colonized by various ferns. Pinaceae and Cupressaceae lived in the surroundings, but presumably not exactly in the locality.

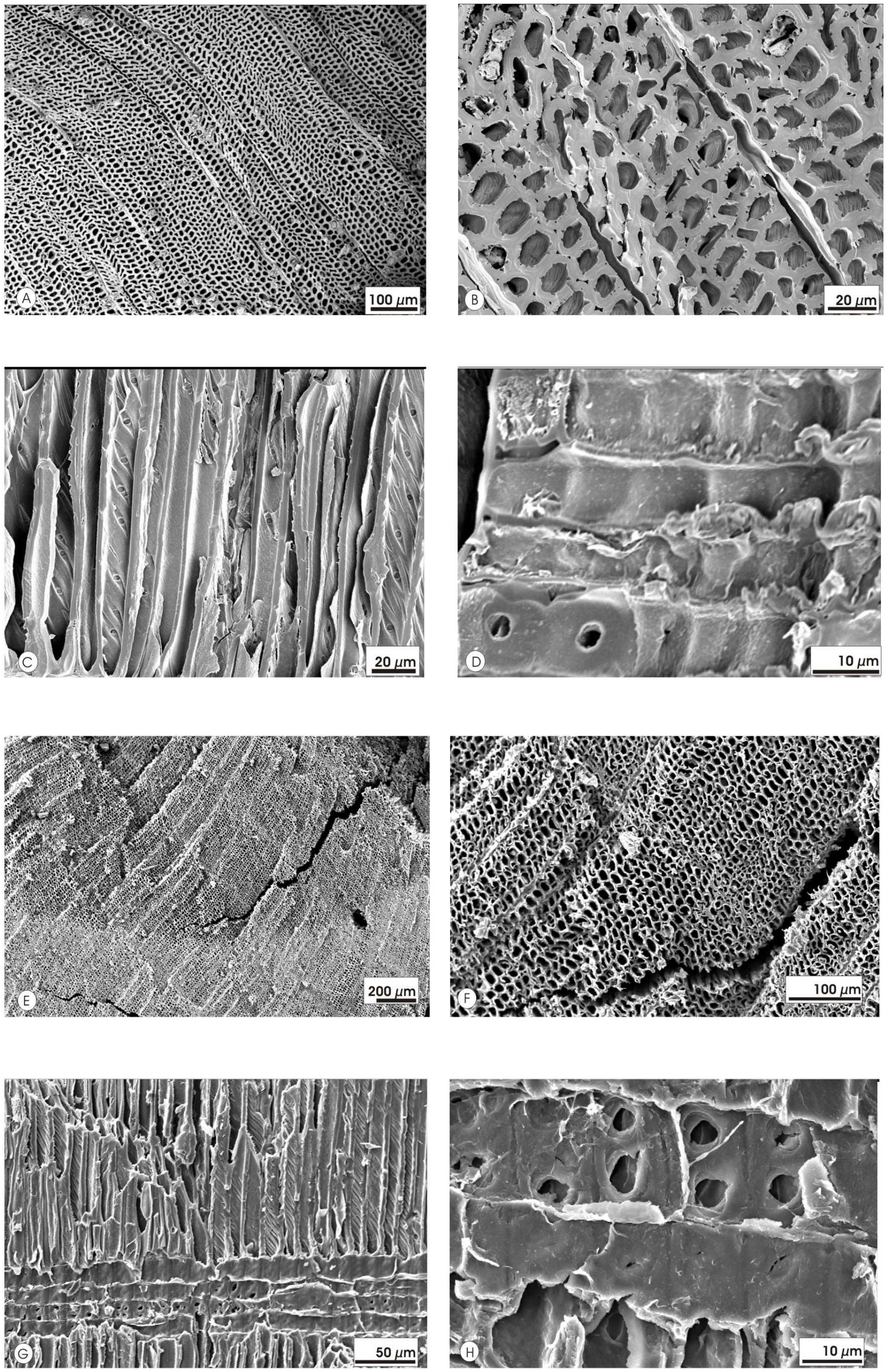

Plate 1.
A-B. *Taxodioxylon*. Gross view (A) and detail (B) of a transverse section showing the O type rings and the absence of resin ducts.
C. *Taxodioxylon*. Radial section, showing the tracheid pits.
D. *Taxodioxylon*. Radial section, showing the taxodioid cross-field pits
E-F. *Thujoxylon*. Gross view (E) and detail (F) of a transverse section showing the DE supertype rings and the absence of resin ducts.
G-H. *Thujoxylon.* Gross view (G) and detail (H) of a radial section, showing the cupressoid cross-field pits.

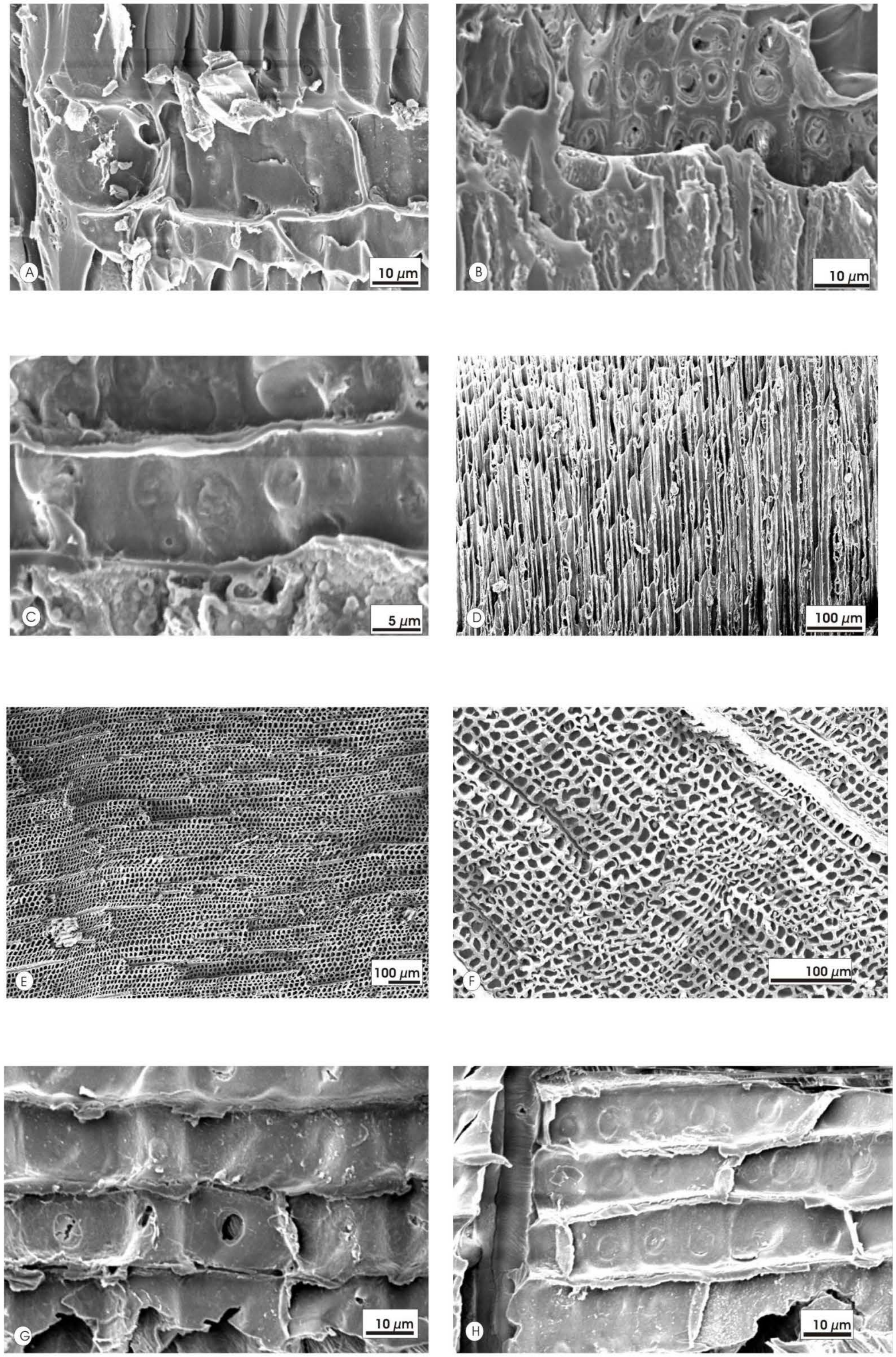

Plate 2.
A-B-C. *Brachyoxylon*. Radial section, showing the araucarioid cross-field pits
D. *Brachyoxylon*. Tangential section, showing the short uniseriate rays.
E-F. *Podocarpoxylon*. Gross view (E) and detail (F) of a transverse section showing the DE supertype rings and the absence of resin ducts.
G-H. *Podocarpoxylon.* Radial sections, showing the podocarpoid cross-field pits

6. References

ALVIN, K.L., 1982. Cheirolepidiaceae: biology, structure and paleoecology. *Review of Palaeobotany and Palynology*, 37: 71-98.

BEYER, A.F., 1954. Some petrified woods from the Specimen Ridge Area of Yellowstone National Park. *American Midland Naturalist*, 51: 553-576.

BRECKLE, S.W., 2002. *Walter's Vegetation of the Earth*. Springer Verlag, Berlin.

BRISON, A.L., PHILIPPE, M. & THEVENARD F. 2001. Are Mesozoic wood growth rings climate-induced ? *Paleobiology*, 27: 531-538.

CREBER, G.T. & CHALONER, W.G., 1985. Tree growth in the Mesozoic and Early Tertiary and the reconstruction of palaeoclimates. *Palaeogegraphy, Palaeoclimatology, Palaeoecology*, 52: 35-60.

DEJAX, J., PONS, D. & YANS, J., 2007. Palynology of the dinosaur-bearing Wealden facies in the natural pit of Bernissart (Belgium). *Review of Palaeobotany and Palynology*, 144: 25-38.

DEJAX, J., PONS, D. & YANS, J., 2008. Palynology of the Wealden facies from Hautrage quarry (Mons Basin, Belgium). This volume.

FARJON, A., 1998. *World checklist and bibliography of conifers.* The Royal Botanic Gardens, Kew.

FRITTS, H.C., 1976. *Tree Rings and Climate*. Academic Press, London.

GARCIA, J.P., PHILIPPE, M. & GAUMET, F., 1998. Fossil wood in Middle-Upper Jurassic marine sedimentary cycles of France: relations with climate, sea-levels dynamics, and carbonate-platform environments. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 141: 199-214.

GERARDS, T. & GERRIENNE, P. 2004. Étude comparative au microscope électronique à balayage du xylème secondaire de gymnospermes et angiospermes actuelles avant et après carbonisation contrôlée. Résultats préliminaires. *O.F.P. Info.*, 29: 11-12; A2-A3.

GERARDS, T., DAMBLON, F., WAUTHOZ, B. & GERRIENNE, P., 2007. Comparaison of cross-field pitting in fresh, dried, and charcoalified softwoods. *IAWA Journal*, 28: 49-60.

GREGUSS, P., 1967. Fossil *Gymnosperm Woods in Hungary from the Permian to the Pliocene*. Akademiai Kiadó, Budapest.

GRENFELL, H., 1995. Probable fossil zygnematacean algal spore genera. *Review of Palaeobotany and Palynology*, 84: 201-220.

IAMANDEI, E & IAMANDEI, S., 2001. Sarmatian fossil wood from the Falticeni-Suceava region. *Analele Stiintifice ale Universitatii AL.I.CUZA IASI, Geologie*, 57: 235-240.

IAMANDEI, S & IAMANDEI, E. 2005. Early Cretaceous Protopinaceous fossil wood from south Dobrogea, Romania. *Acta Palaeontologica Romaniae*, 5: 231-247.

IAWA Committee, 2004. IAWA list of microscopic features for softwood identification. *IAWA Journal*, 25: 1–70.

KVAČEK, J & PACLTOVA, B., 2001. *Bayeritheca hughesii* gen. et sp. nov., a new *Eucommiidites*-bearing pollen organ from the Cenomanian of Bohemia. *Cretaceous Research*, 22: 695–704.

MARLIERE, R., 1970. Géologie du bassin de Mons. *Annales Société géologique du Nord*, 90: 171-189.

MORGANS, H.S., 1999. Lower and Middle Jurassic woods of the Cleveland Basin (north Yorkshire), England. *Palaeontology*, 42: 303-328.

MOSBRUGGER, V., 1999. The nearest living relative method. *In:* Jones, T.P. & Rowe, N.P. (eds), *Fossil Plants and Spores: Modern Techniques*. *Geological Society of London, London*, 261-265.

NÉRAUDEAU, D., ALLAIN, R., PERRICHOT, V., VIDET, B., DE LAPPARENT DE BROIN, F., GUILLOCHEAU, F., PHILIPPE, M., RAGE, J.-C. & VULLO, R., 2003. Découverte d'un dépôt paralique à bois fossiles, ambre insectifère et restes d'Iguanodontidae (Dinosauria, Ornithopoda) dans le Cénomanien inférieur de Fouras (Charente-Maritime, Sud-Ouest de la France). *Comptes Rendus Palevol*, 2 :221-230.

PENNY, J.S., 1947. Studies on the conifers of the Magothy Flora. *American journal of Botany*, 34: 281-296.

PHILIPPE, M., 1995. Bois fossiles du Jurassique de Franche-comté (NE-France). *Palaeontographica B*, 236: 45-103.

PHILIPPE, M., BAMFORD, M., MCLOUGHLIN, S., ALVES, L., FALCON-LANG, H., GNAEDINGER, S., OTTONE, E., POLE, M., RAJANIKANTH, A., SHOEMAKER, R., TORRES, T. & ZAMUNER, A. 2004. Biogeographic analysis of Jurassic-Early Cretaceous wood assemblage from Gondwana. *Review of Palaeobotany and Palynology*, 129: 141-173.

PIRSON, S., SPAGNA, P., BAELE, J.-M., VANBRABANT, Y. & YANS, J., 2008. An overview of the Geology of Belgium. This volume.

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

SCOTESE, C.R. 2000. PALEOMAP Project. http://www.scotese.com/ecretcli.htm

SPAGNA, P., DUPUIS, C. & YANS, J., 2008. Sedimentology of the Hautrage wealden clays quarry. This volume.

THIRY, M., QUESNEL, F., YANS, J., WYNS, R., VERGARI, A., THEVENIAUT, H., SIMON-COINÇON, R., RICORDEL, C., MOREAU, M.-G., GIOT, D., DUPUIS, C., BRUXELLES, L., BARBARAND, J. & BAELE J.-M., 2006. Continental France and Belgium during the early Cretaceous: paleoweatherings and paleolandforms. *Bulletin de la Société Géologique de France,* 177: 155-175.

VOZENIN-SERRRA, C. & PONS, D. 1990. Intérêts phylogénétique et paléoécologique des structures ligneuses homoxylées découvertes dans le Crétacé inférieur du Tibet méridional. *Palaeontographica B*, 216: 107-127.

YANS, J., SPAGNA, P., FOUCHER, J.-C., PERRUCHOT, A., STREEL, M., BEAUNIER, P., ROBASZYNSKI, F. & DUPUIS, C., 2002. Multidisciplinary study of the wealden deposits of the Mons Basin (Belgium) : a progress report. *Aardkundige Mededelingen*, 12: 39-42.

YANS J., DEJAX J., PONS D., DUPUIS C. & TAQUET P., 2005. Paleontologic and geodynamic implications of the palynological dating of the Bernissart wealden facies sediments (Mons Basin, Belgium). *Comptes Rendus Palevol*, 4: 135-150.

YI, S., YI, S., BATTEN, D., YUN, H. & PARK, S., 2003. Cretaceous and Cenozoic non-marine deposits of the Northern South Yellow Sea Basin, offshore western Korea: palynostratigraphy and palaeoenvironments. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 191 : 15-44.

7. Acknowledgments

We are grateful to Patrick Hoffsummer and Jerôme Eeckhout (Centre Européen d'Archéométrie at Liège University) for their kind help with the tree ring measurements. We also warmly thank Jean Dejax and Denise Pons (Paris VI University) for their help with the palynological study, and Muriel Fairon-Demaret for her invaluable advises and her expertise in fossil wood taxonomy.

NEW DATA ON GEOLOGY, ANTHRACOLOGY AND PALYNOLOGY FROM THE SCLADINA CAVE PLEISTOCENE SEQUENCE: PRELIMINARY RESULTS

Stéphane PIRSON[1,3], Mona COURT-PICON[1], Paul HAESAERTS[1], Dominique BONJEAN[2] & Freddy DAMBLON[1]

1. Institut royal des Sciences naturelles de Belgique, Département de Paléontologie, 29 rue Vautier, B-1000 Bruxelles, Belgium. stef.pirson@skynet.be
2. Archéologie Andennaise, 339d rue Fond des Vaux, B-5300 Sclayn (Andenne), Belgium. Scladina@swing.be
3. Association wallonne d'Etudes mégalithiques, c/o Service de l'Archéologie en province de Liège, Ministère de la Région wallonne, 62 avenue des Tilleuls, B-4000 Liège, Belgium

(6 figures and 1 table)

ABSTRACT. Recently, the stratigraphy of Scladina Cave has been reexamined through detailed and systematic field records, leading to an important review of the sedimentary and diagenetic processes involved in the sequence genesis. Palynological and anthracological analyses have also been undertaken, taking the new stratigraphy into account. This paper presents the preliminary results of these analyses together with palaeoenvironmental and chronostratigraphical implications.

KEYWORDS: Scladina cave, Cave entrance sediments, Upper Pleistocene, Anthracology, Palynology, Palaeozoology, Sedimentology, Palaeoenvironment.

1. Introduction (D. Bonjean & S. Pirson)

Discovered by speleologists in 1971, the Scladina Cave has been excavated under the scientific authority of the University of Liège since 1978. It has become also a "school cave" where students from Belgium and abroad improve their investigation methods for prehistorical research in cave sites.

The cave is located in a small valley of a tributary of the Meuse river, in the village of Sclayn (province of Namur, Belgium; Fig. 1). It opens to the South-East in Visean limestone (Lives Formation). Scladina consists of a large gallery, 6 m high and 6-20 m wide, connected with other caves. After thirty years of an almost permanent fieldwork, excavations have reached 40 m beyond the entrance (Figs 2-4).

Since 1978, the cave underwent several multidisciplinary researches, dealing mainly with archaeology, archaeozoology, large and small mammals, palynology, stratigraphy and sedimentology (e.g. Otte, 1992; Otte *et al*., 1998). More than 17,500 lithic artefacts have been collected in the cave, corresponding to four main Mousterian occupations. Thousands of faunal remains have also been found throughout the sequence. However, the most important find from Scladina is undoubtedly the nearly complete juvenile maxillary and mandible of a Neandertal child, unearthed from 1993 onwards (Toussaint *et al*., 1994; Bonjean, 1995; Fig. 5). Dated to 127 + 46/-32 ka by gamma spectrometry (Toussaint *et al*., 1998), this fossil has been discovered in secondary position, reworked in a deep channel eroding the underlying deposits (Pirson *et al*., 2005). It constitutes the main Belgian palaeoanthropological discovery for the 20th century, joining other famous Pleistocene fossils from Belgium like Spy, Engis or La Naulette (Toussaint & Pirson, 2006). Unprecedented analyses on daily perikymata numbers (Smith *et al*., 2007) have established that the individual was ± 8 years old at death. Recently, thanks to high preservation of organic material, a sequence of mitochondrial DNA has been isolated out of the 2nd right lower deciduous molar of the Neandertal child (Orlando *et al*., 2006), which became the most ancient Neandertal individual ever analyzed at the DNA level.

Recently, in the framework of a PhD in geology (Pirson, 2007), new palynological and anthracological analysis were undertaken. This paper presents a preliminary synthesis of these new palaeobotanical and geological results, together with their palaeoenvironmental implications. This new data allows us to reconsider the former chronostratigraphical framework of the Scladina sequence.

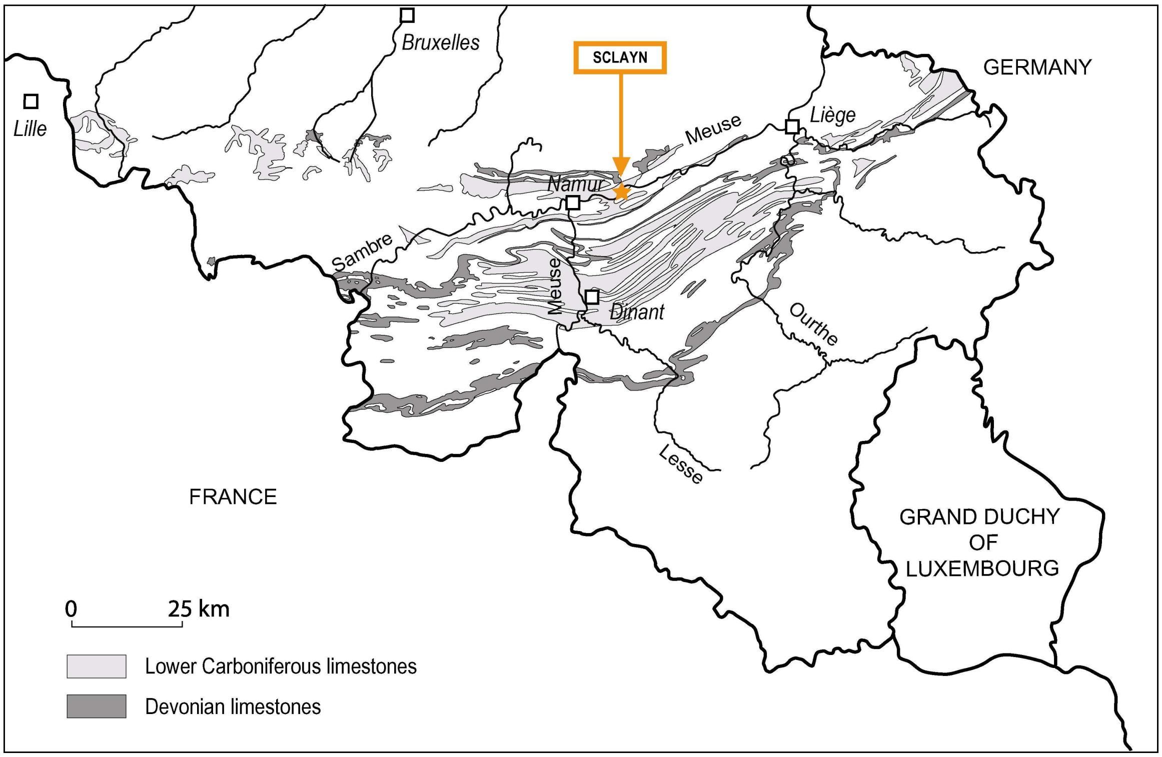

Figure 1. Location of Scladina cave. Grey areas: distribution of the Palaeozoic carbonated rocks in Belgium (after Toussaint & Pirson, 2007, modified from Ek, 1976).

2. Geology (S. Pirson & P. Haesaerts)

2.1. Revision of the stratigraphic sequence

Stratigraphy of Scladina sedimentary sequence has been elaborated by different scholars, leading to the definition of ca. 30 layers (Otte *et al*., 1983; Gullentops & Deblaere, 1992; Haesaerts, 1992; Bonjean *et al*., 2002). Recently, the site stratigraphy has been reviewed through detailed and systematic field records (Pirson *et al*., 2005; Pirson, 2007). In parallel, a geological survey of the excavation was conducted in close collaboration with the archaeologist in charge of the site (D. Bonjean). This led to the definition of a 15m-thick sedimentary sequence encompassing ca. 120 layers grouped in 28 “units” (Fig. 6). These field studies revealed complex geometries, numerous lithologies, as well as a large variety of sedimentary and diagenetic processes (Pirson, 2007). Correlation between the new stratigraphic system and the former stratigraphy is possible for the major units, but detailed correlation involving layers remains problematic.

The following synthesis will briefly present the major features of Scladina's sedimentary sequence. A distinct sedimentary record occurs at the back of the cave, due to a local collapse of the roof (Bonjean *et al*., 2002; Pirson, 2007). It will not be presented here.

2.2. Nature and origin of the deposits

Sediments from Scladina's sequence are mainly composed of limestone clasts embedded in a silty matrix. The limestone clasts are coming from the cave walls and the silty matrix is made of loess reworked from outside the cave. These two major components are generally associated with some siliceous pebbles and a small sand fraction, both originating from an alluvial terrace of the Meuse preserved on the plateau. Locally, *in situ* or reworked speleothems are also present.

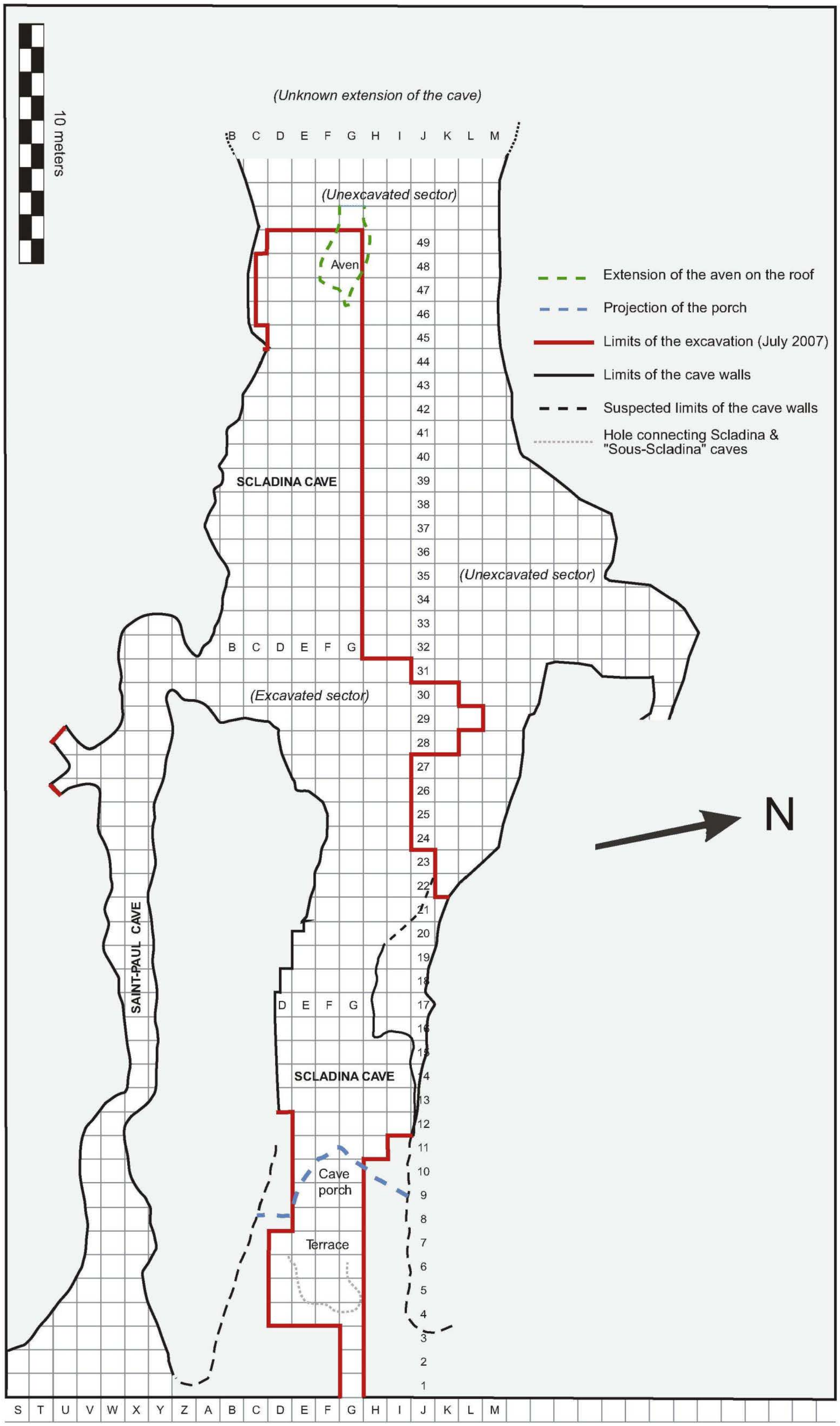

Figure 2. Map of Scladina cave (July 2007). Computer graphics: Archéologie Andennaise & S. Pirson.

Figure 3. Entrance of the cave.

Figure 4. Excavators at work in the cave.

Figure 5. Cast of the Neandertal child mandible and maxillary. The nineteen separate casts were produced and assembled by Dr Michel Toussaint (MRW). Picture: © Archéologie Andennaise.

2.3. Sedimentary and post-depositional processes

In Scladina, the sedimentary dynamic is governed by slope processes. Sediments from the plateau and limestone fragments from the surrounding cliffs accumulated under the cave porch together with aeolian deposits. These were subsequently redistributed towards the inside of the cave ("éboulis assistés" of Bertran *et al*., 2004). Several sedimentary processes involved in the redistribution have been identified: debris flow, run-off, rock fall, settling and torrential flow (Pirson, 2007). Speleothem formation occurred within six units.

Several post-depositional processes have also been identified: deep frost (thick platy structure), cryoturbations, pedogenesis (on the terrace of the cave), epigenesis of calcite by phosphates, mud cracks, cementation of sediments by calcite, burrowing, etc (Pirson, 2007).

2.4. Climatic changes recorded in the sediments

Several sedimentary or post-sedimentary processes evidenced in the Scladina stratigraphic sequence allow climatic reconstruction (Pirson, 2007):
- stalagmitic floors;
- *in situ* palaeosol on the terrace of Scladina, under the cave porch (Haesaerts, 1992);
- possible reworked palaeosol inside the cave;
- secondary phosphate around unsound limestone fragments;
- solifluction;
- post-depositional effect of ice.

Stalagmitic floors are classically used in cave palaeoenvironmental reconstructions (e.g. Quinif *et al*., 1994). Palaeosol is another classic tool used in the study of Quaternary climatic changes, especially in loess sequences (e.g. Haesaerts *et al*., 1999, 2003). The four other identified processes need further explanation.

To demonstrate the presence of a reworked palaeosol and use it as a reliable indicator of a climatic improvement in the sedimentary sequence of a cave entrance, it has to be further documented by other elements, such as the association with stalagmitic floors or data from other disciplines (e.g. palaeontology or magnetic susceptibility). Moreover, as the palaeosol is reworked, there is inevitably a certain time span between the climatic improvement itself and the deposition of the sediments. However, the detailed study of two complex stratigraphical sequences of cave entrance (Scladina and Walou: Pirson, 2007) indicate that most of the time the reworking processes do not mix anything at any time. A rigorous control of stratigraphy and sedimentary dynamics is however absolutely necessary.

In caves, the presence of very unsound limestone clasts exhibiting a black phosphatic cortex is classically interpreted as induced by bat guano accumulation (e.g. Martini & Kavalieris, 1978; Karkanas *et al*., 2000). It is therefore linked to a climatic improvement, bats being often considered as a forest indicator (Cordy, 1992). In Walou and Scladina caves, these authigenic phosphates are associated with other elements indicating major climatic improvements (Pirson, 2007).

Solifluction is a slow downslope displacement of sediments involving two processes linked with ground ice formation: frost-creep and gelifluction (Bertran, 2004). This sedimentary process is typical of periglacial environments and has therefore a clear climatic signature. Other sedimentary processes classically recognized in a slope environment (e.g. run-off, debris flow, rock fall) are not secure climatic indicators as they are active in different climatic environments (Bertran, 2004).

Two types of post-depositional effects of ice have been observed in Scladina (Pirson, 2007). The first one is the development of a thick platy structure, indicating deep frost (Van Vliet-Lanoë, 1985, 1988). The second one is stone tilting linked with cryoturbation, again testifying the presence of a cryosol (Van Vliet-Lanoë, 1985, 1988).

The distribution of all these climatic indicators in the stratigraphic sequence of Scladina is presented in Figure 6.

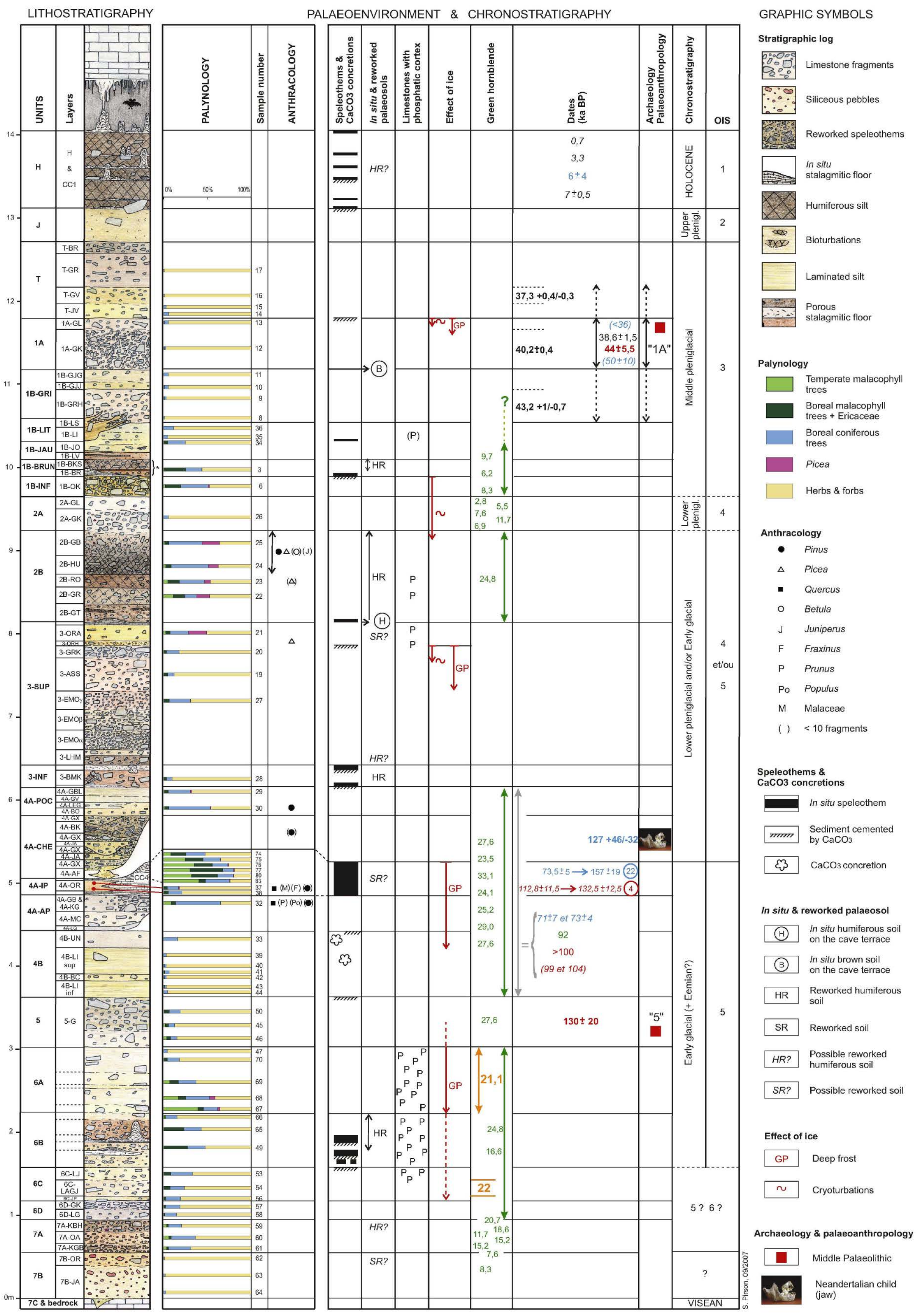
LITHOSTRATIGRAPHY
PALAEOENVIRONMENT & CHRONOSTRATIGRAPHY
GRAPHIC SYMBOLS
UNITS
Layers
PALYNOLOGY
Sample number
ANTHRACOLOGY
Speleothems & CaCO3 concretions
In situ & reworked palaeosols
Limestones with phosphatic cortex
Effect of ice
Green hornblende
Dates (ka BP)
Archaeology Palaeoanthropology
Chronostratigraphy
OIS
HOLOCENE
Upper plenigl.
Middle pleniglacial
Lower plenigl.
Lower pleniglacial and/or Early glacial
Early glacial (+ Eemian?)
VISEAN
4 et/ou 5
5 ? 6 ?
0,7
3,3
6±4
7±0,5
37,3 +0,4/-0,3
40,2±0,4
43,2 +1/-0,7
(<36)
38,6±1,5
44±5,5
(50±10)
"1A"
127 +46/-32
73,5±5 → 157±19 (22)
112,8±11,5 → 132,5±12,5 (4)
71±7 et 73±4
92
>100
(99 et 104)
130± 20
"5"
Stratigraphic log
Limestone fragments
Siliceous pebbles
Reworked speleothems
In situ stalagmitic floor
Humiferous silt
Bioturbations
Laminated silt
Porous stalagmitic floor
Palynology
Temperate malacophyll trees
Boreal malacophyll trees + Ericaceae
Boreal coniferous trees
Picea
Herbs & forbs
Anthracology
Pinus
Picea
Quercus
Betula
Juniperus
Fraxinus
Prunus
Populus
Malaceae
( ) < 10 fragments
Speleothems & CaCO3 concretions
In situ speleothem
Sediment cemented by CaCO3
CaCO3 concretion
In situ & reworked palaeosol
In situ humiferous soil on the cave terrace
In situ brown soil on the cave terrace
Reworked humiferous soil
Reworked soil
Possible reworked humiferous soil
Possible reworked soil
Effect of ice
Deep frost
Cryoturbations
Archaeology & palaeoanthropology
Middle Palaeolithic
Neandertalian child (jaw)
S. Pirson, 09/2007

Figure 6. Scladina cave. Stratigraphic log with a synthesis of the palaeoenvironmental and chronostratigraphical data.
"Green hornblende": percentage of green hornblende (amphibole) in the silt fraction (in green: values calculated from the data of Gullentops & Deblaere, 1992; in orange: data from Pirson, 2007).
"Dates": synthesis of all the reliable dates available for Scladina sequence.
- black: already published ^{14}C date on bone;
- *black italic*: ^{14}C date on calcite (*in situ* speleothem, reworked speleothem or concretion);
- **black bold**: ^{14}C date on teeth recently obtained in Groningen (see Pirson, 2007), accurately positioned in the new stratigraphic system;
- blue : U/Th date on *in situ* speleothem;
- *blue italic*: U/Th date on reworked fragments of speleothem or on calcite concretions;
- blue bold: U/Th date (gamma spectrometry) obtained on the Neandertal mandible;
- red: thermoluminescence date on sediment;
- *red italic*: thermoluminescence date on *in situ* speleothem;
- red bold: thermoluminescence date on burnt flint;
- green: couple of U/Th –ESR dates on bone.
- ( ) = problematic date. When an age interval is given (for CC4), the concerned total number of dates is indicated by a numeral surrounded by a circle.

"Chronostratigraphy": attempt in the chronostratigraphic interpretation of the Scladina sequence based upon all the available disciplines. The presence of *Dama dama* in the former layer 1B lead to questioning the relevance of the attribution of this part of the stratigraphy to the Weichselian middle pleniglacial.
"OIS": suggestion of correlation with the marine oxygen isotopic stages.

(For an A3-version of this figure, see the appendix.)

3. Palynology (F. Damblon, M. Court-Picon & S. Pirson)

Among the various cave sites investigated for pollen in Belgium (Damblon 1974; Heim in Toussaint *et al.*, 1986; Heim, 1993a; Heim, 1993b; Noirel-Schutz, 1994; Bastin in Cordy *et al.*, 1992), the Scladina cave has been the object of the most detailed investigations and hard debates (Bastin & Schneider, 1984; Schneider, 1986a & 1986b; Bastin *et al.*, 1986; Bastin, 1992). The controversy is mainly caused by a combination of problems linked to stratigraphic resolution, reworking processes, intrusive material, low content and poor preservation state of pollen grains as evoked by Sanchez-Goni (1994a, 1994b) and Carrion *et al.* (1999) about palynology in caves in general.

Despite these reservations, the new stratigraphical study achieved by Pirson (2007) was a unique opportunity to test further palynological investigations on refreshed and clean sections with the aim at:
- detecting fossil pollen in fine-grained sediment and speleothems inside the cave;
- comparing the new pollen record with the data of Bastin (1992), notably about the occurrences of mesophilous taxa, not only in layers formed during climatic improvements but also in layers corresponding to dry and cold periods. It was worthwhile indeed to control the presence of possible intrusive pollen in Scladina to the light of the new pollen sequence of Walou cave where modern pollen grains were found in the whole sequence (Damblon *et al.*, in press). The question is still more complicated by the finding of such mesophilous taxa in Belgian loess sequences even in pleniglacial deposits (Bastin 1971);
- gaining palaeoenvironmental information in parallel with pedostratigraphy and anthracology;
- contributing to the chronostratigraphical interpretation of the sequence.

3.1. Sampling for pollen

A first set of 71 samples has been collected throughout the Scladina sequence. Their precise positioning is guaranteed by a detailed knowledge of the stratigraphy (Pirson, 2007). These palynological samples have been collected by the stratigraph (S. Pirson) in the presence of the palynologists (M. Court-Picon & F. Damblon). The sampling has been made on specific sections where the layers selected for the palynological study were best developed, carefully avoiding the visible sources of contamination like bioturbations. This sampling methodology, already applied in Walou cave (Damblon *et al.*, in press), was preferred to the more classic one involving regularly spaced samples taken out of straight columns on a few sections. The major problem with this classic methodology lies in that it does not take into account the strong lateral variations that characterize cave stratigraphies.

For this first set, taking samples was avoided in some highly disturbed layers as the filling of the channel 4A-CHE. Other samples have recently been collected and their study is in progress.

3.2. Laboratory treatment for pollen

The method for extracting pollen from sediment is derived from Bastin (1990) and is adapted so as to favour complete dispersion of the pollen grains from the sediment matrix (Damblon *et al.*, in press).

3.3. Pollen count in the sequence of Scladina

A total of 98 taxa have been identified with 21 tree and shrub taxa, 56 herbs, forbs and ferns as well as 2 algae. For each sample, the pollen and spore counts were made up to a minimum of 400 grains of terrestrial taxa. Percentage calculations were made on this total of arboreal and non arboreal taxa.

3.4. Presentation of the data

The pollen data is presented here in a synthetic form with a unique bar diagram paralleled with the new stratigraphic sequence (Fig. 6). The detailed pollen diagram will be presented later. Each bar gives the proportions of the main Plant Functional Types (PFTs) for the North Hemisphere (see Bigelow *et al.*, 2003; Tarasov *et al.*, 1998; Tarasov *et al.*, 2000): temperate malacophyll trees, boreal malacophyll trees and shrubs, boreal conifers with spruce separately, herbaceous steppe and meadows plants. This kind of diagram has the advantages to 1) stress the relationship with the stratigraphy and 2) take into account the discontinuous character of the sedimentation in such a sedimentary environment. In the same figure, the charcoal data (see § 4) is summarised next to the pollen data.

3.5. The results

3.5.1. The pollen sequence

Independently of their distribution, the main herb and forb taxa represented in the sequence are Poaceae, Cichorioideae, Asteroideae, *Artemisia*, *Plantago* and Chenopodiaceae while tree taxa are mainly represented by *Pinus*, *Juniperus*, *Picea*, *Betula*, *Corylus*, *Quercus*, *Ulmus*, *Carpinus* and *Hedera*. Monolete ferns are also locally well represented, as well as algae like Chrysophyceae.

The 71 samples collected in the Scladina sedimentary deposits provide a long pollen sequence which can be drawn in parallel with the new stratigraphy. It should be stressed here again that such a succession of layers is essentially discontinuous due to the complex geological history of cave infillings. Therefore the interpretation of the pollen record will take into account the set of geological data that permits us to understand the origin of each layer (deposition process, erosion, or reworking processes).

There is no place here to describe and discuss the pollen record in detail. Therefore only the general trends will be presented from base to top. The comparison with geological and other data will be presented and discussed in § 5.

- Unit 7B: very low pollen concentration; pollen spectra highly dominated by steppe herbs and forbs. Suggesting very dry and cold environment.
- Unit 7A: low pollen concentration; dominance of steppe taxa but proportions of trees with *Pinus* and *Juniperus* dominant over some amounts of *Quercus*. Suggesting weak climatic improvement with regard to 7B.
- Unit 6D: very low pollen concentration; dominance of steppe taxa, low amount of trees, mainly conifers. Suggesting cold and dry conditions.
- Unit 6C: a little more pollen grains, conifers rising. About the same conditions as in unit 6D.
- Unit 6B: a little higher pollen concentration; boreal malacophyll trees, mainly *Betula*, draw a maximum while *Corylus* is present, the whole suggesting a weak improvement of the climate. Note that pollen analyses for the two speleothems preserved in 6B are still in progress.
- Unit 6A: low pollen concentration; relatively high percentages of temperate deciduous malacophyll trees at the base; from base to top a trend is drawn with rising proportions of steppe herbs at the expense of trees, especially malacophyll ones. This trend is uneasy to interpret in the present state of research. Analyses in progress (e.g. in speleothems from unit 6B) should help to better understand this part of the sequence.
- Unit 5: a peak in the pollen concentration, essentially by herbs; the spectra remain dominated by steppe taxa over conifers and other boreal trees. Suggesting cold steppe conditions.
- Unit 4B: the six samples from the first three layers in this unit show a clear dominance of steppe plants despite the variable pollen concentration with a peak in layer 4B-LI sup. Suggesting arid open steppe conditions. The upper layer 4B-UN shows a slight rise of the conifers, *Pinus* but mainly *Juniperus*. Spores of algae are rising in percentages. This could announce the following steps in the sequence.
- Unit 4A-AP, layer 4A-KG: one sample with very low pollen concentration; but the amount of conifers, especially *Pinus*, is much higher than previously while various malacophyll temperate taxa appear. A number of charcoal remains, notably of *Quercus*, are preserved in the same layer (§ 4). Proportions of algae show a peak. All of this suggests a clear climatic improvement.
- Unit 4A-IP, layer 4A-OR and stalagmitic floor CC4: the pollen concentration in CC4 is low but the spectra appears highly significant for a strong climatic improvement through relatively high percentages of various temperate malacophyll trees like *Ulmus*, *Quercus*, *Fraxinus*, *Carpinus* and sclerophylous liana as *Hedera* that coexist with *Pinus* and *Picea*. The analyses have provided evidence for a mass of woody micro-remains from vessels and tracheids. Note also high amounts of monolete fern spores, most probably linked to the increase of humidity around the cave. But even so algae are absent from the stalagmitic floor.

  The whole pollen assemblage in CC4 points to a transition from temperate to boreal environmental conditions. The general trend shows a decrease of temperate taxa suggesting a katathermal phase of a strong climatic improvement. This has to be decided with regard to other data.

On the contrary in layer 4A-OR, the high pollen concentration with quasi no temperate taxa, but a few conifers, seems to correspond to forest-steppe or even to cold steppe conditions. Nevertheless, a set of charcoal remains from malacophyll temperate taxa is preserved in layer 4A-OR (§ 4), in good agreement with the pollen record in CC4. Further investigations are necessary to understand this situation.

- Unit 4A-CHE: no sampling in this strongly reworked infilling of a channel.
- Unit 4A-POC: very low pollen concentration in the two analysed layers. The boreal character of the assemblages is underlined by steppe herbs and large amount of *Pinus* complemented by scattered pollen of malacophyll trees, mainly *Betula*. Monolete spores of ferns suggest local humidity around the cave.
- Unit 3-INF: low pollen concentration; the percentages of tree pollen, mainly from boreal taxa, is lower than in 4A-POC. The corresponding environment is an open steppe.
- Unit 3-SUP, layers 3-EMO▯, 3-ASS, 3-GRK: low pollen concentration; the amount of boreal trees is irregular but suggesting a globally steppe environment.
- Layer 3-ORA: low pollen concentration. A disruption occurs at this level with a sudden rise of *Picea* and *Pinus* followed by various malacophyll taxa. The environment could have been a forest-steppe.
- Unit 2B: low pollen concentration in three layers but increasing in layer 2B-GB; the high percentages of *Picea* and *Pinus* are paired with low amounts of malacophyll trees, like *Quercus* and *Tilia*, the whole suggesting more boreal environment. Humid local conditions are reflected in the high percentages of fern spores. Let us notice that the local occurrence of *Pinus* and *Picea* is attested by charcoal remains in this unit.
- Unit 2A, layer 2A-GK: relatively high concentration of herb pollen; the spectrum is highly dominated by steppe taxa, suggesting very dry and cold conditions.
- Units 1B-INF and 1B-BRUN: pollen concentration in layer 1B-BK reaches the maximum of the whole sequence. Here the percentages of boreal tree pollen, with *Pinus* and *Betula*, goes up to 50% and raises the boreal character of the environment while the presence of ferns is attested close by the cave. The corresponding vegetation could have been a forest-steppe.
- Unit 1B-JAU and 1B-LIT: back to very low pollen concentration; the landscape should have been covered by cold steppe with *Juniperus* and *Pinus* as the main tree components.
- Units 1B-GRI, 1A and T: low pollen concentration for trees but rather high for steppe herbs and forbs. Percentages for trees do not rise above 5%. The presence of *Hippophae*, *Ephedra* and *Helianthemum* clearly reflect the open steppe character of the landscape and the hardiness of the climate.

3.5.2. Micro-charcoal

In the whole sequence, brown-black micro-particles are present and appear in high percentages, up to 90% of the total of micro-remains, including pollen grains. Such micro-particles may come from wood but also from herbs and forbs. The highest amounts were observed in layers interpreted as reworked palaeosols like in 7A, 6B, 2B and even in speleothem CC4. This means that wildfires were frequent in boreal and boreal/temperate forest environments.

But micro-charcoal particles are also present in significant amounts in layers where palynology points to a cold steppe environment like in 4B, even if their proportions are lower (around 30%, but very variable). This can be a consequence of running wildfires in the steppe landscape. More thorough investigations should be made on this question.

3.5.3. Distribution of pollen grains from temperate malacophyll taxa

Despite the good agreement between the main pollen assemblages and pedostratigraphy (§ 5), we notice the regular occurrences of very low amounts of pollen grains from temperate malacophyll trees (*Quercus, Tilia, Carpinus, Fagus,* and even *Juglans*) in the whole pollen record, even in layer formed during dry and cold conditions. Their distribution may be explained in different ways:

1) persistence of refuge areas for such temperate trees in the valleys during the pleniglacial periods;
2) input in the cave from long distance transport by wind;
3) intrusion of recent pollen in the sequence by infiltration and bioturbation;
4) secondary input of pollen grains by reworking from older layers formed during interstadial or interglacial periods.

Without entering here in a long discussion on this puzzling question, we suspect that the last hypothesis is more coherent with the constant reworking of the successive layers inside the cave. Indeed, some facts to be stressed are:

a) pollen grains of temperate taxa are less frequent in the layers of the lower part of the sequence pointing to cold steppe conditions;

b) from 4A-POC upward, such frequencies are rising in layers likely to have been reworked from a palaeosol or containing small remnants of speleothem. The future palynological analyses of the other speleothems and fragments of speleothems in this sequence might give an answer;

c) on the contrary to the pollen record at Walou which included a significant amount of intrusive fresh fashioned pollen grains, the one from Scladina does not show the same imprint of intrusion, most probably because sampling was made inside the cave. On the other hand, it is highly suspected that a certain proportion of old pollen grains was reworked from ancient units or layers like 4A-AP or 2B.

The complexity of the problem will be discussed in the future.

3.6. Conclusion

What can the pollen record tell us in the interpretation of the Scladina sequence?

1) The principal contribution of palynology is to provide accurate information on the environment (vegetation and climate) during the formation of the sedimentary record. This comes from the good coherence that appears in the pollen distribution, from the comparison between the pollen record and stratigraphy. However, given the specificity of cave deposits, it is necessary to confront the palynological data with those from other disciplines, notably anthracology and sedimentary dynamics (see § 4-5).

2) In the present pollen sequence, very few taxa (Ericaceae, a part of Cyperaceae and Poaceae, some *Gentiana* and *Saxifraga*) might be assigned to tundra vegetation. The large majority of the non arboreal taxa have to be assigned to a steppe biome with the classic *Artemisia*, Chenopodiaceae, *Plantago*, various Asteraceae, *Ephedra*, *Helianthemum*, etc. The same conclusion was drawn from the study of Walou cave palynological sequence (Damblon *et al*., in press). On the other side, forest elements are mainly represented by boreal trees, either conifers (*Pinus*, *Picea*, *Juniperus*) or deciduous malacophyll angiosperms (*Betula*, *Alnus*, partly *Corylus*), and by temperate deciduous malacophyll trees (*Quercus*, *Ulmus*, *Tilia*, *Fraxinus*, *Carpinus*, *Acer*) and liana (*Hedera*). Fern spores seem to be systematically associated with forest extensions.

3) As a whole, the pollen record faced with stratigraphy in the Scladina cave shows a general trend of balance between open steppe vegetation (in units 4B and 1A, for example) and temperate to boreal forest (in speleothem CC4) with intermediate steppic environments comprising conifers and other boreal trees in various amounts. Surprisingly spruce is playing a considerable role in some periods, notably the one recorded in the unit 2B which could characterise an interstadial episode. As charcoal of *Picea* was present in the same layers (§ 4), this fact attests of the autochthony of spruce in Belgium during the last glacial cycle. Today, spruce is exclusively planted, mainly in the Ardennes.

4) In agreement with the data of McGarry & Caseldine (2004) and Caseldine *et al.* (2008), only speleothem CC4 allows drawing a micro-sequence of a progressive evolution of the plant cover around the site, with a minimal disturbance of the pollen assemblages. In the Scladina sequence, the speleothem records a clearly forested episode as deduced from pollen spectra comprising up to 80% AP and up to 38% temperate malacophyll deciduous tree pollen.

5) The scattered distribution of pollen grains from temperate taxa in layers where palynology points to dry and cold conditions is interpreted here as the result of some reworking rather than other intrusive processes or extra-regional inputs. This needs further verification.

6) In the sequence of Scladina, palynology in itself cannot give precise information about chronostratigraphy due to the flash picture record of the palaeovegetational succession. It may be ascribed to the last glacial cycle but with the help of other data only. The provisional chronostratigraphical interpretation will be discussed below (§ 6) by confrontation of the palaeobotanical data with pedostratigraphy, sedimentology, palaeozoology and dating results. Nevertheless, some key information, as the pollen microsequence in CC4, may be used as a tool for correlation with previous pollen data by Bastin (1992). Moreover, the very restricted distribution of some taxa, like spruce in 2B, in good agreement with other disciplines (§ 5), could provide good markers in a correlation process.

Finally, the present pollen diagram looks promising as one of the best in Belgium for the record of vegetation and climate changes in the course of the last glacial cycle, together with the one from Walou cave (Damblon *et al*., in press).

4. Anthracology (F. Damblon)

Analyses of charcoal or charred material are an exception in Belgian caves (Stockmans 1960; Vanhoorne in Gautier & de Heinzelin, 1980; Fairon-Demaret, 1984; Schoch in Teheux & Otte 1989; Schoch 1994; Damblon in Jadin, 2003, p. 132; Damblon, in press). Unfortunately the results of such analyses are most of the time deceiving or dubious, due to intrusions, reworking phenomena or lack in stratigraphical control. On the contrary, the sequence of Scladina provided a good opportunity to collect charcoal samples in a precise stratigraphic position and to confront the results with those from other disciplines, notably palynology, allowing to test palaeoenvironmental interpretations.

4.1. Sampling for charcoal

Up to now, sampling for charcoal was opportunistic both on sections and excavation surfaces. More systematic collection is planned in the next future by extending the sampling to each layer and collecting larger amounts of sediment.

4.2. Laboratory treatment for charcoal

Charcoal in cave sediments may be found in concentrations or dispersed in the matrix or even included in speleothems. The treatment begins with desiccation of the sample in an oven. This operation makes the dispersion of clay easier and contributes to get the charcoal fragment harder. If necessary the use of a solution of sodium pyrophosphate helps in finishing clay dispersion.

Most often it was necessary to apply a chemical treatment to release charcoal or/and to dissolve calcite or silicate crystals that obstruct the structures. A sequence of treatment with HF, HCl and dist.H_2O was applied for cleaning the charcoal fragments allowing their identification easier.

The determination of the taxa was possible on very small fragments, up to ¼ mm if key characters could be observed, with the aid of a reference collection and atlases (Greguss 1955, 1959; Grosser 1977; Schweingruber 1990, 2001; Hather, 2000; Benkova & Schweingruber, 2004).

4.3. Presentation of the data

The data on charcoal is given in absolute numbers taking the limited sampling and the low amount of fragments into account (Table 1). In the present state of research, we will only consider the presence of a taxon and not the number of fragments.

Unit	Layer	Taxa: number of fragments
2 B	2B-HU/-GB	*Pinus* : 82; *Picea* : 59; *Juniperus* : 6; *Betula* : 2; bone: 1
	2B-RO	*Picea* : 1
3-SUP	3-ORH	*Picea* : 26
4A-POC	4A-BO	*Pinus* : 16
4A-CHE	4A-CHE	*Pinus* : 6
4A-IP	4A-OR	*Pinus* : 1; *Fraxinus* : 3; Malaceae: 4; *Quercus* : 14
4A-AP	4A-KG	*Pinus* : 1; *Populus* : 5; *Quercus* : 23; *Prunus spinosa* : 9

Table 1. The charcoal record of Scladina.

4.4. The results

Charcoal fragments were found in units 4A-AP to 2B.

The taxa may be put in two categories: the boreal trees with *Pinus*, *Picea*, *Juniperus* and *Betula* on one side and the temperate deciduous malacophyll trees with *Quercus*, *Fraxinus*, Malaceae and *Prunus* t. *spinosa* on the other side. The heliophilous *Populus* may be a member of both groups.

Considering the distribution of the taxa in the sequence, it clearly appears that the group of temperate taxa is exclusively represented in layers 4A-KG (unit 4A-AP) and 4A-OR (unit 4A-IP). On the contrary, charcoal fragments of boreal trees, essentially conifers, are more or less well represented in units 4A-POC, 3-SUP and 2B. *Pinus* is also present in units 4A-AP and 4A-IP where pine pollen shows relatively high amounts. The fragments of pine found in unit 4A-CHE are not taken in consideration because this unit consists of reworked sediments filling a large channel.

In layer 4A-KG (unit 4A-AP), the charcoal assemblage is well dominated by *Quercus* (Table 1) which endows it a temperate character. This removes doubt about the local occurrence of oak at that time, a fact suspected in the same layer by the pollen record dominated however by a high percentage of pine (Fig. 6). In this context, we understand 4A-KG as a positive climatic phase that had preceded the climatic improvement of CC4.

Oak is also present with ash and a member of apple tree family in layer 4A-OR (unit 4A-IP) which lies within speleothem CC4. Here we note a disagreement between the charcoal and the pollen assemblages: no temperate taxa are recorded in the pollen spectrum from 4A-OR, largely dominated by steppe herbs and forbs, while in CC4 the pollen spectra include several mesophilous taxa, notably oak and ash. Further analyses are needed to understand this disagreement.

By contrast, the agreement between charcoal and pollen data seems very good in the sedimentary units 4A-POC, 3-SUP and 2B. This is particularly the case for the last two units, with many charcoal fragments of pine and spruce. In unit 3-SUP, pollen of spruce show significant percentages in layer 3-ORA while charcoal of the conifer is preserved in layer 3-ORH.

At the present stage, some conclusion may be drawn.

1) The occurrences of pine charcoal demonstrates that *Pinus* was present locally or at least regionally during the period of time corresponding to layers 4A-KG to 2B-HU/-GB. However the hypothesis of long distant transport by wind cannot be excluded for a part of the pine pollen input.

2) Charcoal of *Picea* was also present in three layers from 3-0RH to 2B-HU/-GB, a fact which attest the occurrence of spruce in Belgium during the last glacial cycle as suggested by the pollen record of the same sequence.

3) The charcoal assemblages in 4A-KG and 4A-OR appear as the result of temperate to boreal climatic conditions most probably in connection with the climatic optimum of the sequence recorded by pollen in speleothem CC4.

4) The charcoal assemblages in the sedimentary units 4A-BO to 2B seem to be the result of boreal climatic conditions in agreement with the pollen record in those layers and, to a lesser extent, with pedostratigraphy that shows a reworked humic palaeosol in unit 2B.

Finally, the coherence between charcoal and pollen data is worth to be pointed out, apart in 4A-OR for which further investigations are needed. The strong relationship of the palaeobotanical data with other disciplines, especially with pedostratigraphy, has also to be stressed (see § 5).

5. Palaeoenvironment synthesis: comparison with previous results (S. Pirson, F. Damblon, M. Court-Picon, D. Bonjean & P. Haesaerts)

The palaeoenvironmental signatures obtained from the new palaeobotanical and geological data are in strong agreement. Palynology appears to be more complete, as most of the sedimentary processes do not carry any climatic signal. However, geology helps in interpreting the palaeobotanical results through the understanding of the sedimentary dynamics and gives access to climatic events for periods without sediment accumulation through post-depositional processes (e.g. frost action or authigenic phosphates). These two approaches therefore appear as highly complementary.

Besides these new results, other palaeoenvironmental data are accessible in the literature. Several disciplines are concerned: macromammals (Gautier in Otte *et al.*, 1983; Cordy, 1984, 1988; Cordy in Bastin *et al.*, 1986; Simonet, 1992), small mammals (Cordy in Bastin *et al.*, 1986; Cordy, 1988, 1992), palynology

(Schneider in Otte *et al*., 1983; Bastin & Schneider, 1984; Bastin *et al.*, 1986; Schneider, 1986a, 1986b; Bastin, 1990, 1992) and magnetic susceptibility (Ellwood *et al*., 2004). The convergent results from all these disciplines are worth mentioning (e.g. Cordy & Bastin, 1992). Unfortunately, detailed comparison between the new geological and palaeobotanical data and the published data is not possible. The major problem is a strong difference in the stratigraphic accuracy. The palaeoenvironmental data available in the literature have been defined in the former stratigraphical frame which appears to be much less accurate than the new one. The lack of precision in the comparison is particularly important for the former layers 6, 4A and 1B. These three layers are now concerned with more than sixty layers grouped in twelve distinct "units" (Fig. 6). Nevertheless, general correlation remains possible. Recent and old data show the same global palaeoenvironmental trends throughout the whole sequence. These major trends are summarized below.

Unit 7B was not sampled during the previous palaeontological studies. The only available reliable palaeoenvironmental data for this part of the sequence comes from palynology which indicates steppe conditions (§ 3).

The brownish sediments of unit 7A could result from the reworking of a palaeosol (Pirson, 2007). This is compatible with the new palynological data: ca. 25% AP dominated by coniferous trees but including small percentage of *Quercus* (§ 3). Ancient data for this part of the sequence is rather heterogeneous and is thus difficult to interpret.

Former layer 6 yields convergent indications from palaeontology, pointing to rather temperate conditions. Palynology indicates 80% AP dominated by *Pinus* and *Corylus*, with locally high values for *Picea* and *Tilia* and small amounts of *Quercus* and *Carpinus* (Bastin, 1992). Small mammal studies show the presence of 40-50% of temperate forest taxa and the important presence of chiroptera (Cordy, 1992). Large mammals show the same trend (75% of forest taxa including *Dama dama*; Simonet, 1992). An important climatic improvement is also recorded in the newly defined units 6B and 6A. Unit 6B yields three stalagmitic floors as well as brownish sediments that could result from the reworking of a palaeosol (Pirson, 2007). Palynology indicates a forest-steppe environment in 6B (50% AP dominated by conifer trees) and a more temperate environment at the bottom of unit 6A (see § 3). The unsound limestone clasts from 6A and 6B exhibiting a black phosphatic cortex (Pirson, 2007) are also indicators of a climatic improvement (see § 2.4) and can be correlated with the abundance of bats in former layer 6 (Cordy, 1992).

Sedimentary structures in unit 5 suggest the influence of solifluction (§ 2.4). A cold environment is further attested by the presence of a thick platy structure developed on top of unit 6A (Pirson, 2007; see § 2.4) as well as by the pollen data (§ 3). The same trend is recorded in former layer 5 with the magnetic susceptibility signal (Ellwood *et al*., 2004). Previous palaeontological results also indicate globally colder environments, with a decrease of the tree cover. In the second half of former layer 5, palynology indicates steppe conditions (<10% AP; Bastin, 1992) similar to the conditions deduced from the new palynological data. Small mammals record the return of arctic taxa (Cordy, 1992). However, small mammals and large herbivores show the persistence of forest taxa (up to 25%) and the bottom of former layer 5 still yields 50% AP including some mesophilous trees (Bastin, 1992; Cordy, 1992; Simonet, 1992).

Unit 4B, dominated by run-off and settling (Pirson, 2007), developed under cold steppe conditions according to the new palynological results (§ 3). The same environment is attested by the ancient palynological and small mammal data (Bastin, 1992; Cordy, 1992).

An important climatic improvement is recorded from units 4A-AP and 4A-IP. Palynology and anthracology both indicate boreal to temperate forest environment (§ 3-4). The presence of a thick stalagmitic floor in 4A-IP ("CC4") is also fully compatible with these conditions (Pirson, 2007). As far as the ancient data is concerned, temperate forest conditions are attested from former palynological studies in layer 4A (60 to 95% AP including high values for mesophilous trees), especially in the stalagmitic floor CC4 (Bastin, 1992). Small mammals also indicate a temperate environment (up to 60% of temperate forest taxa; return of chiroptera; disappearance of arctic taxa; Cordy, 1992). Large mammals from former layer 4A are delicate to use for climatic reconstruction because they were studied together with those from 4B (Simonet, 1992). However, as former layer 4B is very poor in macrofaunal remains, the presence of more than 75% of forest taxa (with 50% of *Dama dama*) amongst the large herbivores from the 4A-4B assemblage (Simonet, 1992) is probably related to the temperate conditions of 4A. Magnetic susceptibility signal suggests the presence of a climatic improvement in both former layers 4B and 4A (Ellwood *et al*., 2004).

Deep frost is recorded between 4A-IP and 4A-CHE (thick platy structure; Pirson, 2007). An important channel (unit 4A-CHE) immediately follows this deep frost episode. It could be a melting channel.

Palynological (§ 3) and anthracological (§ 4) data from unit 4A-POC indicate boreal forest-steppe conditions.

Poorly developed stalagmitic floors and carbonate cementation are recorded in unit 3-INF, together with brownish sediments suggesting the reworking of a palaeosol (Pirson, 2007). However, palynological data does not confirm this climatic improvement (§ 3). New palynological analyses are in progress.

The main part of unit 3-SUP is characterized by an episode of torrential flow and run-off (layer 3-EMO and 3-ASS). It is followed by a debris flow (layer 3-GRK). No climatic signature is recorded in these deposits (Pirson, 2007). New palynological data suggests a steppic environment with some boreal trees (10-30% AP, with *Pinus*, *Juniperus*, *Betula*; § 3). Published palaeontological data from former layer 3 suggests a contrasted environment, with a mixture of taxa from temperate forest and colder milieu (Bastin, 1992; Cordy, 1992; Simonet, 1992). The magnetic susceptibility signal, rather irregular, suggests a global cooling compared to underlying former layer 4A (Ellwood *et al*., 2004). These ancient data are difficult to interpret because we do not know their correspondance with the different layers from the newly defined units 3-INF and 3-SUP.

A marked cooling is then recorded at the interface between 3-GRK and 3-ORH, with the presence of a thick platy structure and small cryoturbations (Pirson, 2007).

On top of unit 3-SUP, conditions are changing. An important climatic improvement, continuing in unit 2B, is recorded by several disciplines. Geological facts are the presence of a possible reworked palaeosol in layer 3-ORA, a stalagmitic floor on top of 3-ORA and a reworked humic palaeosol in unit 2B (Pirson, 2007). Palynology also records a disruption at this level with a sudden rise of *Picea* and *Pinus* (§ 3). The palynological data is further supported by the numerous charcoal fragments from unit 2B and from layer 3-ORH, demonstrating the local character of these coniferous trees (§ 4). Ancient palynological data with a high amount of trees (ca. 70% AP) dominated by *Pinus* and high values of ferns from former layer 2B (Bastin, 1992) also indicate interstadial conditions. Small mammals are poorly represented but the assemblage is compatible with a climatic improvement (dominance of temperate taxa from open field; Cordy, 1992). Large mammals were studied together with former layer 2B (Simonet, 1992) and therefore they cannot be used for palaeoenvironmental reconstruction.

With its light grey color, unit 2A suggests an important new loess input in the system, which is further attested by heavy mineral data, showing a major change in the green hornblende content (Fig. 6; Pirson, 2007). Unit 2A should then correspond to a cold and dry episode in the sequence. This interpretation is confirmed by the new palynological data (§ 3). The ancient palynological data also points to a cooling in former layer 2A (Bastin, 1992). The magnetic susceptibility signal is fully compatible with this interpretation (Ellwood *et al*., 2004). Large mammals were studied together with former layer 2B (Simonet, 1992) and small mammals are poor and polluted (Cordy, 1992; see also Pirson, 2007). Therefore they cannot be used for palaeoenvironmental reconstruction.

Between units 1B-INF and 1B-BRUN, a deep frost episode is attested (highly cryoturbated interface; Pirson, 2007).

This cold episode is followed by unit 1B-BRUN, with a stalagmitic floor and brownish sediments suggesting a reworked palaeosol (Pirson, 2007). This climatic improvement is further attested by palynological data, with relatively high amounts of trees (ca. 50% AP) dominated by boreal taxa (§ 3). The palynological signal from the underlying unit 1B-INF is difficult to interpret in the present state of the research. The hypothesis of a downward intrusion from unit 1B-BRUN is possible because of the frequent openwork structure in layer 1B-OK (Pirson, 2007).

The rest of the sequence up to unit H is characterized by cold steppe environment. This is attested by the new palynological data (§ 3), by all the available ancient palaeontological data (layers 1A, 40 and 39: Bastin, 1992; Cordy, 1992; Simonet, 1992), as well as by geology because deep frost is recorded on top of unit 1A (thick platy structure and cryoturbations: Pirson, 2007). A climatic improvement is recorded in this part of the sequence on the cave terrace, where an *in situ* brown soil-like palaeosol has been described on top of former layer 1B (Haesaerts, 1992); it should correspond to the top of unit 1B-GRI from the new stratigraphic system. It is not documented by other data. Carbonate cementation on top of unit 1A could also suggest the presence of an interstadial (Pirson, 2007), but without any other data, this must stay as a hypothesis.

On top of the Scladina stratigraphic sequence, brownish highly bioturbated sediments from unit H again suggest the presence of reworked palaeosol. This is consistent with the presence of ca. 10 generations of stalagmitic floors at this level of the sequence, as well as with the numerous badger's burrows developing downwards from unit H (Pirson, 2007). Palynological data from Bastin (1992) demonstrate the interglacial signature of these speleothems (CC1).

6. Chronostratigraphy (S. Pirson, F. Damblon & P. Haesaerts)

Several chronostratigraphic interpretations of Scladina sequence are available in the literature (e.g. Bastin, 1992; Cordy, 1992; Cordy & Bastin, 1992; Bonjean, 1998; Ellwood *et al*., 2004). The most important one, on which almost all the others are referring to, is that of Bastin (1992). His scheme rests upon three main arguments.

1) On top of the sedimentary sequence of "Sous-Scladina", a cave situated below Scladina and connected through a hole (Fig. 2), Bastin recorded palynological data he interpreted as a "*true signature of the beginning of Eemian* (...) *to the exclusion of any other interglacial*" (Bastin, 1992, p. 62). Presently we know this is no more valid. The succession of taxa Bastin recorded is indeed typical from the beginning of an interglacial (or an interstadial of an early glacial) but not only from Eemian (e.g. Tzedakis, 1993; Reille *et al*., 1998; Beaulieu *et al*., 2006).

2) According to Bastin, the stratigraphic sequence of Scladina cave and that of the underlying cave ("Sous-Scladina") are in continuity, with the exception of a small hiatus he situated inside the Eemian. Therefore, he interpreted former layer 7A as the end of Eemian. All the subsequent climatic fluctuations are interpreted by reference to this system (Saint Germain I and II in former layers 6 and 4A). We think that the filling of the two caves (Scladina and "Sous-Scladina") are separated by an important hiatus, as suggested by several elements (Haesaerts, 1992; Pirson, 2007).

3) The available dates from the reworked stalagmitic floor observed on top of "Sous-Scladina" sequence (layer VIII) seem to validate Bastin's point of view: with the exception of an aberrant date (>350 ka), 13 dates bracket this speleothem between 177 and 93 ka, with a mean age of 138 ka (Gewelt *et al.*, 1992). As it is reworked, the sediment in which it has been found must be younger. However, the imprecision of this dating method is rather important. In addition, the dated material is a reworked stalagmitic floor whose stratigraphic position remains imprecise: on the drawing of section 7/8 in D (Otte *et al.*, 1983, planche 4 p. 116), this speleothem is against the cave wall and seems to be located between Scladina former layers 7A (VII) et 6 (VI) rather than in "Sous-Scladina" layer VIII. Finally, the dates obtained higher in Scladina sequence (unit 5 and stalagmitic floor CC4) are close to those obtained from this stalagmitic floor (Fig. 6).

As a consequence, the chronostratigraphical framework of Scladina sequence has been reconsidered (Pirson, 2007). It must be stressed here that the chronostratigraphical interpretation of the sequence remains rather imprecise in the present state of research. It is not the place here to develop all the available arguments (see Pirson, 2007). We will focus on three major elements: heavy mineralogy from the silt fraction, climatostratigraphy and dates.

6.1. Heavy mineralogy

Heavy mineralogy from the silt fraction has been studied by several scholars in Scladina (Gullentops & Deblaere, 1992; Balescu in Haesaerts, 1992; Balescu in Pirson, 2007; Pirson, 2007). In the Middle Belgium loess sequence, one of the most useful minerals for chronostratigraphical reconstructions is green hornblende (Gullentops, 1954; Juvigné, 1978; Balescu & Haesaerts, 1984; Meijs, 2002; Pirson, 2007). The comparison between the green hornblende distributions in Scladina (Fig. 6) and in the Belgian loess belt (Meijs, 2002) indicates that former layers 7A to 2B carry the signature of either Weichselian or late Saalian loess (Pirson, 2007). Because of the presence of interglacial (or early glacial) conditions in former layers 6 and 4A (§ 5 & 6.2), a Weichselian age can be discarded and the silt must result from the reworking of late Saalian loess (OIS 6). Boreal to temperate conditions in units 6B-6A and in former layer 6 indicate that the sequence above former layer 6 can be positioned in Upper Pleistocene. Former layer 7A, with rather high green hornblende concentrations, should be positioned either in OIS 6 or in early OIS 5. This data set demonstrates that most of the Scladina stratigraphic sequence belongs to the Upper Pleistocene.

The decrease of green hornblende in former layer 2A suggests, together with other data (§ 5), a new allochthonous loessic input in the sequence. Compared to the Belgian loess sequence, this should correspond to the Weichselian lower pleniglacial.

6.2. Climatostratigraphy

The synthesis of Scladina palaeoenvironmental record has been presented above (§ 5). No chronostratigraphical information can be directly drawn from this data set. Nevertheless, it allows to evidence a succession of climatic events that can not be positionned anywhere in the Pleistocene. Let us recall here that the significance of some of the climatic changes recorded in Scladina still have to be completed by further palaeobotanical analyses, specifically through palynological analyses from speleothems.

Old palaeontological data as well as new palaeobotanical data clearly show the existence of major climatic improvements in former layers 6 and 4A. A wooded temperate to boreal environment is thus attested by data from palynology (mesophilous taxa including *Quercus* and *Ulmus*: Bastin, 1992 ; § 3), large herbivores (important presence of forested taxa, notably *Dama dama*: Simonet, 1992) and small mammals (*Apodemus*, *Clethrionomys*, Chiroptera). These elements suggest the attribution of units 6B and 6A as well as units 4A-AP and 4A-IP to an interstadial of an early glacial or even to an interglacial, especially for stalagmitic floor CC4. Compared to the data from heavy mineralogy of the silt fraction (§ 6.1), this complexity should be attributed either to Eemian or to Weichselian early glacial. However, it is not possible in the present state of the research, to precise the attribution of these two major climatic improvements inside OIS 5.

Besides, the beginning and the end of OIS 5 are difficult to precisely identify in the sequence. It seems that unit 2A can be positioned in the Weichselian lower pleniglacial (§ 6.1) but the presence of *Dama dama* in the former layer 1B (Simonet, 1992) calls for caution. On the other hand, the top of the layer 1B complex should be attributed to Weichselian middle pleniglacial thanks to 1) the dates (§ 6.3) and 2) the presence of an *in situ* brown soil observed on the terrace on top of former layer 1B (Haesaerts, 1992), probably equivalent to Les Vaux soil described in the Middle Belgian loess reference sequence (Pirson, 2007).

6.3. Dates

The Scladina sequence is the most dated Belgian prehistoric site, with more than 60 dates including ca. 40 reliable results. A synthesis of these results is available elsewhere (Bonjean, 1998; Pirson, 2007). Three new radiocarbon dates have been recently obtained from layers 1B-GRH, 1A-GK and T-GV (Pirson, 2007). All the available reliable dates are presented in Fig. 6.

Despite these numerous results, and apart from a few ^{14}C dates, the uncertainty associated with most of these dates remains very important, with 1) standard deviations reaching frequently 20 ka in the lower part of the sequence and 2) strong dispersion of dates for a single event, or sometimes for a single object (e.g. a single stalagmitic floor providing several dates with an important scattering). Another problem is linked with the lack of precise stratigraphic position in comparison with the new stratigraphic system (§ 2.1). All these elements avoid improving the chronostratigraphic framework deduced from the other disciplines.

In Scladina, the chronology of the upper part of the sequence has considerably been improved thanks to the combination of the new stratigraphy and the three new ^{14}C dates obtained between unit 1B-GRI and unit T. Former data are compatible with these new results. On the other hand, for the lower half of the sequence, very few layers gave radiometric data. Most of the numerous available dates are coming from the layer 4A complex, specifically from CC4 stalagmitic floor. These dates are rather inaccurate and therefore can support several distinct hypotheses. For instance, CC4 could either record all OIS 5 or only OIS 5a and/or OIS 5c. The date obtained on burnt flint from unit 5 (130 ± 20 ka) is also compatible with several scenarios when standard deviation is taking into account.

7. Conclusion and perspectives (S. Pirson, F. Damblon, M. Court-Picon, D. Bonjean & P. Haesaerts)

The preliminary interpretation of the new results from Scladina cave sequence indicates a very good concordance between palynology, anthracology and geology. In addition, these new results are also in good agreement with the available data from the literature. The reproducibility of the system and therefore the reality of the recorded climatic fluctuations are thus demonstrated.

However, complementary analyses are necessary to accurately define the precise nature of the climatic events and better understand how the palaeontological material (including pollen grains) is incorporated in the deposits. This should lead to define the limits of the interpretation for all the involved disciplines. A better knowledge of the chronostratigraphical framework is also absolutely necessary to position these climatic fluctuations in the Upper Pleistocene reference sequence. Several analyses are therefore already planned: new palaeontological studies, especially palynology, in order to improve the climatostratigraphical data; sampling for locating the Rocourt Tephra, a very good chronostratigraphical marker in Belgium (e.g. Juvigné *et al*., 2008) which proved to be very useful in cave sequences (Pirson *et al*., 2006); new dates in carefully selected layers; new heavy mineral analyses in order to complete the green hornblende distribution.

A major aspect that stands out from all these results is the importance of a strong interdisciplinary approach in the study of cave entrance sedimentary sequences. Each discipline brings some information but only the confrontation of all the data allows a reliable interpretation. Excellent complementarities of geology and palaeobotany are worth mentioning.

The results from Scladina also highlight the importance of precise and regular stratigraphic records in cave entrance environments, in order to control the numerous lateral changes of lithofacies and geometry, and thus to precisely position in time and space the different samples for palaeoenvironmental reconstruction. The geological approach is also necessary for a good control of the sedimentary dynamics and diagenesis.

With the high complexity of the climatic signal recorded in Scladina, this site appears as an exceptional sequence for Upper Pleistocene in Belgium, together with Walou cave sequence (Pirson *et al*., in press; Draily *et al*., in press). Apart from a few rare loess sequences from Middle Belgium (e.g. Haesaerts, 2004), no other sedimentary record reach such a precision in our region. These results demonstrate that rapid climatic events can be recorded in Belgian cave entrance sequences. However, the lack of precision of the chronostratigraphic framework in Scladina presently appears as a limit for correlating with Upper Pleistocene high resolution sequences.

A direct consequence from these results in a next future is that they should lead to a better understanding of the climatic fluctuations and the palaeoenvironment in Belgium during the last glacial as well as a better knowledge of the context of the numerous archaeological and palaeoanthropological remains from cave entrance sequences.

8. Acknowledgements

The authors wish to thank all persons who have helped in the elaboration of this paper and, more particularly, Michel Toussaint (palaeoanthropologist at the “Direction de l’archéologie du Ministère de la Région wallonne”) for numerous discussions, as well as Grégory Abrams and Kévin Di Modica (archaeologists in “Archéologie Andennaise”), for their help in the field and with the computer graphics. We also would like to express our gratitude to the team of Archéologie Andennaise for their help and their interest (Gérard Bouchat, Marie Rose Bouffioux, Marcel Chardon, Willy Dené, Philippe Frison, Damien Samedi). Thanks to Eric Dermience (RBINS) for help with computer graphics. Last but not least, thanks to Melanie Demoe and Kala Bremner (Vancouver Island University) for their help with improving the English text, and to Cheryl Roy (Vancouver Island University) for her constant support.

9. References

BALESCU, S. & HAESAERTS, P., 1984. The Sangatte raised beach and the age of the opening of the Strait of Dover. *Geologie en Mijnbouw*, 63: 355-362.

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

BASTIN, B., 1990. L'analyse pollinique des concrétions stalagmitiques : méthodologie et résultats en provenance des grottes belges. *Karstologia Mémoire*, 2: 3-10.

BASTIN, B., 1992. Analyse pollinique des sédiments détritiques, des coprolithes et des concrétions stalagmitiques du site préhistorique de la grotte Scladina (province de Namur, Belgique). *In:* Otte, M. (ed.), Recherches aux grottes de Sclayn. Volume 1 : Le contexte. E*tudes et Recherches archéologiques de l'Université de Liège*, 27: 59-77.

BASTIN, B. & SCHNEIDER, A.-M., 1984. Palynologie. *In:* Ek, C. & Pfeffer, K.-H. (eds), Le karst belge. Karstphänomene in Nordrhein-Westfalen. *Kölner Geographische Arbeiten*, 45: 87-93.

BASTIN, B., CORDY, J.-M., GEWELT, M. & OTTE, M., 1986. Fluctuations climatiques enregistées depuis 125.000 ans dans les couches de remplissage de la grotte Scladina (province de Namur, Belgique). *Bulletin de l'Association française pour l'Etude du Quaternaire*, 1986-1/2: 168-177.

BEAULIEU, J.-L. (de), ANDRIEU-PONEL, V., CHEDDADI, R., GUITER, F., RAVAZZI, C., REILLE, M. & ROSSI, S., 2006. Apport des longues séquences lacustres à la connaissance des variations des climats et des paysages pléistocènes. *C. R. Palevol*, 5: 65-72.

BENKOVA, V.E. & SCHWEINGRUBER, F.H., 2004. *Anatomy of Russian Woods. An atlas for the identification of trees, shrubs, dwarf shrubs and woody lianas from Russia*. WSL/FNP. Haupt Verlag, Bern-Stuttgart-Wien, 456 p.

BIGELOW, N.H., BRUBAKER, L.B., EDWARDS, M.E., HARRISON, S.P., PRENTICE, I.C., ANDERSON, P.M., ANDREEV, A.A., BARTLEIN, P.J., CHRISTENSEN, T.R., CRAMER, W., KAPLAN, J.O., LOZHKIN, A.V., MATVEYEVA, N.V., MURRAY, D.F., MCGUIRE, A.D., RAZZHIVIN, V.Y., RITCHIE, J.C., SMITH, B.D., WALKER, D.A., GAJEWSKI, K., WOLF, V., HOLMQVIST, B.H., IGARASHI, Y., KREMENETSKII, K.V., PAUS, A., PISARIC, M.F.J. & VOLKOVA, V.S., 2003. Climate change and Arctic ecosystem: 1. Vegetation changes north of 55°N between the last glacial maximum, mid-Holocene, and present. *Journal of Geophysical Research*, 108: 1-25.

BERTRAN, P. (dir.), 2004. *Dépôts de pente continentaux. Dynamique et faciès*, Paris (Quaternaire, hors-série n°1), 259 p.

BERTRAN, P., FRANCOU, B. & TEXIER, J.-P., 2004. Eboulisation, éboulement. *In:* Bertran, P. (dir.), *Dépôts de pente continentaux. Dynamique et faciès*, Paris (Quaternaire, hors-série n°1): 29-43.

BONJEAN, D., 1995. Dans la foulée de l'Homme de Néandertal : Sclayn 1994. *In:* Plumier, J. & Corbiau, M.-H. (eds), *Troisième journée d'archéologie namuroise*, Namur (Ministère de la Région wallonne, DGATLP, Direction de Namur, Service des fouilles): 45-48.

BONJEAN, D., 1998. Chronologie à la grotte Scladina. *In*: Otte, M., Patou-Mathis, M. & Bonjean, D. (eds), Recherches aux grottes de Sclayn. Volume 2 : L'Archéologie. *Études et Recherches Archéologiques de l'Université de Liège*, 79: 45-57.

BONJEAN, D., LOODTS, I. & LÓPEZ BAYÓN, I., 2002. La doline de Scladina (Sclayn, Andenne, province de Namur). Un second complexe sédimentaire. *Notae Praehistoricae*, 22: 15-19.

CARRION, J. S., MUNUERA, M., NAVARRO, C., BURJACHS, F., DUPRÉ, M. & WALKER, M. J., 1999. The palaeoecological potential of pollen records in caves: the case of Mediterranean Spain. *Quaternary Science Reviews*, 18: 1061-1073.

CASELDINE, C.J., McGARRY, S.F., BAKER, A., HAWKESWORTH, C. & SMART, P.L., 2008. Late Quaternary spleothem pollen in the British Isles. *Journal of Quaternary Sciences*, 23(2): 193-200.

CORDY, J.-M., 1984. Evolution des faunes quaternaires en Belgique. *In*: Cahen, D. & Haesaerts, P. (eds), *Peuples chasseurs de la Belgique préhistorique dans leur cadre naturel*, Bruxelles, Institut royal des Sciences naturelles de Belgique: 67-77.

CORDY, J.-M., 1988. Apport de la paléozoologie à la paléoécologie et à la chronostratigraphie en Europe du nord-occidental. *In*: L'Homme de Néandertal, vol. 2, L'environnement. *Études et Recherches Archéologiques de l'Université de Liège*, 33: 55-64.

CORDY, J.-M., 1992. Bio- et chronostratigraphie des dépôts quaternaires de la grotte Scladina (province de Namur, Belgique) à partir des micromammifères. *In:* Otte, M. (ed.), Recherches aux grottes de Sclayn. Volume 1 : Le contexte. *Etudes et Recherches archéologiques de l'Université de Liège*, 27: 79-125.

CORDY, J.-M. & BASTIN, B., 1992. Synthèse des études paléontologiques réalisées dans les dépôts de la grotte Scladina (Sclayn, province de Namur). *In:* Otte, M. (ed.), Recherches aux grottes de Sclayn. Volume 1 : Le contexte. *Études et Recherches Archéologiques de l'Université de Liège*, 27: 153-156.

CORDY, J.-M., BASTIN, B., EK, C., GEERAERTS, R., OZER, A., QUINIF, Y., THOREZ, J. & ULRIX-CLOSSET, M., 1992. La Belle-Roche (Sprimont, Belgium): the Oldest Archaeological Site in the Benelux. A report on a Field Trip. *In:* Toussaint, M. (ed.), Cinq millions d'années, l'aventure humaine. *Études et Recherches Archéologiques de l'Université de Liège*, 56: 287-301.

DAMBLON, F., 1974. Observations palynologiques dans la grotte de Remouchamps. *Bulletin de la Société royale belge d'Anthropologie et de Préhistoire*, 85: 131-155.

DAMBLON, F., in press. Les analyses anthracologiques du site de Walou. *In*: Draily, C., Toussaint, M. & Pirson, S. (eds), *La grotte Walou : fouilles 1996-2004. Volume 2 : les sciences de la vie et la chronologie*. Namur, Ministère de la Région wallonne, Monograph (Etudes et document – Archéologie).

DAMBLON, F., COURT-PICON, M. & PIRSON, S., in press. L'enregistrement palynologique de la séquence pléistocène et holocène de la grotte Walou (bassin de la Vesdre, Belgique). *In*: Draily, C., Toussaint, M. & Pirson, S. (eds), *La grotte Walou : fouilles 1996-2004. Volume 2 : les sciences de la vie et la chronologie*. Namur, Ministère de la Région wallonne, Monograph (Etudes et document – Archéologie).

DRAILY, C., TOUSSAINT, M. & PIRSON, S. (eds), in press. *La grotte Walou : fouilles 1996-2004. Volume 2 : les sciences de la vie et la chronologie*. Namur, Ministère de la Région wallonne, Monograph (Etudes et document – Archéologie).

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

ELLWOOD, B. B., HARROLD, F. B., BENOIST, S. L., THACKER, P. T., OTTE, M., BONJEAN, D., LONG, G. J., SHAHIN, A. M., HERMANN, R. P. & GRANDJEAN, F., 2004. Magnetic susceptibility applied as an age-depth-climate relative dating technique using sediments from Scladina Cave, a Late Pleistocene cave site in Belgium. *Journal of Archaeological Science*, 31: 283-293.

FAIRON-DEMARET, M., 1984. Paléontologie végétale. Végétaux fossiles récoltés dans les paléokarsts de la Belgique. *In*: Ek, C. & Pfeffer, K.-H. (eds), Le karst belge. Karstphänomene in Nordrhein-Westfalen. *Kölner Geographische Arbeiten*, 45: 107-116.

GAUTIER, A. & DE HEINZELIN, J., 1980. La caverne Marie-Jeanne (Hastière-Lavaux, Belgique). *Mémoires de l'Institut royal des Sciences naturelles de Belgique*, 177: 47 p.

GEWELT, M., SCHWARCZ, H. P. & SZABO, B. J., 1992. Datations ^{230}Th/^{234}U et ^{14}C de concrétions stalagmitiques de la grotte Scladina. *In*: Otte, M. (ed.), Recherches aux grottes de Sclayn. Volume 1 : Le contexte. *Etudes et Recherches archéologiques de l'Université de Liège*, 27: 159-172.

GREGUSS, P., 1955. *Xylotomische Bestimmung der heute lebenden Gymnospermen*. Akademiai Kiado, Budapest, 308 p., 191 pl.

GREGUSS, P., 1959. *Holzanatomie der europäischen Laubhölzer und Sträucher*. Akademiai Kiado, Budapest, 330 p., 303 pl.

GROSSER, D., 1977. *Die Hölzer Mitteleuropas. Ein mikrophotographischer Lehratlas*. Springer, Berlin-Heidelberg, 208 p.

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, p. 125-252.

GULLENTOPS, F. & DEBLAERE, C., 1992. Erosion et remplissage de la grotte Scladina. *In:* Otte, M. (ed.), Recherches aux grottes de Sclayn. Volume 1 : Le contexte. *Etudes et Recherches archéologiques de l'Université de Liège*, 27: 9-31.

HAESAERTS, P., 1992. Les dépôts pléistocènes de la terrasse de la grotte Scladina à Sclayn (province de Namur, Belgique). *In:* Otte, M. (ed.), Recherches aux grottes de Sclayn. Volume 1: Le contexte. *Etudes et Recherches archéologiques de l'Université de Liège*, 27: 33-55.

HAESAERTS, P., 2004. Maisières-Canal (2000-2002) : cadre stratigraphique. *In:* Miller, R., Haesaerts, P. & Otte, M. (eds), L'atelier de taille aurignacien de Maisières-Canal (Belgique). *Etudes et Recherches archéologiques de l'Université de Liège*, 110: 13-26.

HAESAERTS, P., BORZIAK, I., CHIRICA, V., DAMBLON, F., KOULAKOVSKA, L. & VAN DER PLICHT, J., 2003. The East Carpathian Loess Record: a reference for the middle and late pleniglacial stratigraphy in Central Europe. *Quaternaire*, 14: 163-188.

HAESAERTS, P., MESTDAGH, H. & BOSQUET, D., 1999. The sequence of Remicourt (Hesbaye, Belgium): new insights on the pedo- and chronostratigraphy of the Rocourt Soil. *Geologica Belgica*, 2: 5-27.

HATHER, J. G., 2000. *The identification of the Northern European Woods*. London, 187 p.

HEIM, J., 1993a. Résultats palynologiques préliminaires de la grotte Walou à Trooz (Province de Liège, Belgique). *In:* Dewez, M., Collcutt, S. N., Cordy, J.-M., Gilot, E., Groessens-Van Dyck, M.-C., Heim, J., Kozlowski, S., Sachse-Kozlowska, E., Lacroix, D. & Simonet, P. (eds), Recherches à la grotte Walou à Trooz (province de Liège, Belgique). Premier rapport de fouille. *Société Wallonne de Palethnologie*, 7: 33-35.

HEIM, J., 1993b. Analyse palynologique de la coupe transversale du site archéologique du Trou Jadot à Comblain-au-Pont. *In:* Toussaint, M., Becker, A., Burhenne, M., Cordy, J.-M., Gilot, E., Heim, J. & Juvigné, E. (eds), Le Trou Jadot à Comblain-au-Pont (Province de Liège, Belgique). Paléoécologie et archéologie d'un site du Paléolithique supérieur récent. *Etudes et Recherches archéologiques de l'Université de Liège*, 58: 59-66.

JADIN, I., 2003. Trois petits tours et puis s'en vont... La fin de la présence danubienne en Moyenne Belgique. *Etudes et Recherches archéologiques de l'Université de Liège*, 109, 721 p.

JUVIGNE, E., 1978. Les minéraux denses transparents des loess de Belgique. *Zeitschrift für Geomorphologie N. F.*, 22: 68-88.

JUVIGNE, 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.

KARKANAS, P., BAR-YOSEF, O., GOLDBERG, P. & WEINER, S., 2000. Diagenesis in Prehistoric Caves: the Use of Minerals that Form *In Situ* to Assess the Completeness of the Archaeological Record. *Journal of Archaeological Science*, 27: 915-929.

MARTINI, J. & KAVALIERIS, I., 1978. Mineralogy of the Transvaal caves. *Transactions of the Geological Society of South Africa*, 81: 47-54.

McGARRY, S. & CASELDINE, C., 2004. Speleothem Palynology: an undervalued tool in Quaternary studies. *Quaternary Science Reviews*, 23: 2389-2404.

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

NOIREL-SCHUTZ, C., 1994. Palynologie. *In*: Otte, M. (dir.), Le Magdalénien du Trou de Chaleux (Hulsonniaux - Belgique). *Etudes et Recherches archéologiques de l'Université de Liège*, 60: 195-233.

ORLANDO, L., DARLU, P., TOUSSAINT, M., BONJEAN, D., OTTE, M., HÄNNI, C., 2006. The diversity of Neandertals is emphasized by the analysis of a 100.000 year old sequence of Neandertal MT-DNA. *Current Biology*, 16: R400-R402.

OTTE, M. (ed.), 1992. Recherches aux grottes de Sclayn. Volume 1 : Le contexte. *Etudes et Recherches archéologiques de l'Université de Liège*, 27, 178 p.

OTTE, M., LÉOTARD, J.-M., SCHNEIDER, A.-M., GAUTIER, A., GILOT, E. & AITKEN, M., 1983. Fouilles aux grottes de Sclayn (Namur). *Helinium*, 23: 112-142.

OTTE, M., PATOU-MATHIS, M. & BONJEAN, D. (eds), 1998. Recherches aux grottes de Sclayn. Volume 2 : L'Archéologie. *Etudes et Recherches archéologiques de l'Université de Liège*, 79, 437 p.

PIRSON, S., 2007. *Contribution à l'étude des dépôts d'entrée de grotte en Belgique au Pléistocène supérieur. Stratigraphie, sédimentogenèse et paléoenvironnement.* Unpublished Ph.D., University of Liège & Royal Belgian Institute of Natural Sciences, 1 vol. text (435 p.), 1 vol. of 5 annexes.

PIRSON, S., BONJEAN, D., DI MODICA, K. & TOUSSAINT, M., 2005. Révision des couches 4 de la grotte *Scladina* (comm. d'Andenne, prov. de Namur) et implications pour les restes néandertaliens : premier bilan. *Notae Praehistoricae*, 25: 61-69.

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

PIRSON, S., TOUSSAINT, M. & DRAILY, C (eds), in press. *La grotte Walou : fouilles 1996-2004. Volume 1 : les sciences de la terre.* Namur, Ministère de la Région wallonne, Monograph (Etudes et document – Archéologie).

QUINIF, Y., GENTY, D. & MAIRE, R., 1994. Les spéléothèmes : un outil performant pour les études paléoclimatiques. *Bulletin de la Société géologique de France*, 165: 603-612.

REILLE, M., ANDRIEU, V., BEAULIEU, J.-L. (de), GUENET, P. & GOEURY, C., 1998. A long pollen record from Lac du Bouchet, Massif Central, France: for the period ca. 325 to 100 ka BP (OIS 9c to OIS 5e). *Quaternary Science Reviews*, 17: 1107-1123.

SANCHEZ GONI, M. F., 1994a. L'environnement de l'homme préhistorique dans la région cantabrique d'après la taphonomie pollinique des grottes. *L'Anthropologie*, 2-3: 379-417.

SANCHEZ-GONI, M.-F., 1994b. Végétation et climat sur le pourtour de la Méditerranée au cours du Pléistocène supérieur. *In: XXIV^e^ Congrès préhistorique de France*, Carcassone: 237-250.

SCHNEIDER, A.-M., 1986a. Résultats palynologiques à la grotte de Sclayn (Belgique). Contribution à l'étude du dernier interglaciaire. *Revue d'Archéométrie*, 10: 39-42.

SCHNEIDER, A.-M., 1986b. Contribution à l'étude du dernier interglaciaire : résultats palynologiques à la grotte de Sclayn (Belgique). *Revue de Paléobiologie*, 5(1): 57-70.

SCHOCH, W., 1994. Anthracologie. *In*: Otte, M. (ed.), Le Magdalénien du Trou de Chaleux (Hulsonniaux - Belgique). *Etudes et Recherches archéologiques de l'Université de Liège*, 60: 194-195.

SCHWEINGRUBER, F.H., 1990. *Anatomie europäischer Hölzer.* W.S.L./F.N.P., Stuttgart: Haupt, 800 p.

SCHWEINGRUBER, F.H., 2001. *Dendroökologische Holzanatomie. Anatomische Grundlagen der Dendrochronologie*. Bern-Stuttgart-Wien, Paul Haupt, 472 p.

SIMONET, P., 1992. Les associations de grands mammifères du gisement de la grotte Scladina à Sclayn (Namur, Belgique). *In*: Otte, M. (ed.), Recherches aux grottes de Sclayn. Volume 1 : Le contexte. *Etudes et Recherches archéologiques de l'Université de Liège*, 27: 127-151.

SMITH, T. M., TOUSSAINT, M., REID, D. J., OLEJNICZAK, A. J. & HUBLIN, J.-J., 2007. Rapid dental development in a Middle Paleolithic Belgian Neanderthal. *Proceedings of the National Academy of Sciences of USA*, 104 (51): 20220-20225.

STOCKMANS, F., 1960. *Guide de la salle des végétaux fossiles à l'IRSNB. Initiation à la Paléobotanique stratigraphique*. Bruxelles (Les naturalistes belges 41-3): 128-130.

TARASOV, P. E., CHEDDADI, R., GUIOT, J., BOTTEMA, S., PEYRON, O., BELMONTE, J., RUIZ-SANCHEZ, V., SAAD, F. & BREWER, S., 1998. A method to determine warm and cool steppe biomes from pollen data; application to the Mediterranean and Kazakhstan regions. *Journal of Quaternary Science*, 13(4): 335-344.

TARASOV, P.E., VOLKOVA, V.S., WEBB III, T., GUIOT, J., ANDREEV, A.A., BEZUSKO, L.G., BEZUSKO, T.V., BYKOVA, G.V., DOROFEYUK, N.I., KVAVADZE, E.V., OSIPOVA, I.M., PANOVA, N.K. & SEVASTYANOV, D.V., 2000. Last glacial maximum biomes reconstructed from pollen and plant macrofossil data from northern Eurasia. *Journal of Biogeography*, 27: 609-620.

TEHEUX, E. & OTTE, M., 1989. Foyers magdaléniens à Chaleux (Belgique). *In*: Olive, M. & Taborin, Y. (eds), *Nature et Fonction des Foyers préhistoriques*. Actes du Colloque de Nemours 1987 (Mémoires du Musée de Préhistoire d'Ile de France, 2): 189-196.

TOUSSAINT, M., BONÉ, E., GILOT, E., HEIM, J., LAWARRÉE, G., SABLON, R. & VAN GOETHEM, J. L., 1986. Paléoenvironnement du Paléolithique supérieur ancien de la caverne de la Traweye Rotche à Sprimont (province de Liège, Belgique). *Bulletin de la Société royale belge d'Anthropologie et de Préhistoire*, 97: 99-132.

TOUSSAINT, M., BONJEAN, D. & OTTE, M., 1994. Découverte de fossiles humains du Paléolithique moyen à la grotte Scladina à Andenne. *In:* Corbiau, M.-H. & Plumier, J. (eds), *Actes de la deuxième journée d'archéologie namuroise. Facultés universitaires Notre-Dame de la Paix, Namur, 26 février 1994,* Namur, Ministère de la Région wallonne (DGATLP) - FUNDP (Département d'Histoire de l'Art et d'Archéologie): 19-33.

TOUSSAINT, M., OTTE, M., BONJEAN, D., BOCHERENS, H., FALGUÈRES, C. & YOKOYAMA, Y., 1998. Les restes humains néandertaliens immatures de la couche 4A de la grotte Scladina (Andenne, Belgique). *Comptes rendus de l'Académie des Sciences de Paris*, 326: 737-742.

TOUSSAINT, M. & PIRSON, S., 2006. Neandertal Studies in Belgium: 2000-2005. *Periodicum Biologorum*, 108: 373-387.

TOUSSAINT, M. & PIRSON, S., 2007. Aperçu historique des recherches concernant l'homme préhistorique dans le karst belge aux XIXe et XXe siècles : archéologie, géologie, paléoanthropologie, paléontologie, datations. *In:* Evin, J. (ed.), *Un siècle de construction du discours scientifique en préhistoire. Actes du XXVIe*

Congrès préhistorique de France. Avignon, 21-25 septembre 2004. Volume 3, Paris, Société préhistorique française: 117-142.
TZEDAKIS, P. C., 1993. Long-term tree populations in northwest Greece through multiple Quaternary climatic cycles. *Nature*, 364: 437-440.
VAN VLIET-LANOË, B., 1985. Frost Effects in Soils. *In:* Boardman, J. (ed.), *Soils and Quaternary Landscape Evolution*. London, John Wiley & Sons: 117-158.
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*. Paris (Thèse de doctorat d'état inédite, mention géographie. Université de Paris I - Sorbonne, Centre de Géomorphologie du C.N.R.S.), 2 vol. (378 & 667 p).

Memoirs of the Geological Survey of Belgium

The series, which started in 1955, welcomes papers dealing with all aspects of the earth sciences, with a particular emphasis on the regional geology of Belgium and adjacent areas. Submitted papers should present the results of syntheses of original studies (e.g. theses). High scientific level is requested. Papers written in English are preferred. Each paper will be reviewed by at least by two reviewers.

Editor Geological Survey of Belgium
Jenner str. 13
B-1000 Brussels
Belgium

Guide for authors: see website Geologica Belgica
http://www.ulg.ac.be/geolsed/GB

List of publications and conditions of sale: see website Geological Survey of Belgium
http://www.naturalsciences.be/institute/structure/geology/gsb_website/products/pp
or website Royal Belgian Institute of Natural Sciences
http://www.natuurwetenschappen.be/common/pdf/science/publications/Cata/index.html

ISSN 0378-0902

Dépôt légal: xxxxxxxx
Wettelijk depot : xxxxxx

Impression: Service public fédéral Economie, P.M.E., Classes moyennes et Energie
Drukwerk: Federale Overheidsdienst Economie, K.M.O., Middenstand en Energie