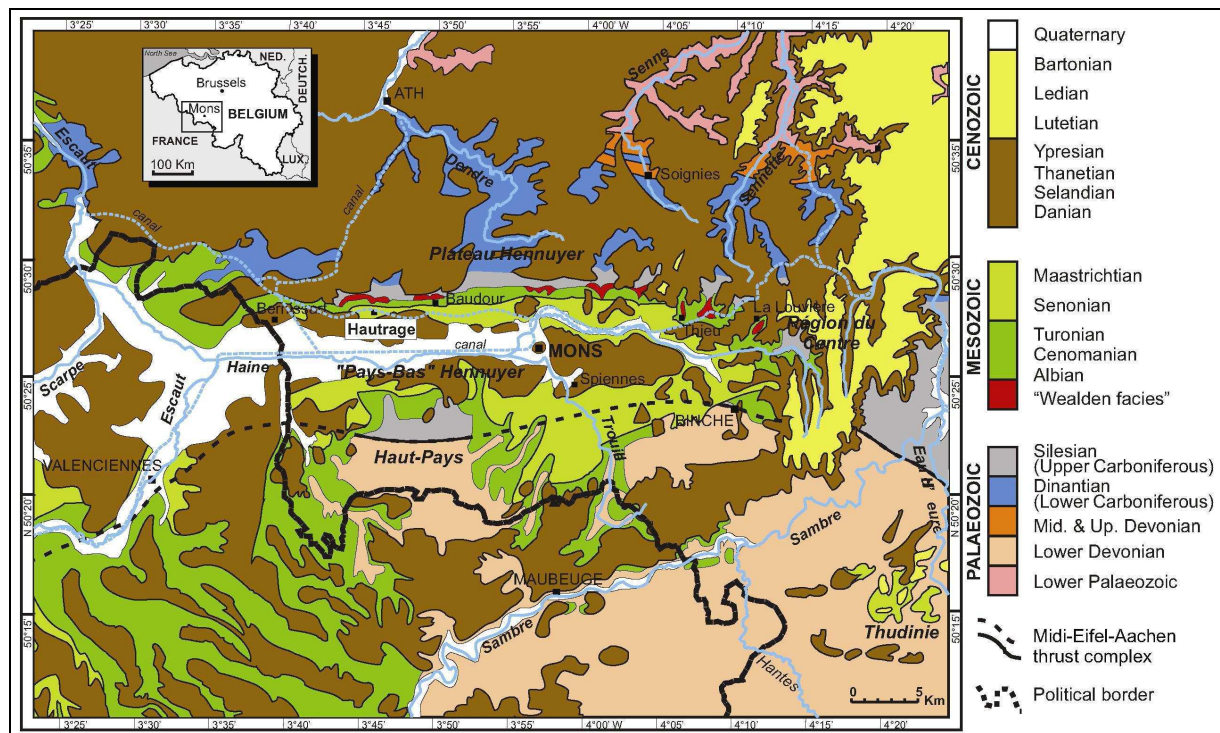


## INTRODUCTION. Lithostratigraphy of the Mons Basin.

The La Malogne underground quarries, Hautrage quarry and Bernissart belong to the Mons Basin (MB). The MB is located in the western part of Belgium, in the Hainaut Province. It is connected with 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, and filled with Cretaceous-Cenozoic sediments. The MB is limited by the maximal extension of the Turonian deposits.



**Figure 1.** Schematic geological map of the Mons Basin.

The deposition of the sediments in the MB is the result of relative sea-level fluctuations (Pirson et al., 2008) and original subsidence (Vandycke et al., 1991).

The oldest sediments of the MB are the Wealden facies (see **stop 2** and **stop 3**).

In the MB, the Wealden facies are locally covered by glauconiferous calcirudites, sandstones and conglomerates of the Albian-Cenomanian Haine Group. They correspond to neritic sedimentation and can reach 180 meters of thickness in local depressions, or large “cuves”, where the subsidence rate is higher than in adjacent areas. Marls mainly dominate in the overlying Turonian sediments (“dièves”), showing frequent lateral variation of thickness. Upper Turonian deposits consist of 5 to 40m of siliceous marls (“Chailles de Ville-Pommeroeul”) overlain by cherty limestone (“Silex d’Hautrage”). 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. Chalks are widespread in the MB during the Coniacian, Santonian, Campanian and Maastrichtian stages. The chalks are locally covered by the phosphatic “Craie de Ciply” (chalk of Ciply) and by the “Tuffeau de Saint-Symphorien” (see **stop 1**). During Late Maastrichtian, the MB experienced a (eustatic?) sealevel fall with condensed beds (hardgrounds) and hiatuses. The Cretaceous-Palaeogene boundary itself lies within a long hiatus in the MB.

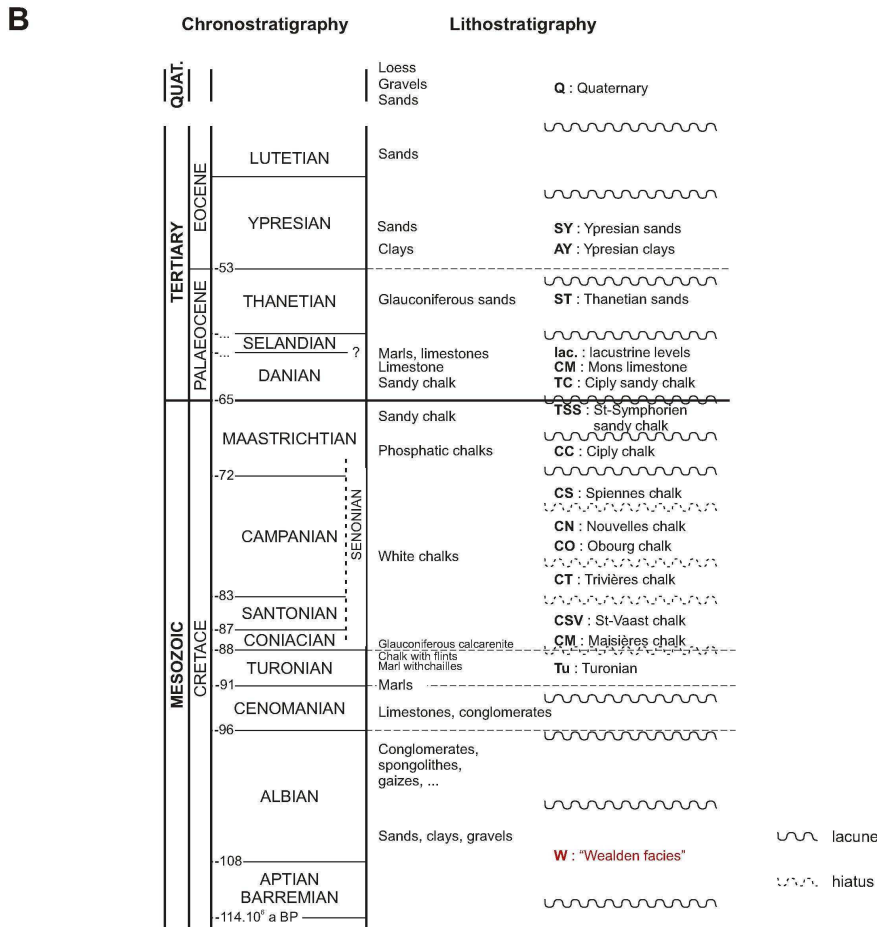
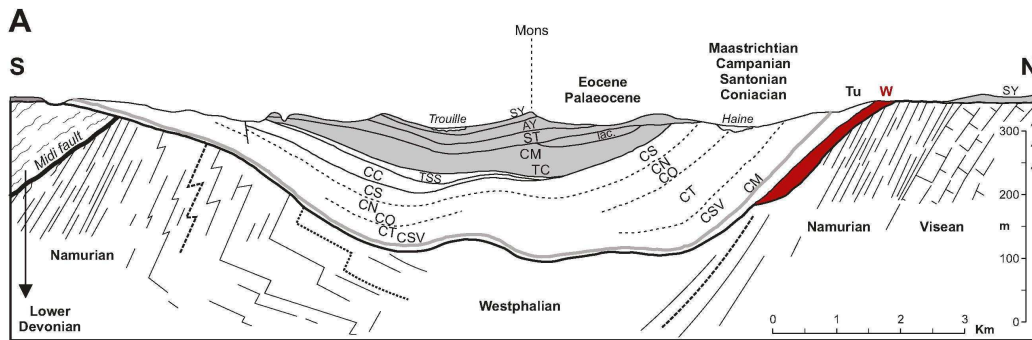


Figure 2. A. North-South section in the MB; vertical amplitude = x10. B. Simplified lithostratigraphy of the MB.

The Cenozoic sedimentation starts with the “Dano-Montian” and “Montian”. 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 during Paleocene. 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 occurrence of fluvial deposits, locally containing **terrestrial fauna** (like in Erquelinnes) and **terrestrial plant remains**. Continental conditions are further attested by a large meteoric weathering of the latest Thanetian marine sands and the fluvial sands, resulting in widespread quartzitic concretions. The early Eocene is characterized by Ypresian sandy clays. Coarse Lutetian sand is located only in the eastern part of the MB.

## STOP 1. La Malogne underground quarries

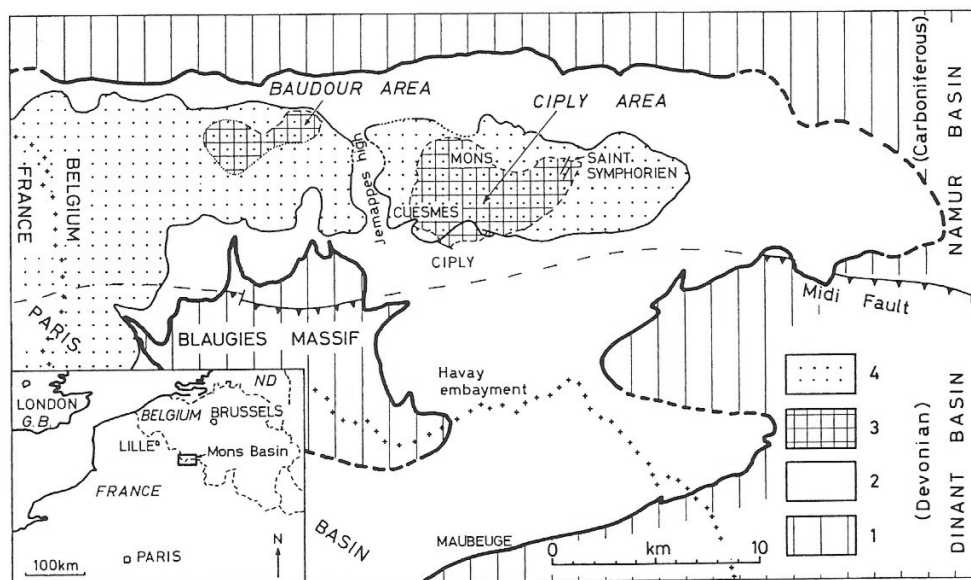
### What to be seen?

Phosphatic beds, hainosaures, sedimentological and tectonic context of deposit of fossils.

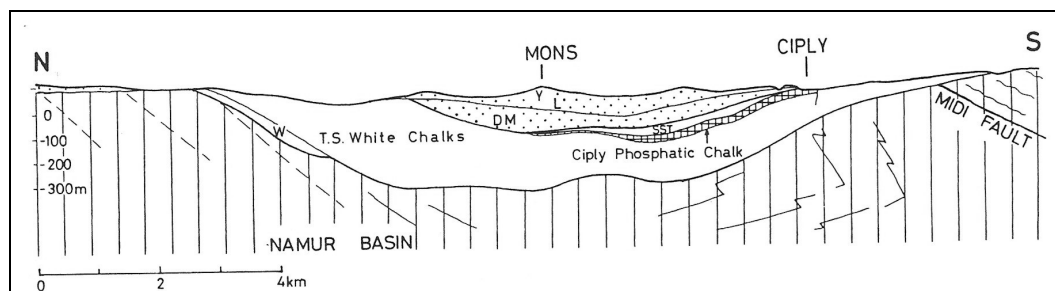
### History

From the end of the 19th century until World War II, the Ciplly-Malogne Phosphatic Chalk of the Mons area was a significant source of phosphate for Belgium. The first to be used were the “phosphatic sands”, resulting from natural atmospheric water leaching of phosphatic chalk, that reached 30-35 %  $P_2O_5$ . Then, phosphatic chalk with 8-10 %  $P_2O_5$  was extracted intensively in underground galleries and later in open quarries (Jarvis, 1992). From the whole phosphatic basin, more than 3 million tons were mined between 1880 and 1945. Mining was interrupted due to the economic competition from North African and US phosphate products (Robaszynski & Martin, 1988).

### Location



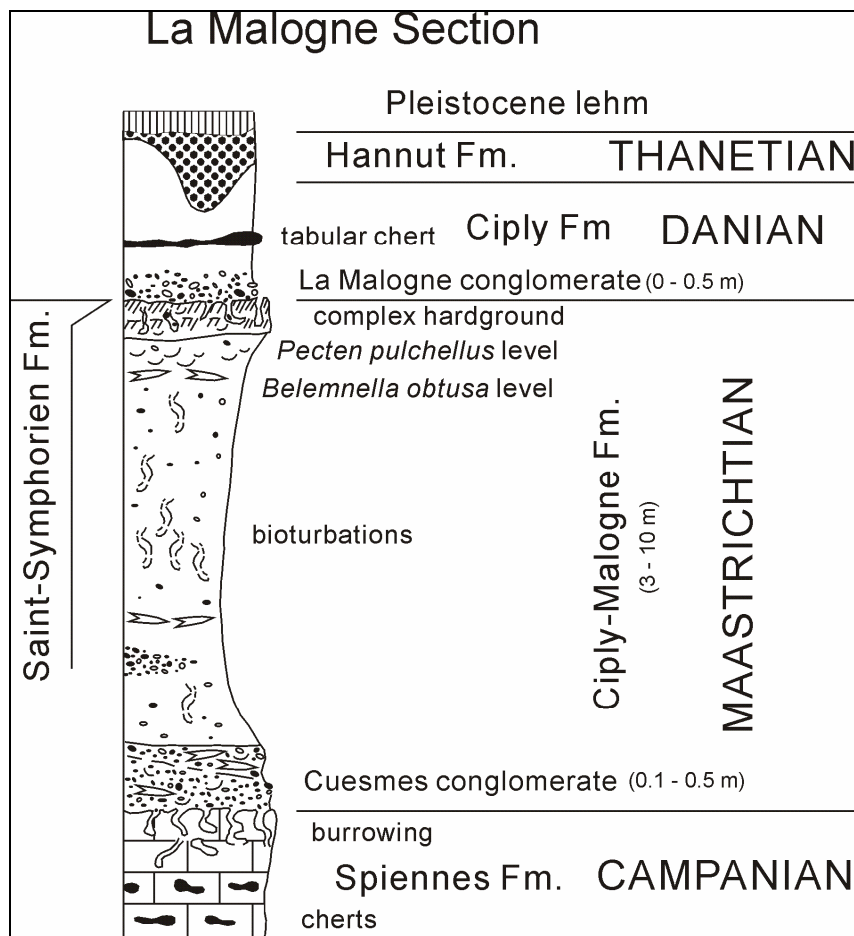
**Figure 3.** Geological sketch-map of the Mons Basin and location of the Ciplly and Baudour phosphatic chalk areas. 1. Palaeozoic basement; 2. Cretaceous marls and white chalks; 3. Maastrichtian Ciplly-Malogne Phosphatic Chalk; 4. Tertiary calcarenites, sands and clays. Note: The largest part of the phosphatic strata in the Ciplly and Baudour areas is overlain by Tertiary sediments. The extension of subsurface phosphate is shown under these Tertiary sediments (from Robaszynski & Martin, 1988).



**Figure 4.** North-South geological section of the Mons Basin with the general setting of the phosphatic layer (same patterns as in Fig. 3). W Wealden facies; TS Turonian-Senonian white chalks; SST Saint Symphorien Fm.; DM Danian and Montian; L Landenian=Thanetian; Y Ypresian (from Robaszynski & Martin, 1988).

## Lithostratigraphy

Stratigraphic succession in the La Malogne quarry (Robaszynski et al., 2001):



**Figure 5.** Lithostratigraphy of the La Malogne quarry.

### **Spiennes Formation**

**Description:** A white to whitish-grey, rather coarse-grained chalk, which becomes calcarenitic towards the top. It contains many large black to grey-brown cherts and some chert bands, 10 to 60 cm thick (used by Neolithic man for tool making).

**Thickness:** 20 to 25 m on the margin of the Mons Basin (e.g. at Harmignies) to 50 m in the centre of this basin in its most subsided zones.

**Age:** Upper Campanian.

**Fossils:** At the base there occasionally is a thin layer of phosphatised chalk pebbles and inoceramid, echinoid and ostreid fragments and sponges. Cephalopods: *Belemnitella minor* I Jeletzky, *Belemnitella minor* II Christensen.

Echinoids: *Cardiaster granulatus*, *Echynocorys belgica*.

Benthic foraminifers: *Bolivinoidea australis*, *Globorotalites hiltermanni*, *Gavelinella voltziana involutiformis*, *Eponides beisseli*.

## Ciply-Malogne Formation

**Description:** Cohesive or crumbly calcarenite, invariably intensely bioturbated, consisting of phosphate granules within a chalky matrix. The granules are brown at the surface, but grey inside. The average content in P<sub>2</sub>O<sub>5</sub> is around 8%. Bands with rounded black or brown flints with phosphate grains are sometimes intercalated between the calcarenites. At the margins of the phosphatic basin, the base of this formation is marked by a conglomeratic level (« Poudingue de Cuesmes » = Cuesmes Conglomerate) with chalk gravel, sponges, fragments of baculitid ammonites, all of them phosphatised whereas in the central part of the basin there is a continuous transition between this unit and the underlying Spiennes Chalk Formation.

The top of the formation is almost always marked by a hardground, often complex in structure, 0.4 to 1.4 m thick. This hardground was the “roof” of the underground quarries of the La Malogne Plateau where the phosphate chalk was worked at the end of the 19<sup>th</sup> century.

**Thickness:** One to a few metres on the margins of the Ciply and Baudour basins, up to 76 m in the centre of the Ciply Basin. In the underground quarries of the Malogne the Ciply-Malogne Formation had a thickness of 3 to 12 m.

**Age:** Early Maastrichtian.

**Fossils:** Fossils are extremely common. Cephalopods: *Belemnella obtusa*, *Belemnitella pulchra*, *Belemnitella minor* II, *Pachydiscus* cf. *neubergicus*, *Hoploscaphites constrictus*, *Baculites knorrianus*, *Baculites baculus*, etc. (Christensen, 1989).

Brachiopods: *Trigonosemus palissy*.

Foraminifers: *Neoflabellina praereticulata*, *Gavelinella bembix*, *Osangularia navarroana*.

Marine reptiles: The Ciply-Malogne Phosphatic Chalk furnished numerous **mosasaurid marine-reptile remains**. During the only period going from 1880 to 1895, **52 almost complete skeletons** have excavated and prepared (Jagt, 2005). Dollo provides a huge literature of these specimens (Dollo, 1882a, 1885a, 1885b, 1889a, 1889b, 1889c, 1892, 1904, 1924). The fossils came mainly from the open quarries. Following Lingham-Soliar & Nolf (1990), the association is almost monospecific: *Mosasaurus lemonnieri*. Other taxa correspond to: *Plioplatecarpus houzeau*, *Hainosaurus bernardi*, *Halisaurus ortliebi*, *Prognathodon solvayi*, *Bottosaurus belgicus*. Other vertebrates have also been found: turtles, shark teeth, ...

## Saint-Symphorien Formation

**Description:** Crumbly, porous, poorly cemented, grey when fresh, yellow to brownish at the altered surface, often bioturbated, calcarenites or calcirudites. Locally the calcarenites may contain grey, green or brown phosphatised granules and pebbles. Flint bands may be intercalated within the calcarenite (or “tuffeau”). The base of this formation is often clearly distinguished by the presence of an indurated and phosphatised chalk pebble conglomerate; the top is generally a hardground of 10 to 40 cm thick, but locally reaches a thickness of 140 cm, burrowed, with bivalve and gastropod internal moulds and pyrite crystals.

**Thickness:** From one to a few metres, sometimes absent between the underlying Ciply-Malogne phosphatic Chalk Formation and the overlying Ciply Calcarenite (of Cenozoic age). Reaches about 10 m in boreholes near Ciply.

**Age:** Upper Maastrichtian on the basis of belemnites. The presence of numerous *Thecidea papillata* and *Trigonosemus pectiniformis* are good regional markers.

**Fossils:** Numerous, either complete, or in fragments or forming bioclastic base of the rock: scaphopods, echinoid spines, oysters and other bivalves, belemnite guards, brachiopods.

## Ciply Formation

**Description:** The Ciply Formation contains a yellowish white calcarenite, which is porous and commonly loosely indurated, with some nodular black chert levels. The  $\text{CaCO}_3$  content is high, reaching sometimes more than 99 %. Benthic foraminifera are abundant, bryozoans and shark teeth are also present.

The base of the formation corresponds to a nonsequence and is marked by a conglomerate, from some cm to 30-40 cm thick (« Poudingue de la Malogne » = Malogne conglomerate). This level is composed of elements reworked from the underlying strata (Ciply-Malogne and Saint-Symphorien Formations). That is more or less rounded phosphatised pebbles, brown, from several mm to several cm in diameter, and phosphatised reworked fossil fragments.

**Thickness:** Some metres in La Malogne quarries, about 20 m in the Ciply quarries and more than 30 m in borehole.

**Age:** Paleocene, Middle to Upper Danian.

**Fossils:** often internal molds. Campanian and Maastrichtian ammonites were found (Kennedy, 1993; Jagt, 2005): *Nostoceras cf. hyatti* and *Hauericeras cf. sulcatum*.

## Hannut Formation

The formation contains two members.

### Chercq Member

**Description:** Moderately indurated greenish grey sandstone, with medium coarse quartz grains, abundant coarse glauconite grains, often moderately argillaceous.

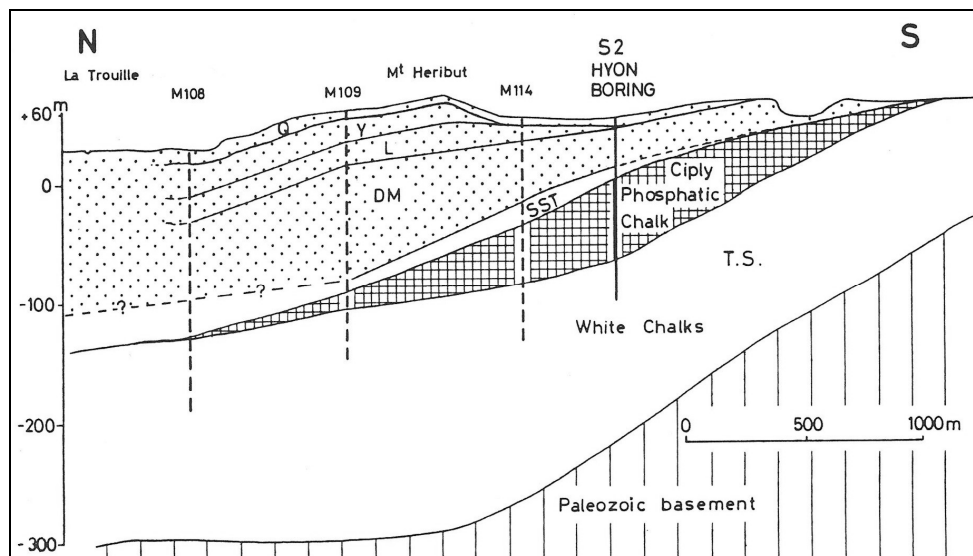
**Thickness:** 10 to 15 m. **Age:** Thanetian.

**Fossils:** Sometimes fossiliferous (bivalves, gastropods, nautiloid cephalopods).

### Grandglise Member

**Description:** Fine grained quartz sand, well calibrated, sometimes moderately argillaceous, very often glauconitic and green grey, or yellow when altered.

**Thickness:** 5 to 18 metres. **Age:** Thanetian.

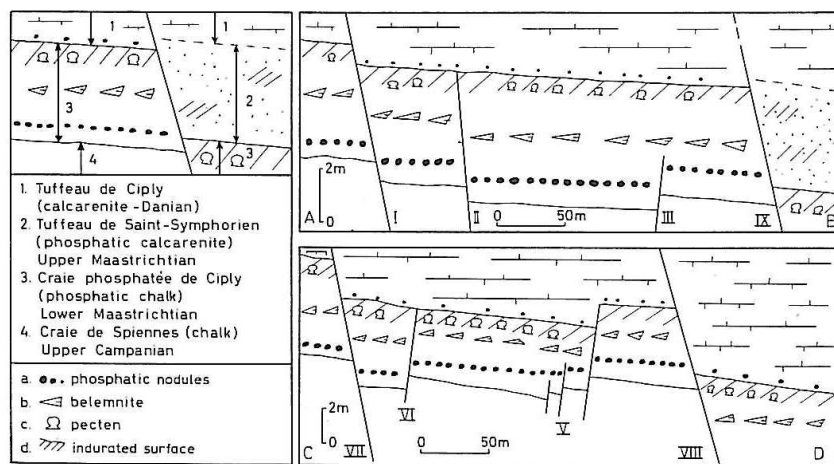


**Figure 6.** Details of the southern part of the section presented in Fig. 4 showing the lenticular feature of the phosphatic layer (from Robaszynski & Martin, 1988).

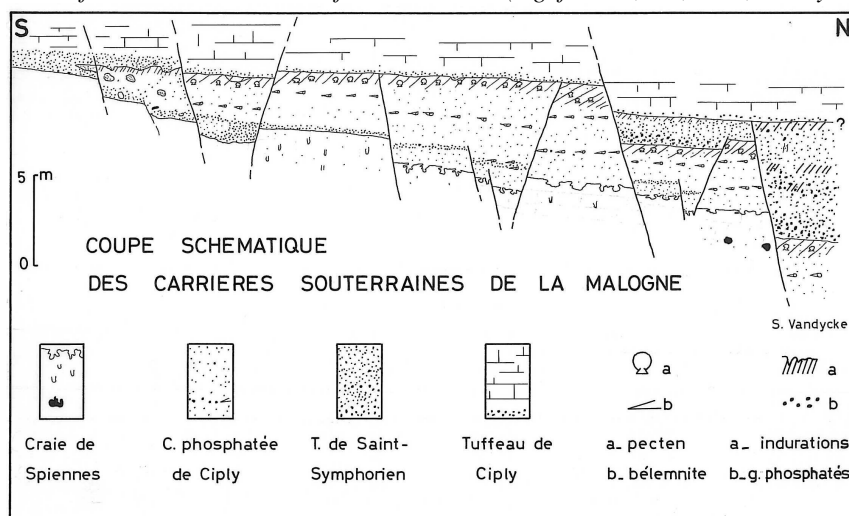


## Tectonic setting

The sedimentation of Maastrichtian phosphatic calcarenite results from an evolution which synsedimentary extensional tectonics have taken place since at least the Campanian and lasted until the Maastrichtian. This area is characterised by horst and graben structures trending N120°-N130° and N160°-170°. Approximately 30 large normal faults or fault zones have been system identified. At the base of the Ciply-Malogne Formation some strike-slip indicators are also observed. The phosphatic deposits are as well limited to the South by a major strike-slip fault. Some parts of major faults are also active during the Cenozoic. Levels of fossils, in particular belemnites and pectens, have been used to precise displacements along the faults. Belemnites are also used to quantify and define the process of faulting during the Maastrichtian (Angelier et al., 2006). The tectonic events in the Malogne quarries are related to the activity of a major tectonic zone called the North Artois Shear Zone. It is correlated to an inversion phase deciphered in the North part of Europe. The faulting in the Malogne quarries is related to the stress transmission in the European platform between the Alpine collisional events and the opening of the Atlantic (Vandycke, 2002).



**Figure 7:** Stratigraphic and tectonic cross-sections in the “La Malogne” underground quarry. The present appearance of the faults results from several Maastrichtian and Tertiary motions. Strike-slip and normal synsedimentary systems were active during Early Maastrichtian (e.g. faults III, V). Another system appears between the early Maastrichtian and the Danian in which some of the previous faults are reactivated (e.g. faults II, V, VI). Some of them are reactivated after the Danian (e.g. faults I, VII, VIII ; Vandycke et al., 1991).



**Figure 8.** Example of South-North cross sections in the Malogne underground quarries. The levels of fossils, in particular belemnites and petens are used to determine precise displacement of each faults.

## STOP 2. Hautrage (Danube-Bouchon) quarry

### What to be seen?

Fragments of wood, alluvial plain, quite coeval to the iguanodonts of Bernissart.

### Quarry

The Danube-Bouchon quarry cuts clayey and sandy sediments rich in organic matter (root traces, lignite, fragments of wood, ...), sideritic nodules and pyrites. The sediments are clearly stratified and east-west oriented, global dipping south with 15 to 25° dip. Clays are exploited by companies Lebailly and CBR-Heidelbergcement for its high alumina and silica contents. These latter are raw materials for the fabrication of white cement and refractory bricks.

### Wealden facies

In the Mons Basin, the Wealden facies are 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 (Hautrage Clays Formation, Baudour Formation and Saint-Pierre Formation),
- infilling of several natural pits (also called “Cran”) developed into the basement (for example at Bernissart),
- as white sands and sandstones containing lignite and glauconitic material in the eastern part of the MB (=“Strep Formation” or “Cénomaniens à faciès Wealdien” *sensu* Gulinck, 1974).

### Fossils content

In Hautrage, mesofossil plant remains include various fertile and sterile parts of ferns (*Weichselia reticulata* (Stokes et Webb) Fontaine, *Phlebopteris dunkeri* Schenk, *Gleichenites nordenskiöldii* (Heer) Seward), Cheirolepidiaceae (*Alvinia* Kvaček, *Frenelopsis* (Schenk) Watson), Miroviaceae (*Arctopitys* Bose et Manum), Taxodiaceae (*Sphenolepis* Schenk), other conifers (*Brachyphyllum* Brongniart and *Pagiophyllum* Heer), and Ginkgoales (*Pseudotorellia* Florin). Although the plant assemblages vary from one bed to another, the taxa remain globally unchanged along the whole 235-m-thick succession, suggesting repeated vegetation changes that may be related to lateral divagations of stream channels in a continental freshwater floodplain. Integration of taphonomic and sedimentological data suggest that fires may have played a role in the production, transport and preservation of the mesofossil plant remains that may mostly represent the local vegetation (Gomez et al., 2008).

### Age

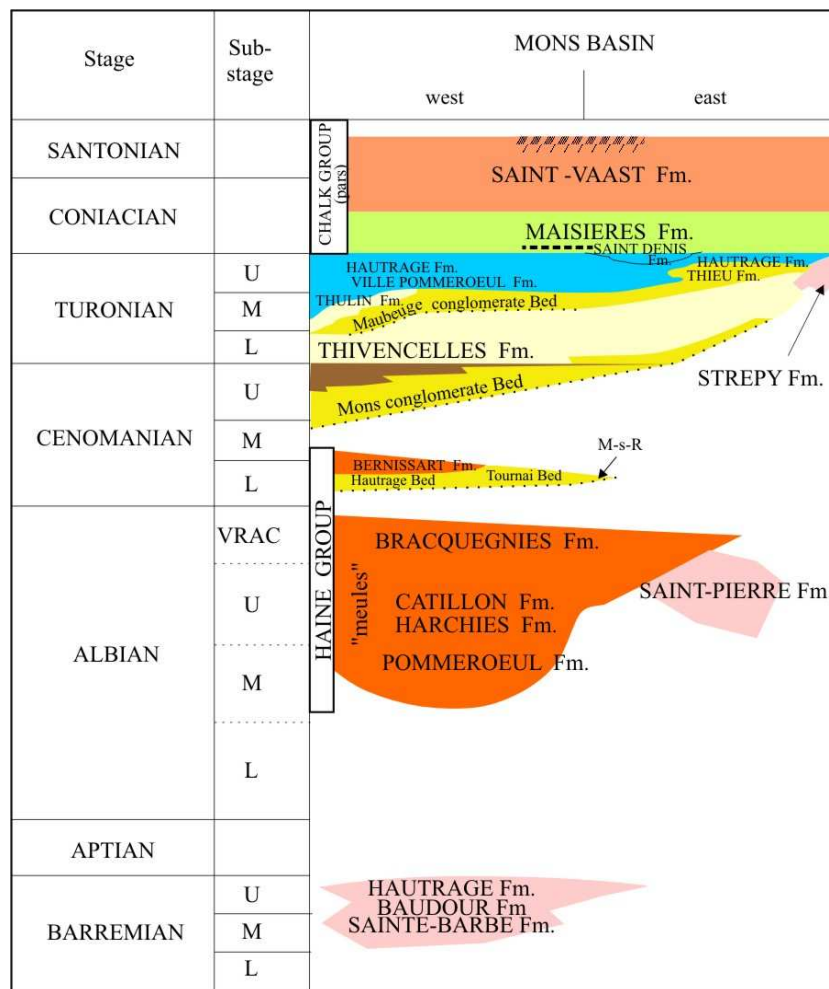
In the last decade recent works on new boreholes and new sections have used both palynology (especially pollen of angiospermous affinity) and chemostratigraphy (carbon isotopes on dispersed organic matter and fossil wood) to refine the age of the Wealden facies (Yans et al., 2010; Dejax et al., 2008; Schnyder et al., 2009).

The age of Wealden facies from **Bernissart** is discussed below (STOP 3).

In **Hautrage**, the Wealden facies are **late Early Barremian – early Late Barremian** in age (see attached papers below).

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 “Cénomaniens à faciès wealdien” or “Strépy Formation” is Turonian in age (Yans, 2007). The Wealden facies may have supplied the filling of regional endokarsts during Late Cretaceous to Early Cenozoic (Quinif et al., 2006).





**Figure 9:** Detailed lithostratigraphy of Wealden facies in the Mons Basin.

**Following papers in relation with Hautrage quarry:**

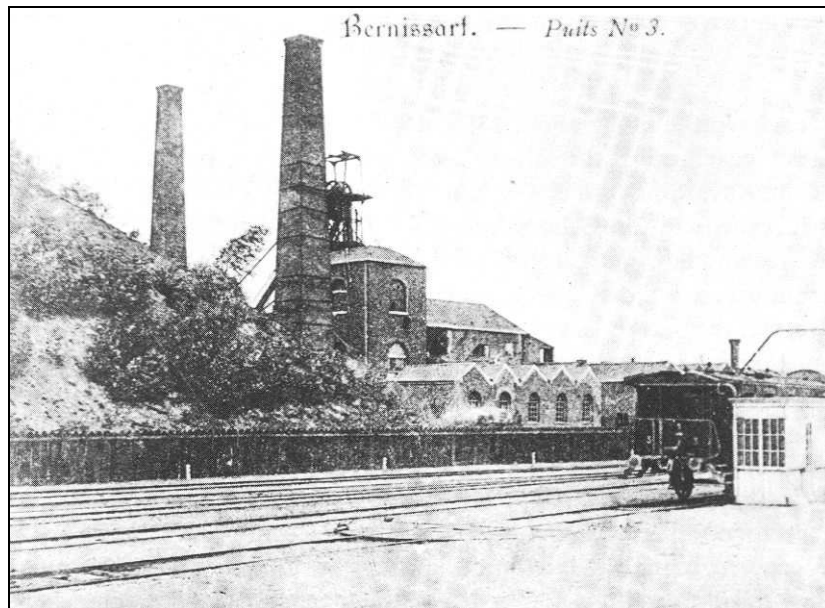
Yans J., Gerards T., Gerrienne P., Spagna P., Dejax J., Schnyder J., Storme J.-Y., Keppens E. 2010. Carbon-isotope of fossil wood and dispersed organic matter from the terrestrial Wealden facies of Hautrage (Mons basin, Belgium). *Palaeogeography, Palaeoclimatology, Palaeoecology* 291, 85-105.

Gomez B., Gillot T., Daviero-Gomez V., Spagna P. & Yans J. 2008. Paleoflora from the Wealden facies strata of Belgium: Mega- and meso-fossils of Hautrage (Mons Basin). *Memoirs of the Geological Survey of Belgium* 55, 53-60.

### STOP 3. Bernissart Museum (+ lunch)

#### Bernissart site

Bernissart is a former coal-mining village in southwestern Belgium, situated 21 km south of Mons and less than 1km from the Franco-Belgian frontier. Pre-industrial coal extraction began at Bernissart around 1717 (Delguste, 2003). In the 19<sup>th</sup> century, the Bernissart Coal Board limited Company dug five coal pits on the Bernissart territory. The Négresse (nr 1, exploited from 1841) and Sainte-Barbe (nr3, exploited from 1849) pits were used for coal extraction and coupled with the Moulin (nr 2, exploited from 1842) pit for ventilation. The Sainte-Catherine (nr 4, exploited from 1864) pit was the third extraction pit and was coupled with pit nr5 - exploited from (?) 1874 - for ventilation.



**Figure 10.** The Sainte-Barbe pit and mine buildings in 1878, at the time when the *Iguanodon* were discovered.

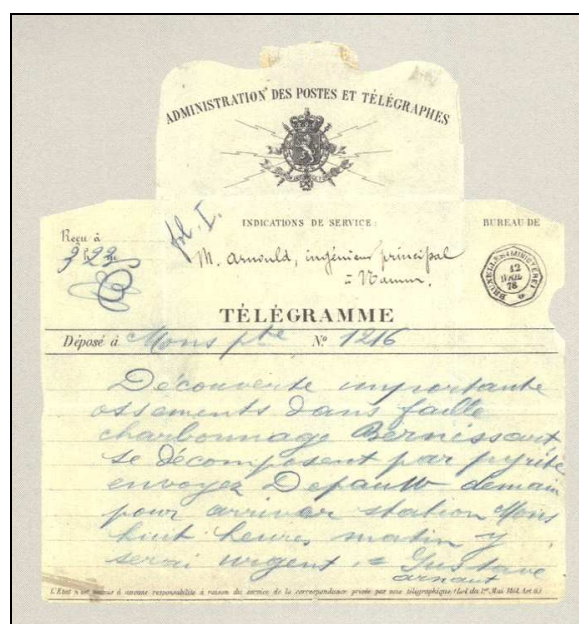
The discovery of complete and articulated skeletons of *Iguanodon* at Bernissart in 1878 came at a time when the anatomy of dinosaurs was still very poorly understood and thus considerable advances were made possible. It revealed for the first time the anatomy of dinosaurs and thus considerable advances were made possible.

On February 28, 1878, miners digging a horizontal exploration gallery 322 m below ground level suddenly encountered, 35 m to the south of the Luronne seam, disturbed rocks indicating that they were penetrating inside a vertical ‘cran’, a local term meaning a pit formed by natural collapse through the coal seams that was filled especially with clayey deposits normally located above the coal measures. It was decided to traverse this ‘cran’ and to rejoin the coal seam on the other side. The overseer Motuelle and the miners Jules Créteur and Alphonse Blanchard were put in charge of continuing the exploration gallery through the perturbed layers of the ‘cran’. On March 9, Ballez noticed that the exploration gallery was still in the perturbed zone of the ‘cran’. In March, the miners already collected dinosaur remains like fragmentary bones and teeth. The latter are housed in the palaeontological collections of the RBINS, labelled ‘remains of the first *Iguanodon*, March 1878’. But little attention was paid to these discoveries, believing that these were just fossil wood.

On April 3, the engineer Latinis estimated that they had reached again the coal-bearing formations. However, the mine manager Fagès decided to accompany the engineer and the chief overseer in the exploration gallery on April 5. While inspecting the deposits, Fagès found a long object, with an oval cross-section and a fibrous texture. Some believed that it was a fossil oak branch. Conversely, Fagès ironically supported that it was a rib of Father Adam. The miner Jules Créteur mentioned that he had already found a larger fossil and the team soon unearthed limb bones in the gallery. In the evening, miners brought several fragments of these fossils to Café Dubruille. There the local doctor Lhoir, who also worked for the coalmine, burnt one of the fragments and confirmed that the fossils collected by the miners were bones, not wood. Many new fossils were discovered by the miners in the night from April 5 to 6.

On April 6, it was ordered to bring up to the surface all the fragments of bones that they had collected and to lock up the end of the gallery. On Sunday April 7, Latinis was commissioned to go to Mons and to show the fossils to the well-known geologist François-Léopold Cornet. But Cornet was absent from his home, consequently Latinis left the fossils to his young son Jules (a future renowned geologist!) and asked him to tell his father that these bones had been found in the Sainte-Barbe pit at Bernissart. On April 8, F.-L. Cornet came to Bernissart and discussed shortly with Latinis about the Bernissart discovery. He could not meet with Fagès, who was with Ballez in the Sainte-Catherine Pit. On April 10, Cornet told the zoologist Pierre-Joseph Van Beneden, professor of palaeontology at Leuven University, that Latinis, who was a former student of Van Beneden, discovered fossil bones at Bernissart and sent him some of the bones that Latinis had left to his son. Van Beneden quickly identified the teeth as belonging to the dinosaur *Iguanodon*, previously described from Wealden deposits in England.

On April 12, Fagès went to Mons in order to meet the chief mining engineer Gustave Arnould, who immediately sent a telegram to Edouard Dupont, director of the Musée royal d'Histoire naturelle de Belgique (MRHNB) at Brussels '*Important discovery of fossil bones at 322m below ground level, Sainte-Barbe Pit, Bernissart. Send De Pauw tomorrow at first light. Letter will follow. Arnould*'.



**Figure 11.** Telegram sent to the RBINS by coal mine Chief Mining Engineer (April, 12, 1878).

On Saturday April 13, Louis De Pauw, head preparator at the MRHNB who already had a great experience in the excavation and preparation of fossil vertebrates, met Arnould at Blaton and they went together to Bernissart. Fagès showed them the bones recently found in the gallery and De Pauw could recognize two ungual phalanges and one vertebral centrum. It was then decided to go down together in the fossiliferous gallery. **De Pauw (1902) reported that the walls of the exploration gallery were completely covered by fossil bones, plants and fishes.** Quickly, Fagès gathered the board of directors of the Bernissart Coal Board Limited Company, who decided to donate the fossils discovered in the Sainte-Barbe Pit to the Belgian State and to notify Charles Delcour, Minister of the Interior, and Edouard Dupont, director of the MRHNB, about this decision. But the excavations could not begin immediately, because the MRHNB team was then busy with the preparation of the Paris World's Fair. De Pauw settled in Bernissart on May 10 and the excavations began on Wednesday May 15.

In 1881, a new horizontal gallery was dug at a depth of -356 m. The miners also encountered fossiliferous clays, but the diameter of the crane was extremely restricted (~ 8m) at this level. Three more articulated skeletons were recovered from this third series of excavations. The clayey layers had completely disappeared three metres below.

After three years of excavations at Bernissart, about six hundred blocks, totalling more than 130 tonnes, were transported to Brussels in furniture removal vans, each of 3 tonnes capacity. The excavations at Bernissart were of course particularly expensive for the Belgian state (about 70 000 francs in this time), and the government had already allocated two extraordinary grants. In 1881, the expenses involved by this enterprise were considered too high by the Belgian government and the excavations were stopped. 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.

### **New boreholes within the Iguanodon Sinkhole**

In 2002-2003, three new boreholes were drilled within and around the Iguanodon Sinkhole at Bernissart. Initially, the aim of this drilling program was to evaluate the chances of finding more fossils, to understand the genesis of the Iguanodon Sinkhole, and to test a seismic geophysical technique for ground imaging. In October 2002 the drilling program started with a completely cored well (named BER 3) using the PQ wireline technique. BER 3 reached 349.95 meters of Thanetian, Late Cretaceous, Early Cretaceous and Westphalian sediments (Yans et al., 2005). During the operations, different parameters were recorded: rate of penetration, core recovery and a brief core description (Tshibangu et al., 2004). BER 3 provided exceptional material to improve our knowledge of the Iguanodons-bearing Wealden facies, with a multidisciplinary research funded by FRS-FNRS (FRFC n°2.4.568.04.F). Another borehole (BER 2) also cut Wealden facies.

The formation processes of the Iguanodon sinkhole were documented by sedimentological studies of the lacustrine Wealden facies (including clay mineralogy, granulometry and magnetic susceptibility), and by characterization of the organic matter with Rock-eval, palynofacies, soluble alkane content, carbon isotope and structural analyses (Schnyder et al., 2009). These latter authors suggest two steps in the life of lacustrine Wealden facies of Bernissart: a first step with intense supply of plants debris, and a second step with active algal/bacterial activity providing amorphous organic matter, following the level variations of the lake. The paleontological content was studied using paleohistology and diagenesis of the bone fragments, characterization of amber, and preparations for diatoms and ostracods

analyses, unfortunately barren (C. Cornet, pers. comm.; B. Andreu, pers. comm). A late Late Barremian to earliest Aptian age was estimated for the Iguanodon-bearing sediments, using both palynology and chemostratigraphy and allowing a better knowledge of the initial steps of the subsidence in the Mons Basin. Moreover, Wealden facies samples from RBINS collection (historical searches of 1878-1881) and other localities in the Mons basin (Hautrage, Thieu, Baudour) were also investigated. Rare dinosaur fossils are described from the Baudour Clays Formation. Palynology and determination of wood and plant-mesofossils fragments provide further information about the paleoenvironment of the Mons Basin during the Early Cretaceous (Dejax et al., 2008; Gomez et al., 2008). In Thieu, the occurrence of dinoflagellate cysts suggests marine influences in the Wealden facies of the Eastern part of the Mons Basin (Yans, 2007). These data were integrated into the Early Cretaceous geological context of Northwest Europe (Thiry et al., 2006; Quinif et al., 2006). Studies are still in progress...



**Figure 12.** Fragment of bone in the 2002-2003 BER 3 core (296,5 m of depth).

### **Age of the Wealden facies**

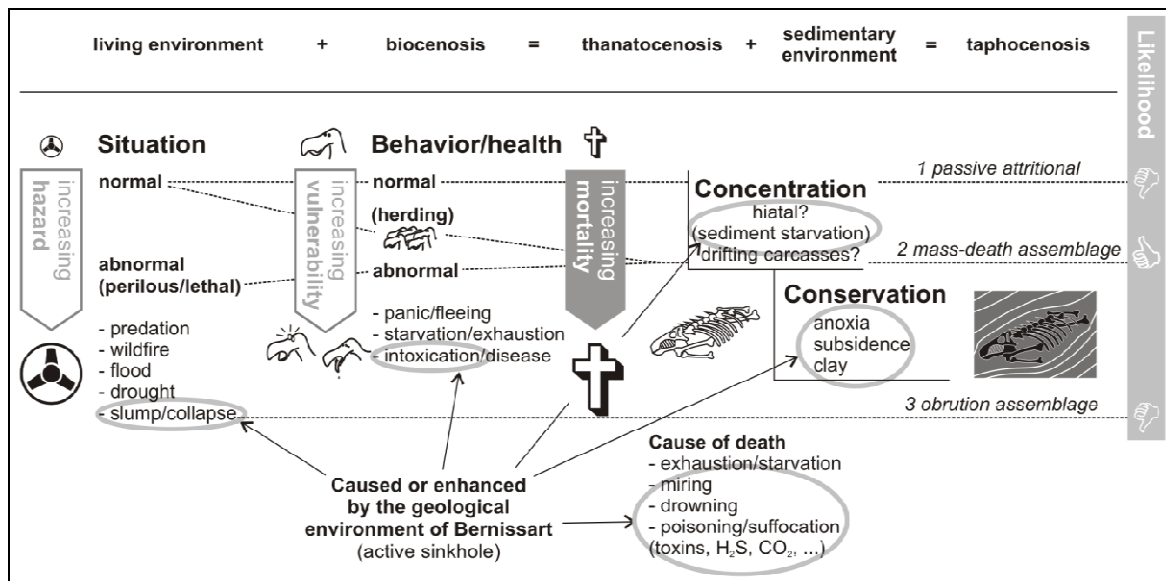
The age of the Iguanodons-bearing Wealden facies trapped in the natural pit of Bernissart (Sainte-Barbe Clays Formation) is **late Late Barremian-earliest Aptian** (Schnyder et al., 2009; Yans et al., 2010). Moreover, spectral analysis of a high-resolution gamma-ray record demonstrates that the sedimentation was controlled by orbitally-induced climatic changes. Precession, obliquity and short- and long-term eccentricity cycles are recognized. The 12 m-thick and the 38 m-thick TOC cycles fit well with a 100 kyr short-term and a 400 kyr long-term eccentricity cycle, respectively. Long-term organic fluctuations are interpreted as resulting from orbitally-induced fluctuating lake levels through time. According to this new dataset, the duration of deposition is now estimated to range between **0.55 and 2.2 myr**.

### **New taphonomical scenarios for the iguanodons of Bernissart, Belgium.**

Efforts to unravel the processes that caused the accumulation and preservation of many dinosaurs along with other taxa are here based on a new geological model that relies on



several discrete, continuous bonebeds. Several taphonomic scenarios are proposed within the specific geological and environmental specificities of the so-called Lower Cretaceous Bernissart lake. Attrition and obrution processes appear less likely than mass-death by drowning and/or intoxication, based on sedimentological and taphonomic evidences. Contamination of the aquatic environment by sulfate-rich brines related to deep solution-collapse processes could support the hypothesis of intoxication by H<sub>2</sub>S or biological toxins as direct or indirect lethal agent in a context of seasonally shrinking water. The opisthotonic posture observed in many iguanodon specimens was probably induced by brain affliction consequent to intoxication or asphyxiation.



**Figure 13:** Synopsis of the taphonomic parameters identified for the Bernissart bonebeds, listed as mortality and preservation parameters from the left to the right, respectively. Mass-death caused either by herding or abnormal behaviour under perilous situation is the most likely scenario. Passive attrition, which results from normal biological activity under normal circumstances but efficient concentration and conservation processes, is not likely. Quick burying due to catastrophic sedimentary events (obrution) seems not likely either. The possible influence of the specific geological environment of Bernissart by Lower Cretaceous times is shown.

### Following papers in relation with Bernissart:

- Schnyder J., Dejax J., Keppens E., Nguyen Tu T., Spagna P., Boulila S., Galbrun B., Riboulleau A., Tshibangu JP & Yans J. 2009. An Early Cretaceous lacustrine record: Organic matter and organic carbon isotopes at Bernissart (Mons Basin, Belgium). *Palaeogeography, Palaeoclimatology, Palaeoecology* 281, 79-91.
- Dejax J., Pons D. & Yans J. 2007. Palynology of the dinosaur-bearing Wealden facies sediments in the natural pit of Bernissart (Belgium). *Review of Palaeobotany and Palynology* 144, 25-38.

## Stop 4. Royal Belgian Institute of Natural Sciences

### What to be seen?

Iguanodons + related fossils; Messel collection; Boom dugong; gallery of evolution.

### Preparation, mounting, and exhibition of the Bernissart Iguanodons

Many manuscripts and plans relating to the original excavations at Bernissart are preserved in the palaeontological archives of the RBINS and allow reconstructing the circumstances of the discovery of these fantastic dinosaurs.

From 1882 onward, once the excavations at Bernissart had ceased, museum preparation proceeded rapidly. 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, and now preserved as an exhibition hall in the Albert I Royal Library. De Pauw (1902) described in details the preparation of the *Iguanodon* skeletons. De Pauw believed that the arsenic was able to 'kill' pyrite. The excess of glue mixture was cleaned off and blocks hardened in a drying-room. The reverse side of the block was then prepared with a cold-chisel to remove the plaster and the matrix, and the glue mixture was applied on this side. The pyrite was systematically curretted 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.

It was decided to mount the best preserved *Iguanodon* specimens in a lifelike gait. In 1882, the first complete specimen (individual 'Q', RBINS R51, the holotype of *Iguanodon bernissartensis*) was assembled and mounted by L. De Pauw and his team. 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. This first mounted specimen was publicly exhibited in 1883 in a glass cage constructed in the interior court of the Nassau Palace. In 1884, the cage was lengthened to accommodate a second specimen (individual 'T', RBINS R57, the only complete specimen of *Mantellisaurus atherfieldensis*) and a selection of fossils of the Bernissart flora and fauna.

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 were transported to the new location of the Royal Museum of Natural History 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 MRHNB. Eleven complete specimens were exhibited in a lifelike gait, while twelve more or less complete and eight fragmentary individuals were presented 'en gisement' display.

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.

During the Second World War, all the specimens were again dismantled and stocked in the cellars of the museum, for fear of aerial bombings. But the humidity was too important for these fragile fossils, which were mounted again in the exhibition hall before the end of the war (Bultynck, 1989).



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.

### **The study of the Bernissart Iguanodons**

P.-J. Van Beneden, who estimated that he had to be credited with first discovering the Iguanodons because it was him who first identified the fossils as belonging to the genus *Iguanodon*, published the first scientific note about these dinosaurs (Van Beneden, 1878). It was the starting point of epic, although completely futile, disputes between Van Beneden and Dupont over the authorship of the Bernissart Iguanodons during noisy sessions of the Academy of Sciences in 1883.

A contentious point, involving P. J. Van Beneden, concerned the species that had been discovered at Bernissart: did it belong to a new species or to *Iguanodon mantelli*, already described from disarticulated specimens discovered in England? Just after the discovery of the Bernissart Iguanodons, Dupont had asked the young naturalist Georges Albert 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 *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), then president of the science section of the Academy, who claimed that observed anatomical differences was most probably attributable to sexual dimorphism and that the Bernissart Iguanodons belonged to *Iguanodon mantelli*. 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 Louis Dollo, a mining engineer of French origin who eventually became a Belgian citizen and devoted entirely to vertebrate palaeontology at the MRHNB. Between 1882 and 1923, Dollo (1882b,c, 1883a,b,c, 1884, 1885c,d, 1888, 1906, 1923) published many preliminary notes on the Bernissart fauna and, especially, on *Iguanodon*. 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. 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.

In 1980, the British palaeontologist D. **Norman** published a monographic study of *Iguanodon bernissartensis*. In 1986, Norman described the small *Iguanodon* species from Bernissart and concluded that it belongs to *Iguanodon atherfieldensis* Hooley, 1925, a species previously described from the Wealden Beds of the Isle of Wight. Moreover, he stressed that the former name for it, *Iguanodon mantelli*, is a *nomen dubium* due to the very fragmentary preservation of the type material of that species.

On the occasion of the mounting of an *Iguanodon bernissartensis* cast in a quadrupedal position at the RBINS in 1992, **Bultynck** discussed in a short paper the posture and gait of this species.

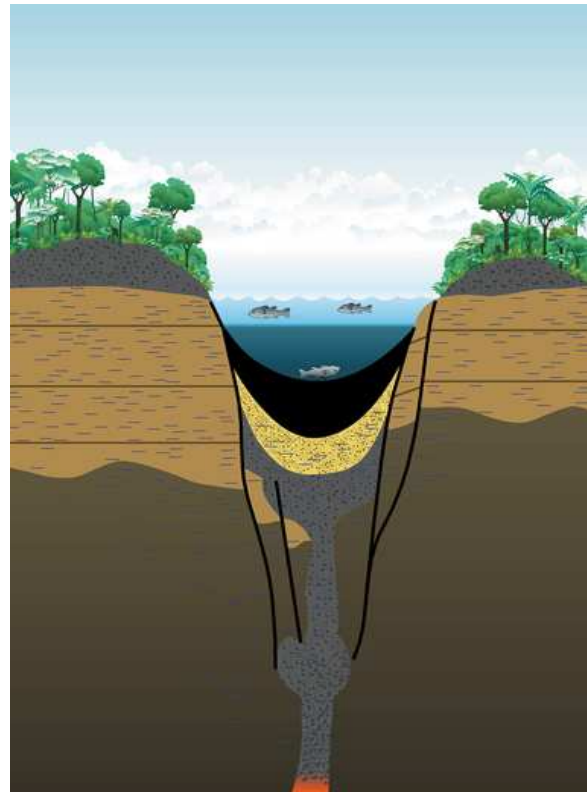
## The vertebrates from the middle Eocene Messel pit

One of the best fossil sites in the world for the understanding of the warm Eocene period is the Messel Pit near Darmstadt in Germany.



Since 1995, this famous fossil site is listed by UNESCO as world heritage, but amazingly in the 1980s it was destined to become a landfill. At that time, an important paleontological project was therefore developed in order to save as much fossil remains as possible before the destruction of the locality. During 8 years, the Senckenberg Institut of Frankfurt organized excavations at the Messel site in collaboration with the Royal Belgian Institute of Natural sciences and the Landesmuseum of Darmstadt. Through the financial and technical efforts of the RBINS, four hundred vertebrate specimens from this extraordinary fossil site were collected and prepared by Belgian members. Today, these specimens are conserved in the collections of the Department of Palaeontology of the RBINS and some of them are exhibited in the Gallery of Evolution.

The specimens were collected from oil shale deposits that allowed an extraordinary preservation, including not only the skeleton but also traces of skin and hair and sometimes the stomach content. Since 2001, we know that these shales were deposited in a maar (volcanic lake) and the fossils have been dated at about 47 million years old (Lutetian), based on a radiometric dating of basalt fragments collected from the volcanic chimney just below the maar (Franzen, 2005). However, study results also indicate that the 200m thick maar deposits were formed over a period of more than 1 million years, thereby rejecting the need to invoke catastrophic scenarios to explain the richness and composition of the fossil accumulation.



Among the vertebrates, swimming and flying animals such as fish, birds and bats are the most common, but frogs, snakes, lizards, crocodilians, turtles and mammals were also found. These forms were probably living near the lake, and only some of them died on the lake shore and were deposited and preserved on the bottom of the maar. With the exception of bats, mammals are therefore not abundant and they are mainly represented by rodents, artiodactyls, perissodactyls, erinaceomorphs (hedgehog-like insectivores) and primitive extinct groups (leptictids, apatemyids, paroxyclaenids...). Three decades of active fieldwork, only yielded 56 equoid perissodactyls including 39 skeletons of *Eurohippus messelensis* (Franzen, 2007). Primates are very rare and the famous *Darwinius masillae* (the young female Ida) is the exception which proves the rule (Franzen et al., 2009).



## The Boom dugong

In 1889 the famous paleontologist Louis Dollo published the description of a nearly complete skeleton of a fossil sea cow discovered in brickworks of Charles De Kock in the area of Boom (Antwerpen; Dollo, 1889d). He named the taxon *Miosiren kocki*. The Boom area is particularly rich in fossil vertebrates from the Oligocene to the Pliocene and for long the age of these fossils, including numerous sharks, cetaceans and sirenians, was difficult to determine. More recently, the age of the deposits was clarified based on micro- and nanofossils and *Miosiren kocki*, from the Edegheem Sands was found to be early Miocene in age (lower Burdigalian, NN3, Hooyberghs, 1996; Louwye et al. 2000).



*Miosiren kocki* is historically called the “Boom dugong”, although it does not belong to the family Dugongidae but to the family Trichechidae which includes the extant manatee. It represents a good example of pachyostosis, a condition in which the ribs and other long bones are unusually thick and contain little or no marrow. These heavy bones, which are among the densest known in animals, may act as a ballast to help keep sirenians suspended slightly below the water's surface.

Among the two main marine mammal groups, whales are closely related to artiodactyl ungulates based both on molecular studies and on the recent paleontological discovery of footbones of earliest cetaceans (Gingerich et al., 2001). The origin of sirenians is less well understood and they are generally classified with the proboscideans (elephants) in the tethytheres.

The decline in sirenian taxonomic diversity in the late Miocene was likely due to the rapid climate and oceanographic changes and their impacts on available dietary resources (Clementz et al., 2009). Today, only two genera of sirenians, the dugong and the manatee, are still extant.





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