Chalk of the Mons Basin (Belgium)

Organized by

Sara Vandycke (UMons)

Ophélie Faÿ (UMons)

Fieldbook

Programme

Friday, September 20th

8h30: Meeting @Aparthotel Casteau Resort, Mons Soignies

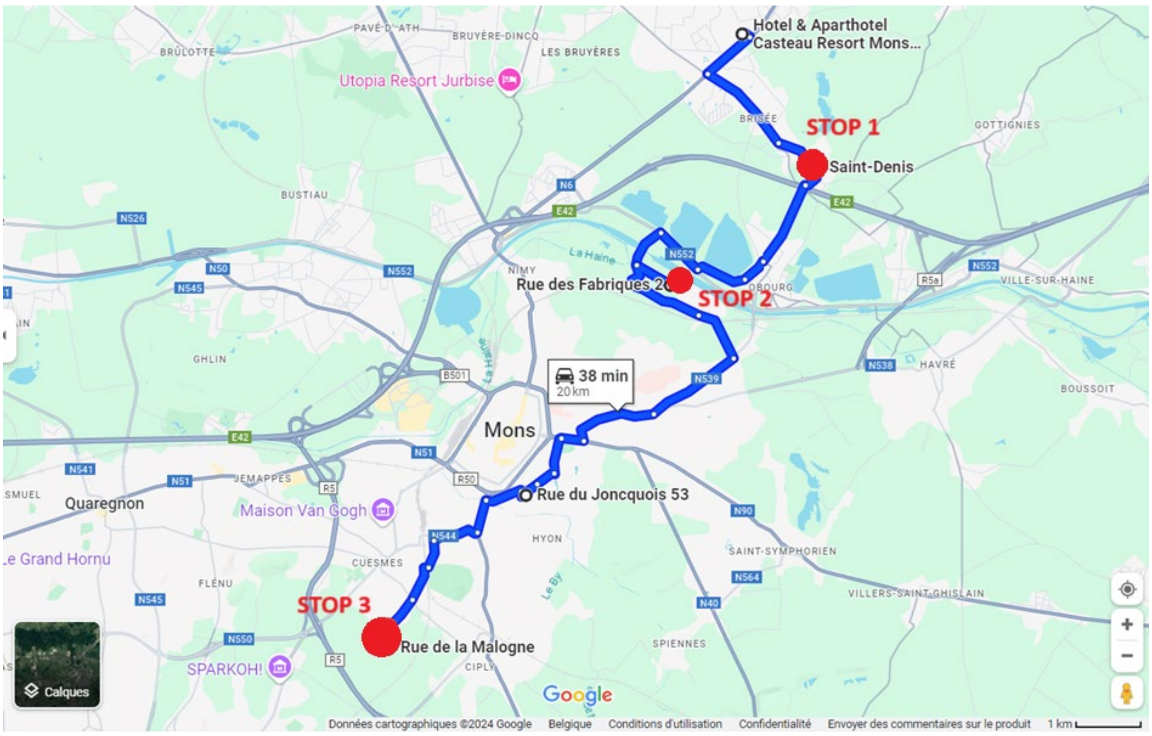
8h45 - STOP 1
Maisières Chalk
208 rue grande, 7020 Maisières

9h30 - STOP 2
Holcim Quarry Belgium (Trivières to Spiennes Chalk Fm)
Entrée carrière 3, route industrielle, 7034 Obourg

12h15 – 13h30 - Lunch
Service de Génie Minier, UMONS
Rue du Joncquois 53, 7000 Mons

14h - STOP 3
La Malogne Underground Quarry (Phosphatic Chalk Fm)
Rue de la Malogne, 7033 Mons

16h30- 17h – End of the visit



Liste des participants

- Sara Vandycke (UMONS)
- Ophélie Faÿ (UMONS)
- Julien Vergari (UMONS)
- Julien Denayer (Service Géologique de Wallonie)
- Bastien Paternostre (ULB-UMONS – MSc Student)
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- Guido Heintz (Utrecht University – BSc. Student)
- Geert-Jan Vis (TNO)
- Eva De Boever (TNO)

Mons Basin : stratigraphic and tectonic context

The Mons Basin is located at the Variscan front, near the Midi Fault,and a marked depression in the landscape. It is the site of persistent subsidence where brittle tectonics have played a significant role.

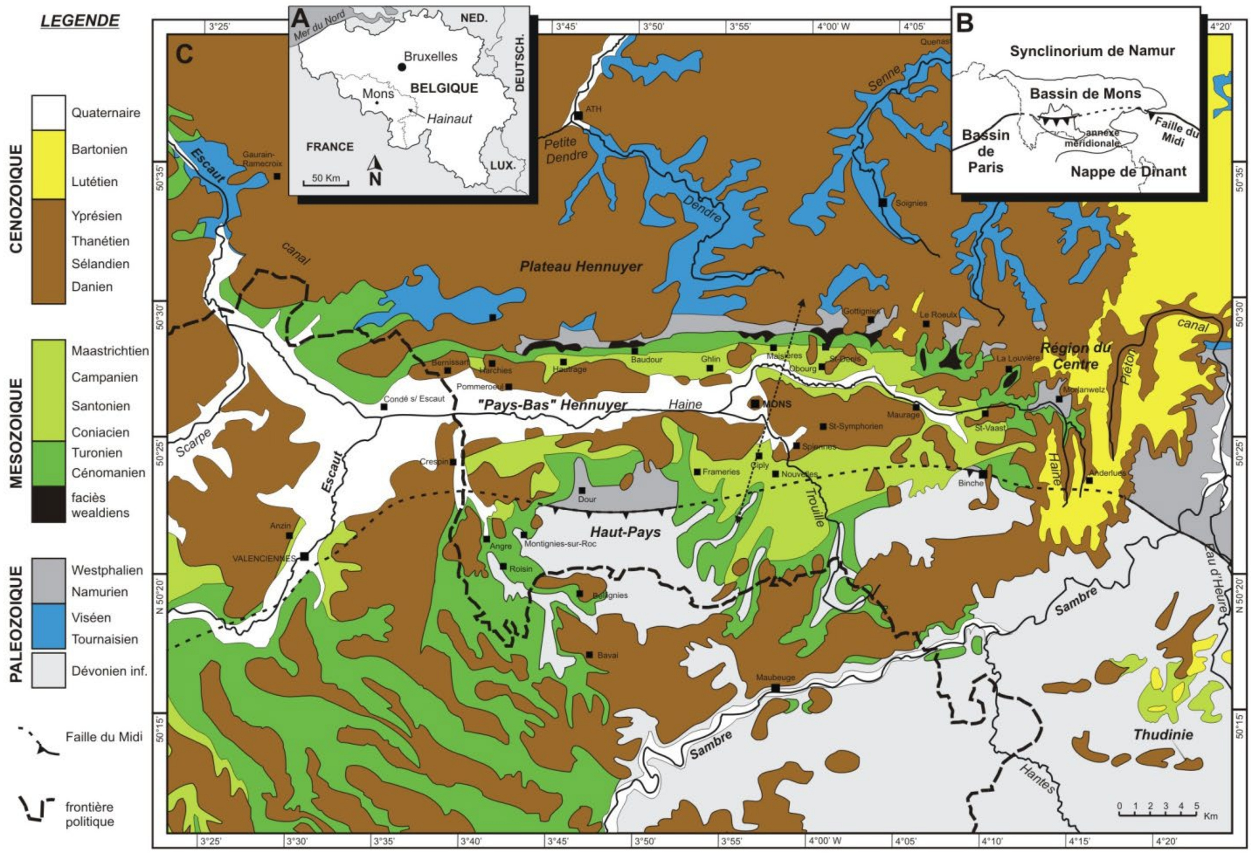

Figure 1 : Geological map of the Mons Basin (from Baele, 2002)

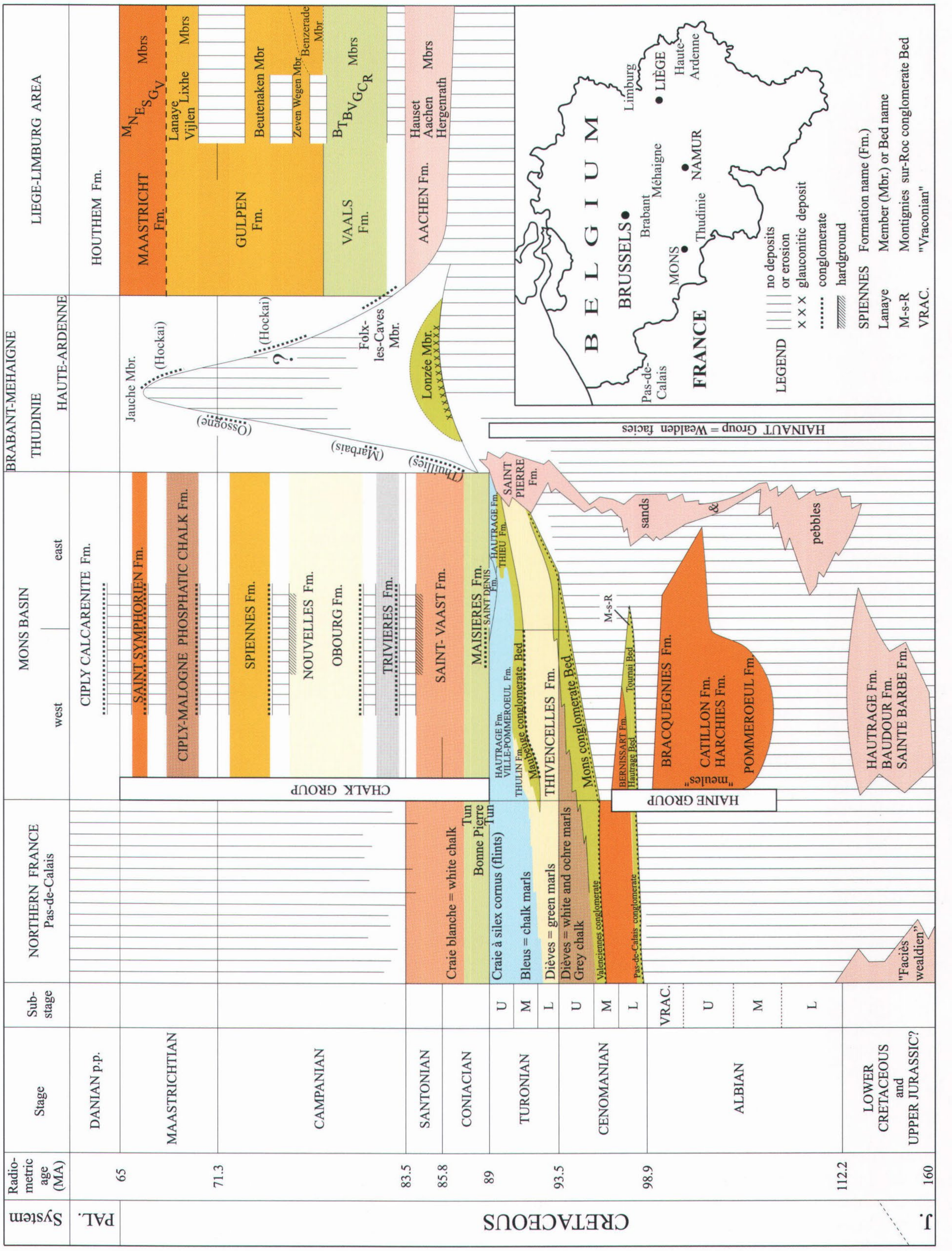

Figure 2 : Stratigraphic distribution and age of the Cretaceous formations in Belgium (from Robaszynski et al, 2001)

The Cretaceous lithostratigraphic series of the Mons Basin begins with Wealden sediments. These Lower Cretaceous sediments are preserved due to two burial phenomena active during this continental, fluvio-lacustrine period: (i) the karst pits of the mining pits where the famous Bernissart iguanodons were found, and (ii) a directional subsidence of sandy-clayey sediments which are now concentrated, on the northern edge of the Mons Basin, notably at Hautrage (Spagna, 2010; Yans, 2007).

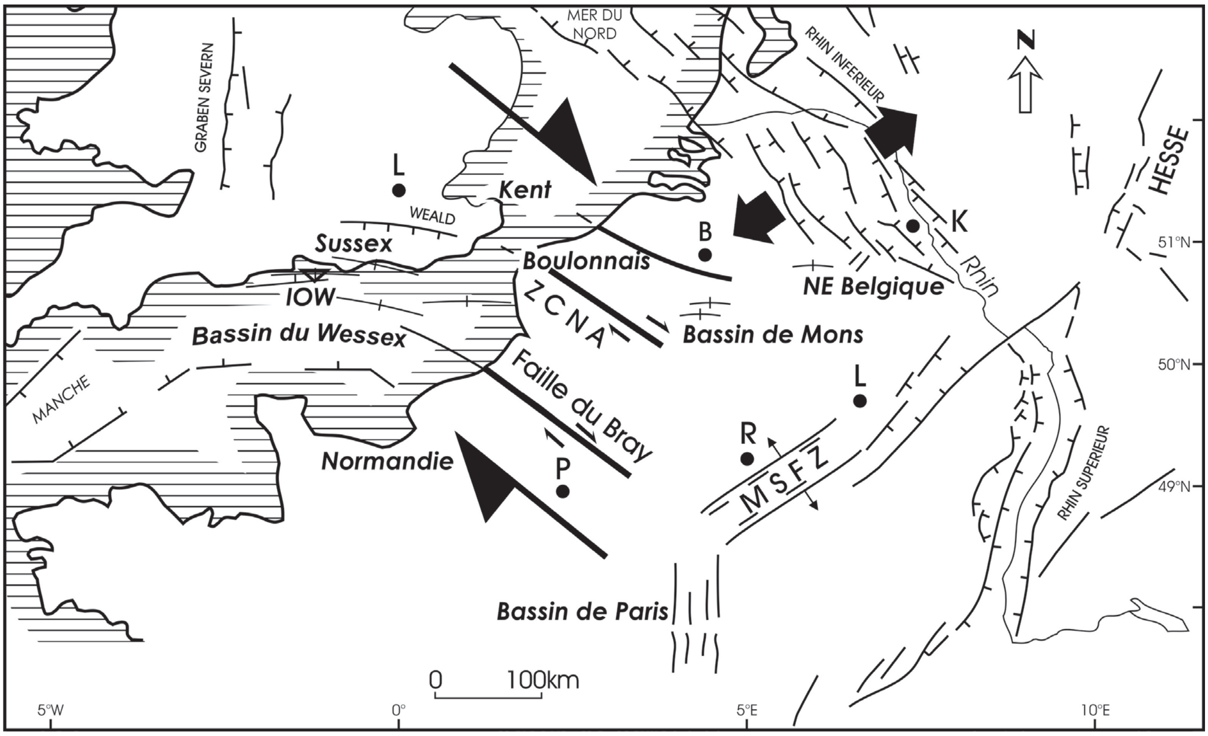

Figure 3: Structural environment of the Earth's crust in northwestern Europe over the past 150 million years. The European plate is characterized by tectonic axes, including dextral shear zones along NW-SE trending structures (Bray Fault in Normandy, North Artois Shear Zone in the Boulonnais and northern France) and the opening of the Rhine Graben (Vandycke, 2010).

After this transitional period of the Lower Cretaceous, the chalk sea invaded this part of northwestern Europe, as it did elsewhere on the European plate. The Mons Basin remained under the influence of regional tectonics through the presence of a crustal relay zone with the North Artois Shear Zone and other European structural units such as the Lower Rhine Graben (Vandycke, 2007) (Figures 3 & 4). The subsidence of the Mons Basin continued due to brittle tectonics, which generated numerous normal faults and joints in the white chalks (Vandycke, 2010). In the center of the Basin, such as in Harmignies, these chalks are preserved. The mechanical behavior of these chalks around faults has been studied. By studying the petrophysical variations of the chalk, it is possible to quantify the deformation due to normal faults (Gaviglio et al., 2009; Schroeder et al., 2006). The arrangement of Upper Cretaceous belemnites is also used to characterize the deformation related to these normal, often synsedimentary faults (Angelier et al., 2006).

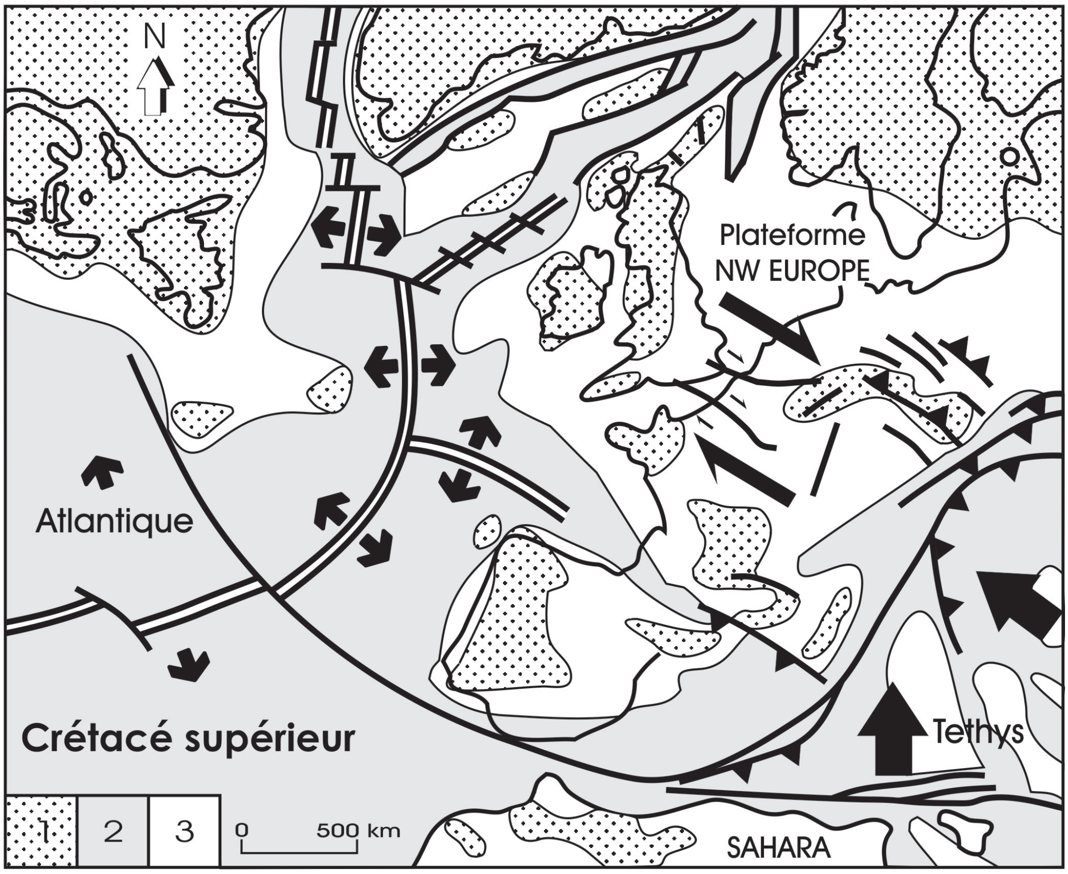

Figure 4 : Geodynamics of the European Plate during the Cretaceous. The European Plate served as a relay zone between the opening of the Atlantic and the push of Africa towards Europe within the Tethys. (1: emerged zone, 2: seas and oceans, 3: marine deposits).

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STOP 1

Silicite of Saint-Denis (Turonian) Maisières Chalk (Coniacian)

Silicite of Saint Denis

The Silicite of Saint-Denis is a highly siliceous formation from the Upper Turonian age, found between Maisières and Saint-Denis on the northern edge of the Mons Basin. Its thickness varies from 1 to 8 meters and it represents a lateral facies variation of the Hautrage Flint formation. This formation is characterized by carbonate sediment containing abundant and large flint nodules. The sediment and flint characteristics vary slightly but significantly across the basin, suggesting different depositional conditions. The flints often have irregular shapes and a scoriaceous patina, and are frequently embedded with visible sponge spicules.

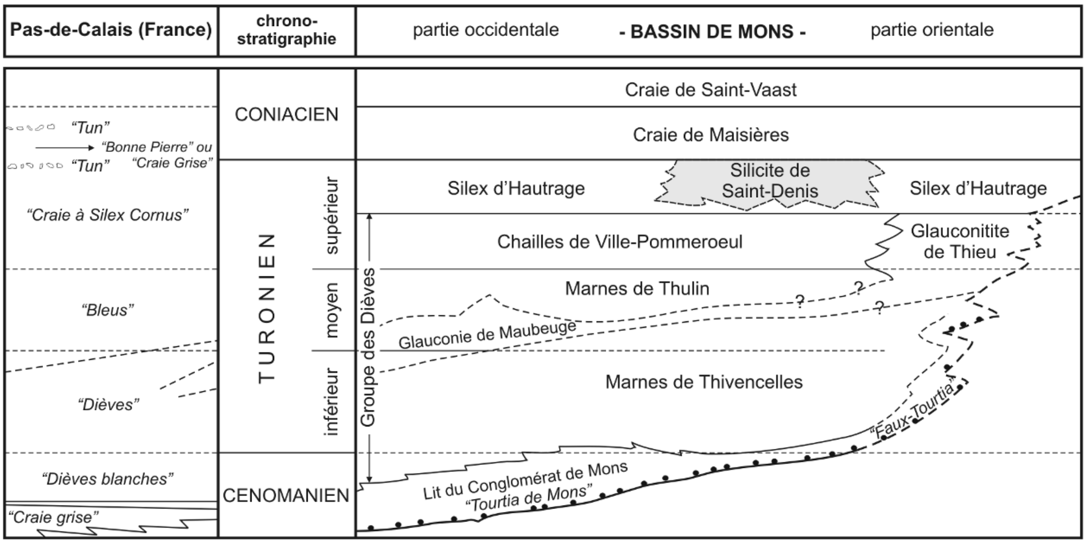

Figure 1. – Lithostratigraphy of the Turonian in the Mons basin (from ROBASZYNSKI, 1975).

In Saint-Denis, three types of silicite facies are observed: flint silicite, "grey" silicite, and "white" silicite.

1) Flint Silicite (SSx2): This facies is similar to that of Maisières but differs in that the sediment is sandy-glauconitic and pyritic rather than carbonate. The primary flints are more brecciated, producing angular fragments and splinters. Early diagenetic dissolution processes likely played a role during flint formation.
2) "Grey" Silicite (SL1a): This facies results from the mass silicification of carbonate sediment, showing improved quartz crystallinity compared to flint. It contains microscopic carbonate relics, less vitreous texture, and less conchoidal fracture surfaces. Dissolution structures, sometimes forming microkarsts, are filled with finely

laminated silicified sediments, originally carbonate, containing calcite inclusions and microfossils.

3) "White" Silicite (SL1b): This transitional facies between flint and grey silicite lacks carbonate relics, replaced by glauconite and pyrite in a nodulo-brecciated structure. Microkarst cavities are filled with finely stratified pyrito-glauconitic silicified sediments. Recent alteration leads to total bleaching by leaching non-quartz minerals, likely due to oxidative pyrite dissolution.

The different facies of Saint-Denis silicite show lateral variations over short distances (tens to hundreds of meters). The thickness of the silicite varies with the facies type, being greatest in grey silicite and least in flint silicite. The frequency of internal sediment cavities and nodulo-brecciated structures increases in the same direction, with an abundance peak in the transitional facies (white silicite). This suggests dissolution occurred in sediment with highly variable silicified volumes laterally. Where disjointed flint nodules develop, dissolution leads to their compaction and brecciation, reducing formation thickness. In areas with more continuous silicification (grey silicite), dissolution effects are minimal and do not affect formation thickness.

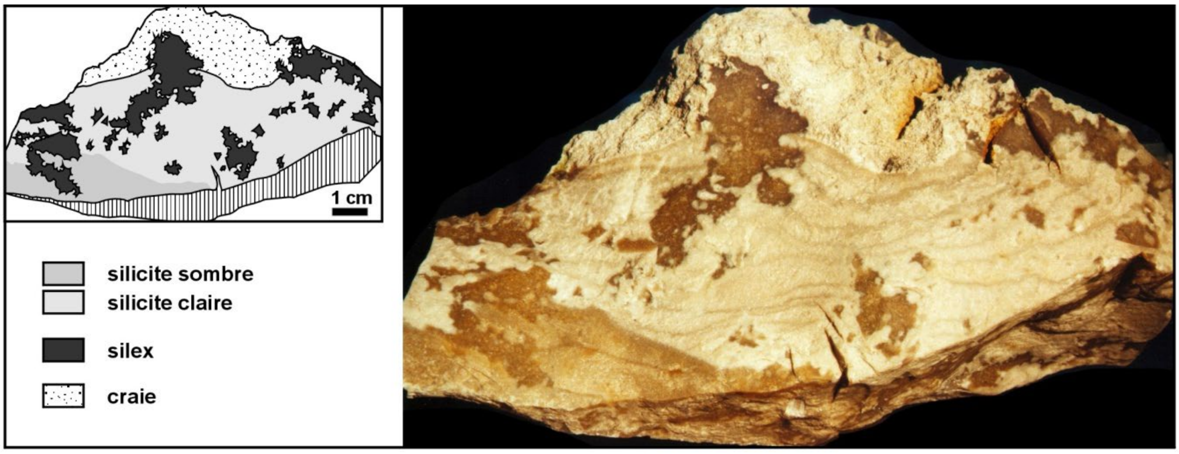

Figure 2. *– Typical facies from the silicite of Maisières (SSx1),*

The origin of silica is quite clearly found in the spicules of sponges, which are abundantly present in almost all facies. However, the reasons for the significant lateral variation in silicite facies remain unclear. They are likely related to environmental variations in a coastal context, most probably in connection with the late Turonian eustatic regression.

Maisières Chalk

The Maisières Chalk Formation is a glauconitic calcarenitic chalk. This rock is characterized by its coarse texture, sand-sized glaucony grains and a high occurrence of bioclasts. The latter, mostly bivalves, vary in size from a few millimetres to several centimetres. Within the Maisières Formation, the coarse fraction with about 26%, consists essentially of large glaucony pellets, ranging in size from 50 μm to 1 mm. Grain maturity ranges from evolved to well-evolved. The alteration and cracks of the grains are variable, but their morphology is consistently sub- to well-rounded. Interestingly, a number of these grains display an external alteration rim that is manifested by a colour ranging from light green to white, while the internal glaucony grain coloration is vivid green. This suggests a potential variation in the mineralogical composition or state of weathering within the same grain. Grains also include large bioclasts, which are frequently corroded. Local matrix silicification by calcedony also

occurs. Evidence of phosphatization, silicification, glaucony and pyrite formation are found in this key stratigraphic level, suggesting hypo- to anoxic conditions.
At the base of the Chalk sequence, the Maisières chalk Formation represents the beginning of a major transgressive sequence starting with a condensed interval. Glauconite deposits often correlate with lowstand systems and/or the early stages of transgressive sequences in geological records (e.g. Banerjee et al., 2016; Bansal et al., 2018). The Maisières chalk deposits likely formed in a relatively shallow environment, probably in a lower offshore mid-ramp environment based on Lasseur et al. (2009). Stratified water and oxygen depletion in deeper waters are also typical characteristics of the onset of transgressive trends.

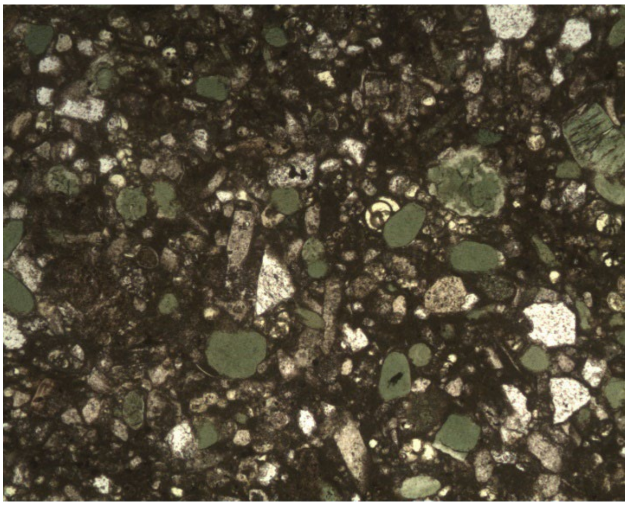

Figure 3. *– Thin section from the Maisères Chalk formation*

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STOP 2

Obourg Holcim Quarry (Trivières to Spiennes Chalk Fm) Campanian

In the center of the Mons Basin, subsidence is maximal (Dupuis & Vandycke, 1989). The Upper Cretaceous chalks are thus primarily preserved. The Obourg quarry is exploited in stages for the production of white cement. It is one of the best places to study the lithostratigraphy as well as the deformation and fracturing of the white chalk. On one hand, the outcrop conditions are exceptional, and on the other hand, numerous studies have been conducted there over the past 20 years. For the needs of exploitation, the lithostratigraphic context is regularly monitored. Moreover, the white chalk, with low marl content, responds excellently to tectonic stresses.

Lithostratigraphic Context of the Chalks

The Holcim quarry in Obourg allows observation of the top of Trivières Chalk, at the bottom of the quarry, the Obourg Chalk, the Nouvelles Chalk, and the Spiennes Chalk. All these chalks are between 71 and 83 million years old (Robaszynski & Christensen, 1989; Robaszynski, 2001).

Trivières Chalk

Grayish-white to gray, marly chalk, forming the local substrate of the white chalks. The top is generally marked by a hardground or a proto-hardground whose thickness varies greatly from 0.10 m to 1.10 m. This is the "durillon" of the quarry workers. Its color varies greatly but is sometimes greenish to yellowish-white and white in areas above the piezometric surface of the aquifer. It often contains hardened, perforated, and greenish chalk gravels, a few millimeters to a few centimeters in diameter. The belemnite Belemnitella mucronata is not rare near the "durillon". Immediately below this durillon is the Trivières Chalk, grayish-white to gray, with a thickness of 1 to 13 m. Below, a greenish hardground with green pebbles separates this grayish-white chalk from the truly gray Trivières Chalk with large gray bioturbations below. The Trivières Chalk is unsuitable for the production of white products and white cement due to its high iron, silica, and alumina content. Fe2O3 (calcined) contents up to 0.46% have been measured on drill samples.

Obourg Chalk

White, fine chalk without flint. The base of the formation is often marked by greenish gravels probably resulting from reworking under high energy conditions of the underlying hardground or "durillon". The few meters at the base of the formation show, in most drill cores, on longitudinally sawn and carefully cleaned cores, long bioturbations filled with slightly grayish chalk. The Obourg Chalk gradually transitions upwards into the Nouvelles Chalk. Therefore, the estimated thickness of the Obourg Chalk is about 10 to 12 meters. In the quarry, after weathering and frost action, the Obourg Chalk shows vertical flaking, parallel to the face.

Nouvelles Chalk

White and smooth chalk, with a smooth touch, without flint in its lower part, with some flints sometimes aligned in bands in its lower part. In the quarry, it can be seen that the flints are arranged in three levels distributed over the upper 10 to 12 meters. The flints being quite dispersed, the drill cores do not always show the three levels. In the quarry, the middle flint level is sometimes highlighted by flat flints. The top of the Nouvelles Chalk is marked in the western part of the quarry by a yellowish-white to white hardground, with a thickness varying from 0.15 to 0.40 m, which sometimes overlies a Nouvelles Chalk with large bioturbations filled with calcarenitic chalk. In other drill cores, the hardground is not expressed and is sometimes replaced by a level of a few decimeters of calcarenitic chalk. Given the gradual transition between the underlying Obourg Chalk and the Nouvelles Chalk, the thickness of the latter is estimated at 15-20 meters. The upper part of the Nouvelles Chalk sometimes yields specimens of the brachiopod Magas “pumilus” (= chitoniformis), a small terebratulid 5 to 7 mm long, practically smooth, characterized by its very prominent and curved beak. Fragments of Belemnitella mucronata and, closer to the Obourg Chalk, tests of irregular echinoids of the Echinocorys cf. vulgaris group are also found. The Fe2O3 (calcined) content of the Nouvelles Chalk is often less than 0.1%.

Spiennes Chalk

Generally quite granular chalk, sometimes becoming finely or coarsely calcarenitic, with a rough touch, yellowish-white, very rich in decimetric to pluridimetric flints arranged in more or less visible beds in the quarry. The base of the Spiennes Chalk is always marked over 2 to 3 meters (sometimes 1 m but up to 4 to 5 m) by a calcarenitic chalk containing reddish phosphatic gravels, 2 to 10 mm in diameter, irregular, sometimes perforated. In the absence of a hardground at the top of the Nouvelles Chalk, this level of phosphatic gravels is an excellent marker for placing the Spiennes Chalk. Fossils and bioclasts are often associated with it, with whole or fragmented Belemnitella mucronata, valves of various lamellibranchs, and fragments of inoceramids with prismatic tests 2 to 4 mm. Between 5 and 10 meters above this phosphatic gravel level, a second level is sometimes noted over 3 to 5 meters thick, also with reddish phosphatic gravels, whole or fragmented fossils, and also bioturbations filled with yellowish calcarenite. The greatest thickness of the Spiennes Chalk is more than 40 meters around the quarry. It is in this formation that the black flints of the Neolithic mines of Spiennes were exploited.

Fracturing and Deformation of the White Chalk

A stress tensor investigation based on striated faults was performed in the white chalk formations of the Mons Basin. The measured faults and joints affect the top of the Trivières Chalk, Obourg Chalk, Nouvelles Chalk, and Spiennes Chalk, all of Campanian age. The displacement of the normal faults is on the order of a meter. Normal faults often appear in characteristic conjugate systems forming grabens.

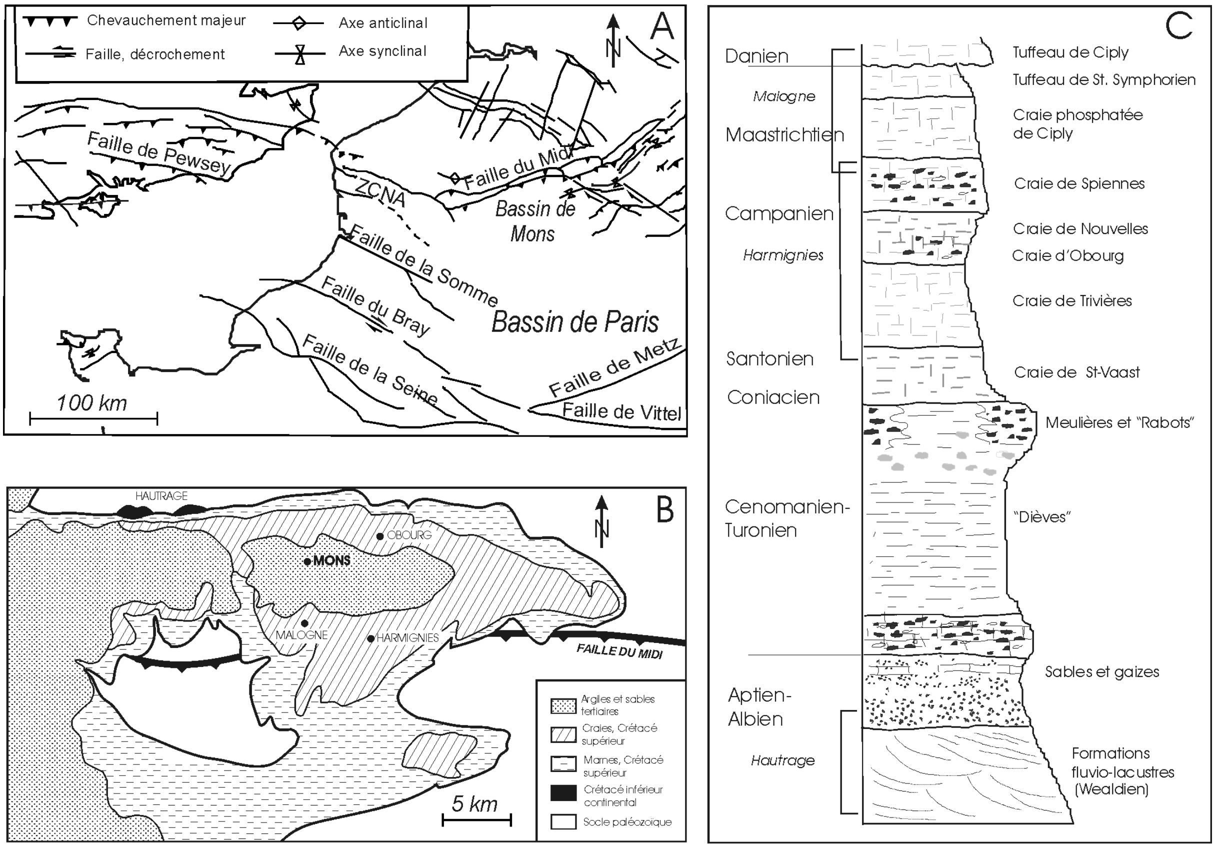

Figure 1 (A): Schematic structural map of the northern Paris Basin, ZCNA: North Artois Shear Zone, (B): geological map of the Mons Basin with the location of the sites presented below, (C): Characteristic lithostratigraphic succession of the Mons Basin with the location of the facies encountered at the Harmignies site.

Different fault systems have been identified (Figure 4):

1) Normal faults trending NE-SW induced by NW-SE extension affect all observed formations. In the Spiennes Chalk, of upper Campanian age, these faults are filled with black flint connected to the flint levels of the chalk. This system is not identified in formations younger than the upper Campanian and is thus dated to the syn-Cretaceous, upper Campanian.
2) Strike-slip faults induced by an NE-SW extension/NW-SE compression system (identified as synsedimentary in the lower Maastrichtian). The dextral faults trending E-W are sometimes accompanied by Riedel fractures trending N140°.
3) Normal faults trending NW-SE induced by NE-SW extension posterior to the two previous systems. Three extension joint networks also appear, trending NE-SW, E-W, and NW-SE, with a predominance of the latter direction NW-SE (Vandycke and Bergerat, 1989, Vandycke, 1992) (Figure 3).

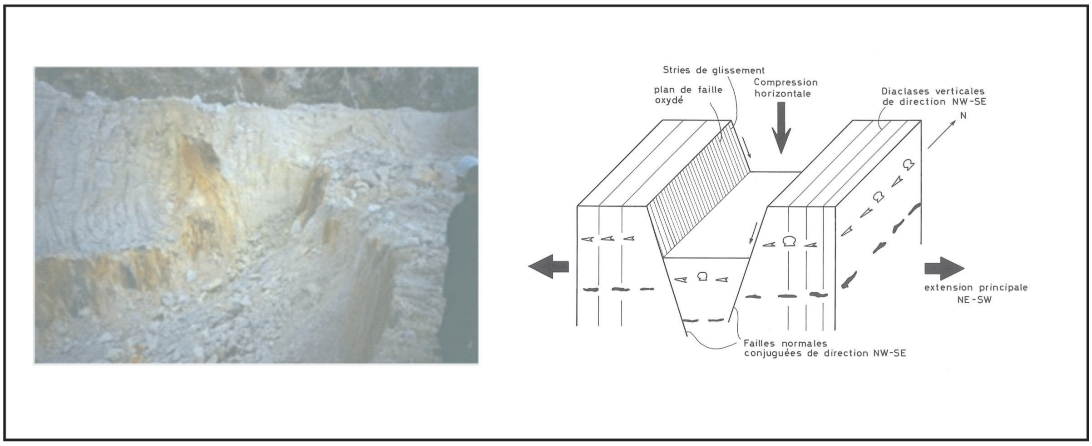

Figure 2 : Example of a graben in the white chalk. The fault planes are striated, colored, and characterize perpendicular extension. It is in this type of graben that the quantification of chalk deformation was undertaken.

Figure 3. Decametric joints, regular, marked by a brownish to blackish coloration in the white chalks of Harmignies.

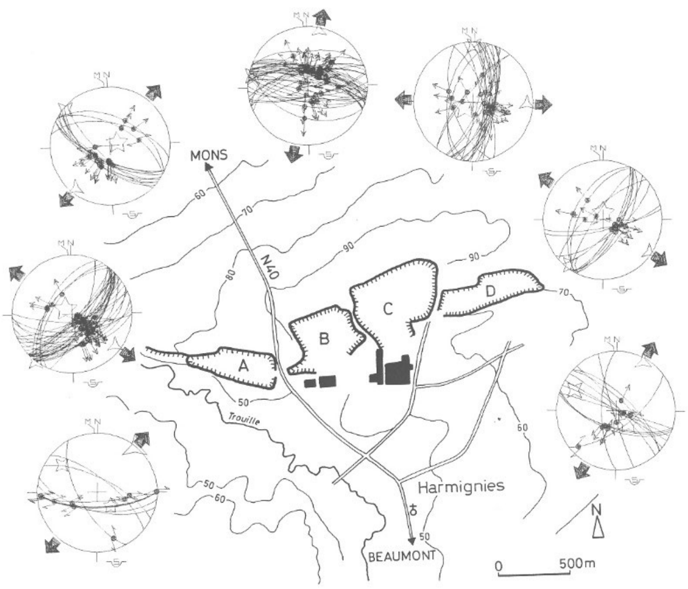

Figure 4. Striated faults and stress tensors calculated from measurements in the white chalk formations outcropping in the quarries (A, B, C, D) of Harmignies (Gaviglio et al., 1997). Quarry D is the currently exploited quarry. Stereographic projections (Schmid net, lower hemisphere) of the fault planes with striations and the calculated stress axes, stars with 5, 4, 3 branches respectively for σ1, σ2, σ3 of the stress tensor.

Study of Brittle Deformation

To evaluate the transformations accompanying the formation of a normal fault in white chalk, several profiles perpendicular to multiple fault planes were created by manual sampling and then by coring (Figure 5). At Harmignies, in particular, the first experiments were conducted on the faults of a small graben (Figure 2) (Gaviglio et al., 1993; 1997; 1999). Modifications in the chalk texture were thus highlighted near the fault plane. They manifest as a decrease in porosity and pore size, due to material redistribution by compaction, dissolution, and cementation. These modifications are thought to be induced by compaction and pressure-dissolution processes (Gaviglio et al., 1993). Examination of a material slice under an electron microscope, through image analysis and tomography, shows the presence of partitions and large pores forming a network of channels (Figure 6).

Sonic velocity and porosity measurements, thanks to the close correlation between these characteristics, have highlighted significant, progressive texture variations related to matrix deformation from the fault plane. These measurements were taken on samples from the same profiles, between 0 and 30 cm from a normal fault plane. The use and adaptation of a microcracking index derived from sonic velocity (Schroeder et al., 2006) indirectly showed the effects of material cementation. Since sonic velocity measurements are fast and non-destructive compared to porosity measurements, more systematic experimental investigations could be conducted (Darquennes, 2005). Other investigations were undertaken in the Campanian chalk of Lixhe (East Belgium). It seems that deformation is more intense in the Mons Basin. This is interpreted as a more significant influence of the tectonic context.

Figure 5. Example of parallel and perpendicular sampling to the fault plane by coring.

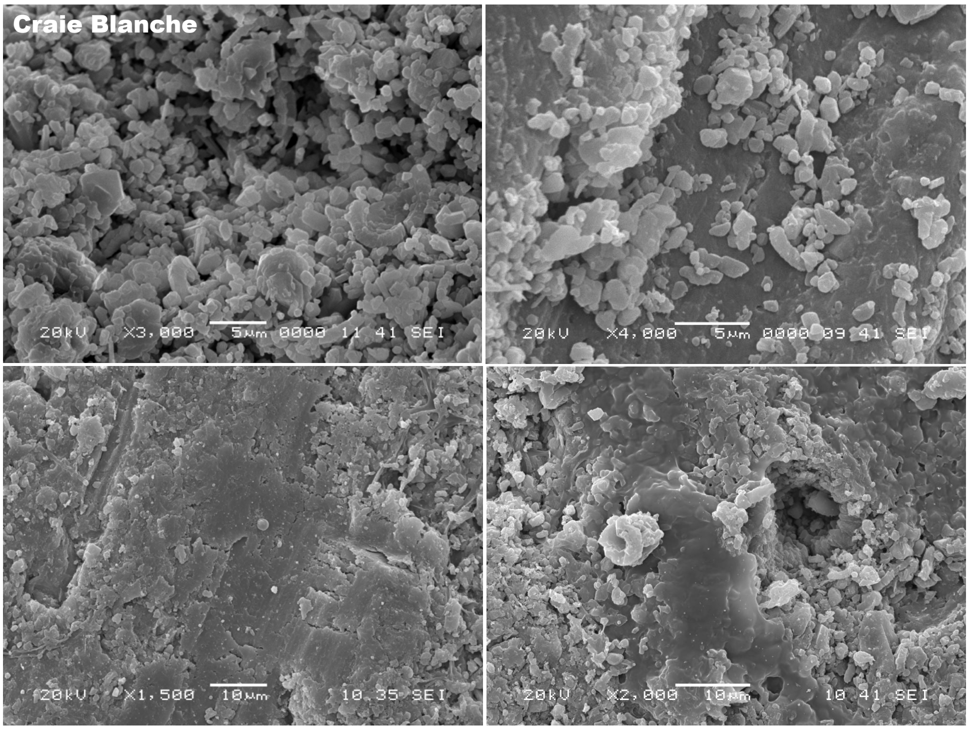

Figure 6. Electron microscope images of chalk on a fault mirror and its surroundings. Top left, undeformed chalk with its coccolith aggregates, some pores, and newly formed calcite crystals. Top right and bottom left, detail of the mirror striations, bottom right, a pore on the fault mirror surface.

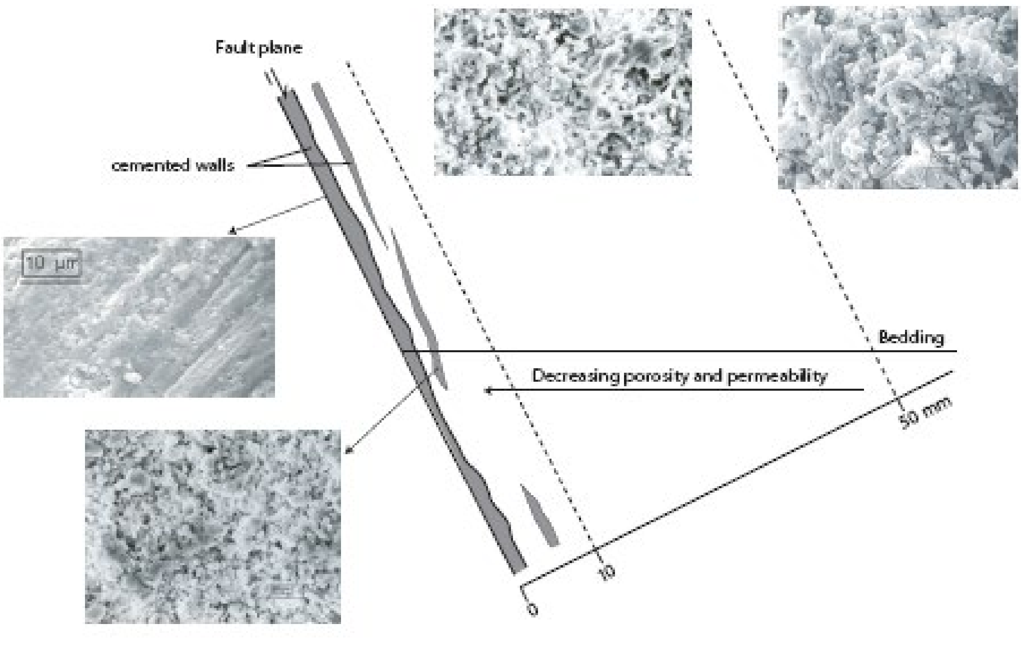

Figure 7. Matrix deformations at the fault walls (Gaviglio et al., 2009). Different textural modifications of the chalk are observed depending on the distance from the fault plane.

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STOP 3

La Malogne Quarry
(Ciply Phosphatic Chalk Fm)
Maastrichtian

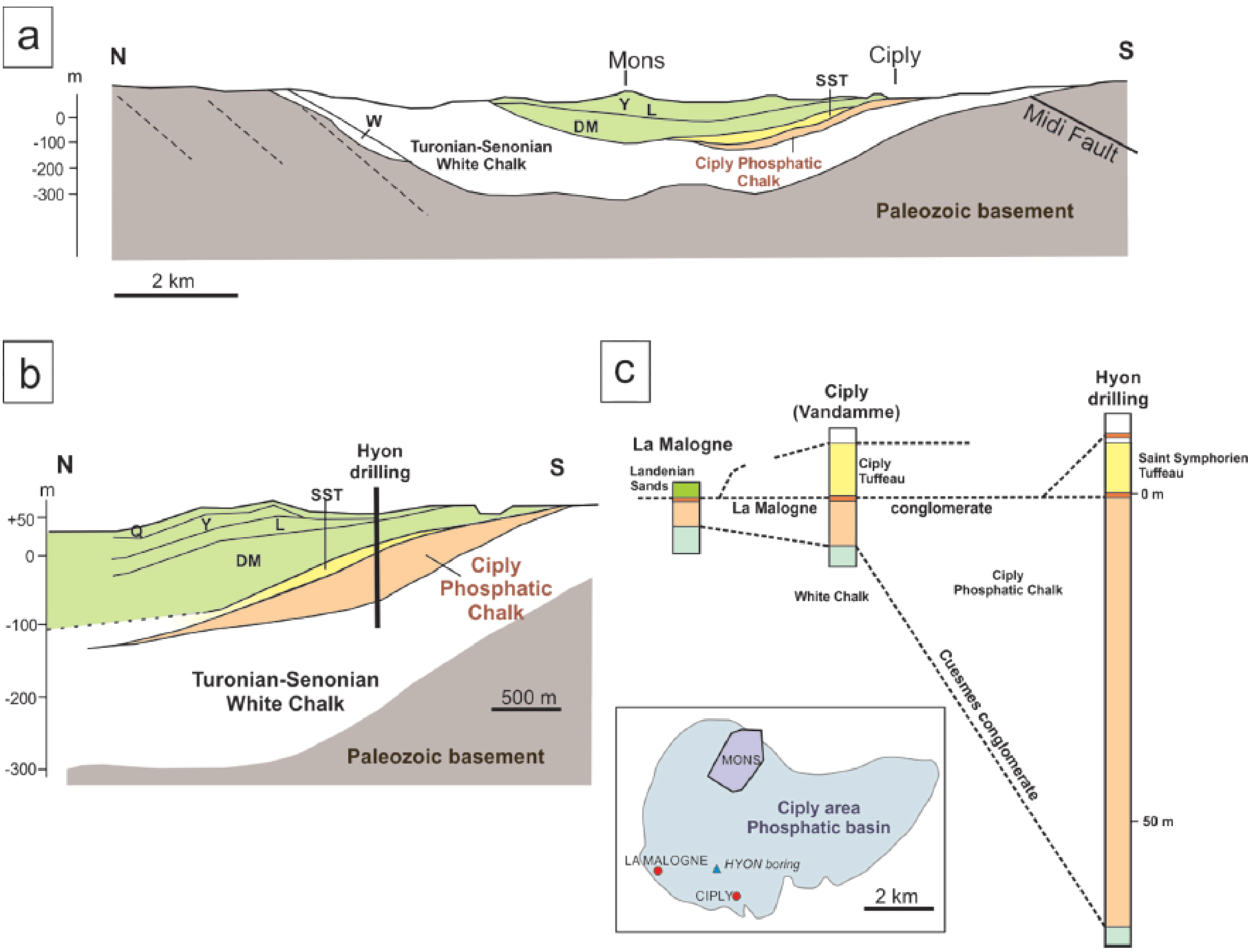


Figure 1. a. North-south geological section of the Mons Basin. W: Wealden facies; SST: Saint-Symphorien Tuffeau; DM: Danian and Selandian (former Montian); L: Thanetian (former Landenian); Y: Ypresian. From Robaszynski & Martin (1988); b. Detail of the southern part of the section presented based on data given by three old boreholes (M108 to 114) and the Hyon drilling and showing the lenticular feature of the phosphatic basin. From Robaszynski & Martin (1988); c. Variation in thickness of the Ciply Phosphatic Chalk from six lithological outcropping sections and one borehole from the southern to the eastern border of the Ciply area. From Mortimore et al. (2017).

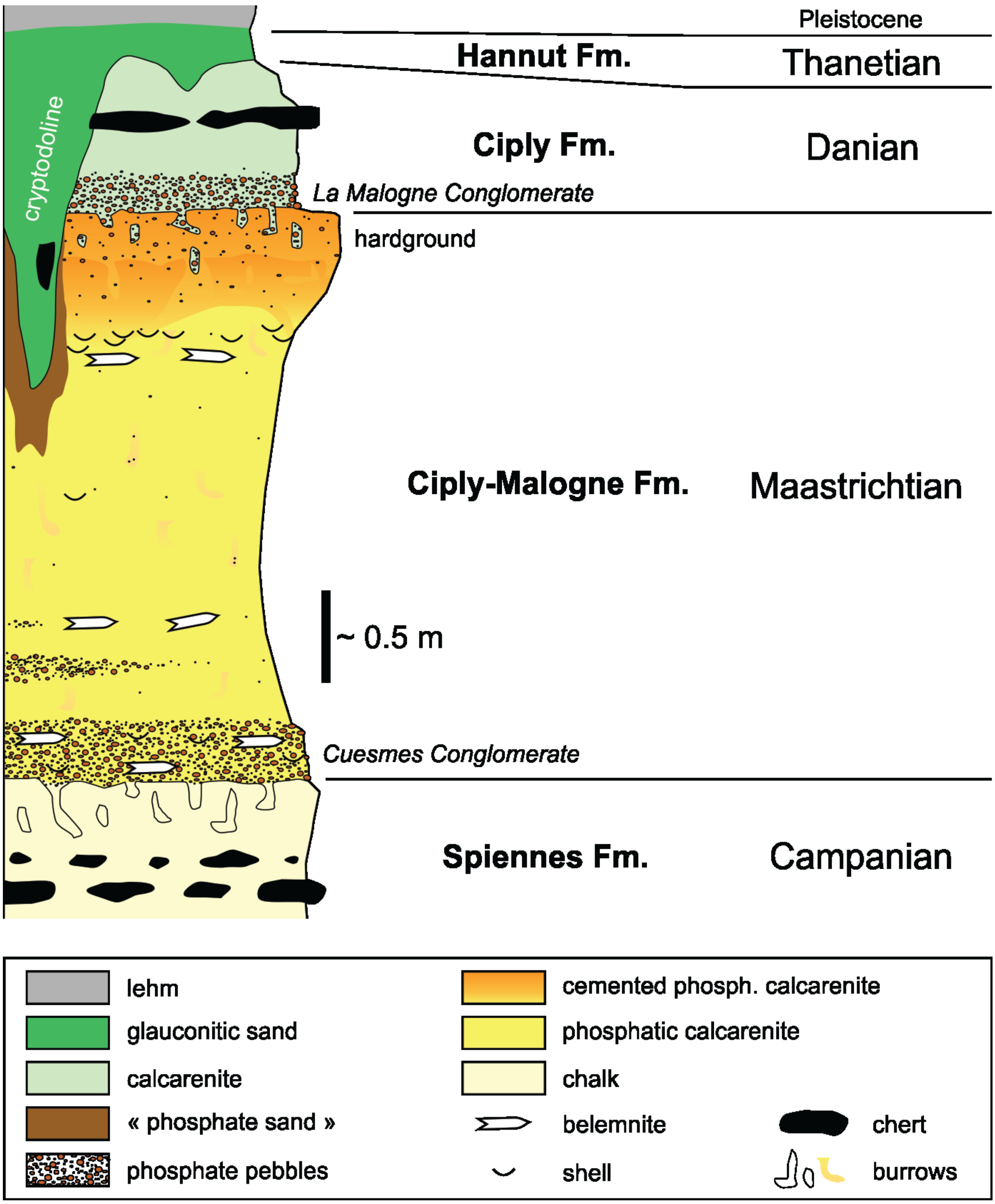
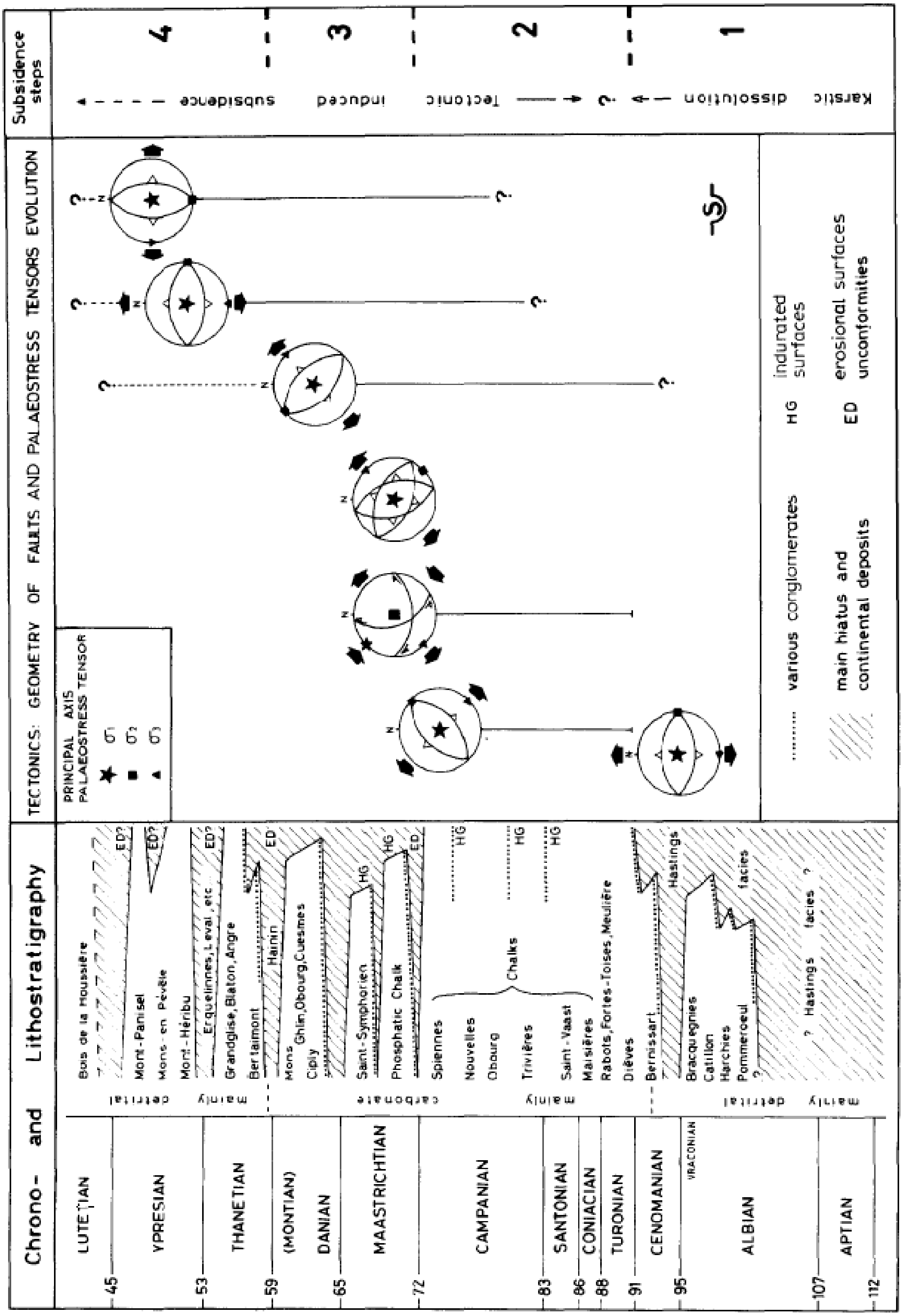


Figure 2. Stratigraphic section of the La Malogne underground quarry. From Baele and Hennebert (2016), modified after Vandycke (1987).

Figure 3. Palaeostress field exhibits a fast evolution in relation to the intermittent subsidence and the stratigraphic succession in the Mons Basin. Note that the succession of brittle deformation of the tectonism during the Late Cretaceous, characterized by inversions of principal stress axes. These tectonics coincide with drastic changes in both subsidence trends and lithological record. Later, the tectonic stress field becomes entirely extensional. (Vandycke et al., 1991)


Chrono- and Lithostratigraphy
TECTONICS: GEOMETRY OF FAULTS AND PALAEOSTRESS TENSORS EVOLUTION
Subsidence steps
PRINCIPAL AXIS PALAEOSTRESS TENSOR
σ1
σ2
σ3
LUTETIAN
YPRESIAN
THANETIAN
(MONTIAN)
DANIAN
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
VRACONIAN
ALBIAN
APTIAN
45
53
59
65
72
83
86
88
91
95
107
112
mainly detrital
mainly carbonate
mainly detrital
Bois de la Houssière
Mont-Panisel
Mons-en Pévèle
Mont-Héribu
Erquelinnes, Leval, etc
Grandglise, Blaton, Angre
Bertaimont
Hainin
Mons
Ghlin, Obourg, Cuesmes
Ciply
Saint-Symphorien
Phosphatic Chalk
Spiennes
Nouvelles
Obourg
Chalks
Trivières
Saint-Vaast
Maisières
Rabots, Fortes-Toises, Meulière
Dièves
Bernissart
Hastings
Bracquegnies
Catillon
Harchies
Pommeroeul
Hastings facies
facies
ED?
ED
HG
Karstic dissolution
Tectonic induced subsidence
1
2
3
4
various conglomerates
main hiatus and continental deposits
HG indurated surfaces
ED erosional surfaces unconformities

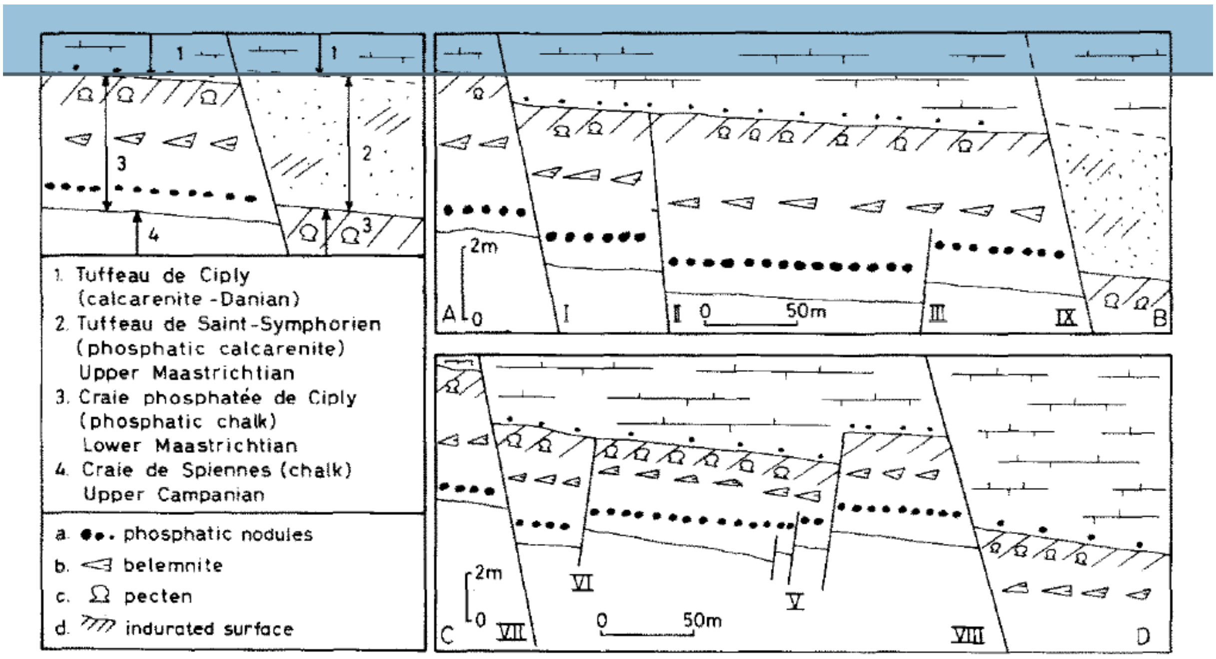


Figure 4: Stratigraphic and tectonic cross-sections in the "La Malogne" underground quarry. The present appearance of the faults results from several Maastricht and Tertiary motions. Strike-slip and normal synsedimentary systems were active during the Early Maastrichtian (Vandycke et al., 1991)

A detailed study was carried out in the"La Malogne" abandoned underground quarry. In this quarry, synsedimentary tectonic events which occurred during the Maastrichtian are particularly well developed. This area is characterized by horst and graben structures trending N120-130 o and N160-170. Approximately ten large faults or fault zones have been systematically surveyed on about 120 rock pillars in this underground quarry. The entire fault-slip data set contains 412 measurements (5 measurements per square metre. By a simple analysis of the geometry of the fault population in the "La Malogne" quarry, tectonic events can be identified which correspond to (1) strike-slip faulting (Early Maastrichtian) (Vandycke et al., 1988) and (2) synsedimentary normal faulting (Maastrichtian and Early Tertiary). The strike-slip Early Maastrichtian fault population consists essentially of NNW-SSE and NW-SE right-lateral strike-slip faults which are characterized by horizontal ur and u, axes, trending NW-SE and NE-SW respectively. The analysis of normal and strike- or obliqueslip faulting was dealt with separately, for the sake of clarity. Computations yielded well defined tensors which correspond to two stress-fields with, in both cases, horizontal trending NE-SW u3 axes. Permutations between u, and a, axes occurred in a vertical plane trending NW-SE. These relationships suggest that both strike-slip and oblique- or dip-slip faulting belong to the same tectonic regime. In fact, the pull-apart process probably began with strike-slip movements (some fault planes show the superposition of two generations of slickenside lineations) and progressed towards oblique- and dip-slip movements. Qualitative observations and quantitative analyses provide good information about the structural evolution of the "La Malogne" area, with approximately E-W trending right-lateral strikeslip faulting and associated NW-SE to NNW-SSE trending dip-slip faulting, during Early Maastrichtian times. This model is consistent with a rightlateral strike-slip motion along the "Nord-Artois" Shear Zone and the pull-apart development of the Mons Basin (Vandycke et al., 1988). This structural evolution is also consistent with Late Maastrichtian and Tertiary normal faulting, sometimes reactivating the pre-existing normal faults.

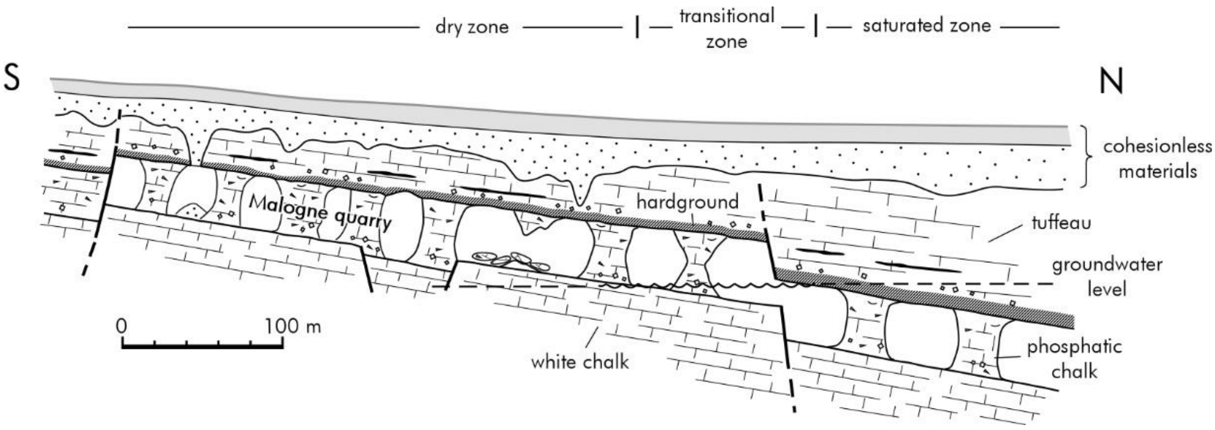


Figure 5: Schematic cross-section (not scaled) of the Malogne phosphatic chalk quarry (modified after Pacyna, 1992) with the area of the dry, transitional, and water-saturated zones.

Minerals	Phosphatic chalk (%)	Hardground level (%)
Calcite	58.81	68.98
Apatite	38.04	28.80
Quartz	1.02	0.65
Others	2.13	1.57

Figure 6 : Average mineral composition of the samples based on QEMSCAN analysis

Lithology of the Ciply Phosphatic Chalk

The Ciply Phosphatic Chalk is not a phosphorite, which is defined as containing more than 18% P2O5 (Slansky, 1980). It is a light brown phosphatic calcarenite with P2O5 grades around 10% (Robaszynski & Martin, 1988). The rock is generally friable and can be broken down between the fingers. It is made up of mostly two types of particles: (a) very fine carbonate particles (such as intraclasts, bioclasts and coccoliths; size less than 0.05 mm, with a P2O5 content of about 1.5 to 2%); and (b) coarser carbonate and brown phosphate particles (0.100-0.270 mm, with a P2O5 content of about 14%) consisting mainly of microfossil fragments, rounded granules of more or less phosphatic white, yellow to brown grains, faecal pellets, bioclasts, intraclasts and small calcite crystals (Robaszynski & Martin, 1988).

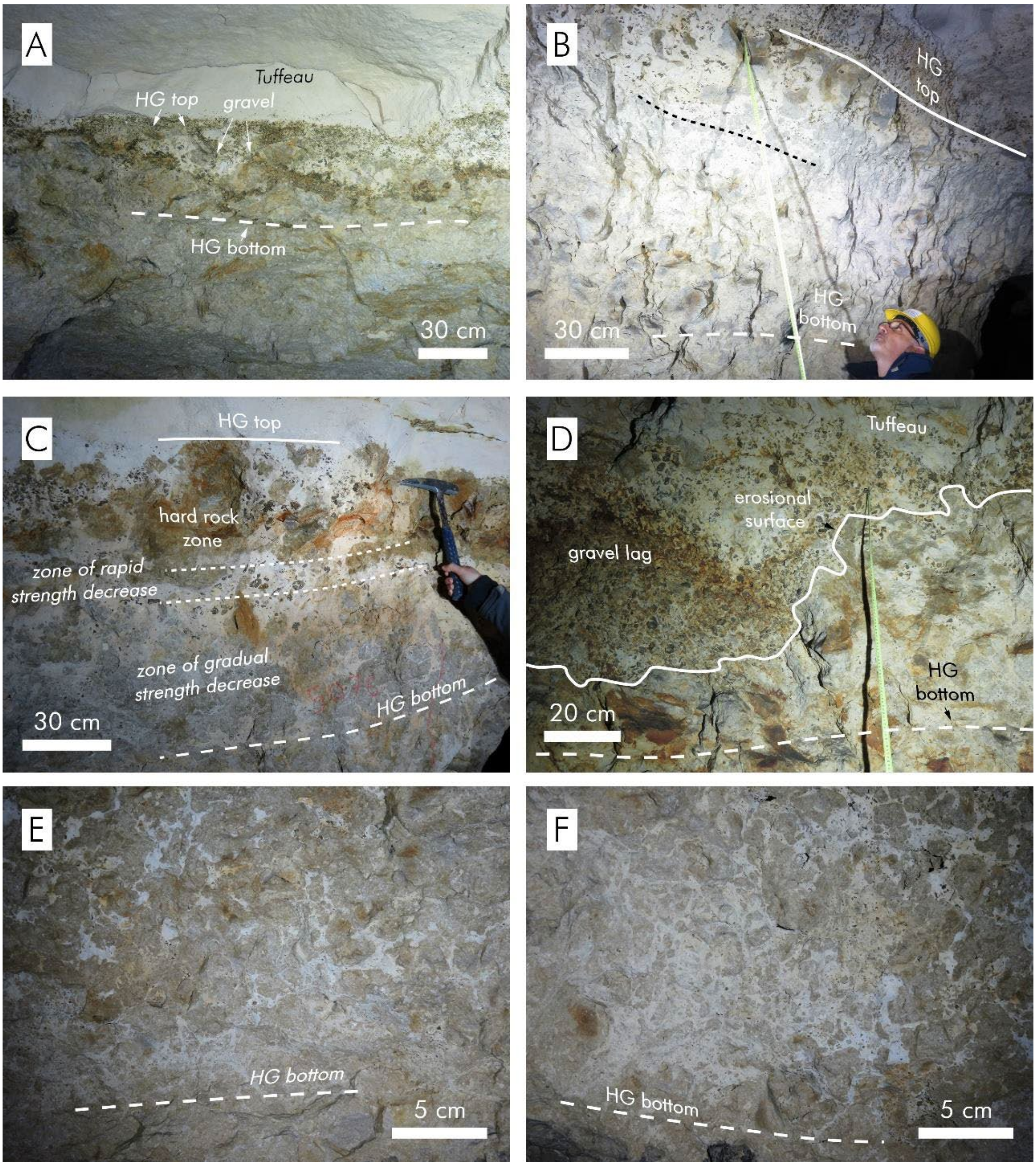


Figure 5: Vertical profiles of hardground level: (a) 40 cm thick interval, with intensively burrowed upper half and very random as amount and size burrowing of the gravel infill; (b) development of over 1.2 m thick interval that upper one-third (35 cm) is intensively burrowed; (c) 60 cm thick interval with pronounced strength zonation. The false "cobble-size intraclasts" along the top are due to the prevailing horizontal over the vertical host rock burrowing at the end of the hardground level formation. The zone of rapid strength decrease here is intensively burrowed with an increased presence of calcarenite/gravel infill; (d) about 50 cm deep erosion of 70 cm thick level filled by dm thick gravel lag. The 23 cm thick zone of high strength on top of the level is completely eroded. The ir-regularity of the erosional surface is due to the intensive host; (e) low intensity (about 15 %) irregular distributed and (f) very intensive (over 50 %) burrowing documented just above the bottom of 65 cm thick level. The distance between the photos is about 3 m. (Georgieva, 2022)

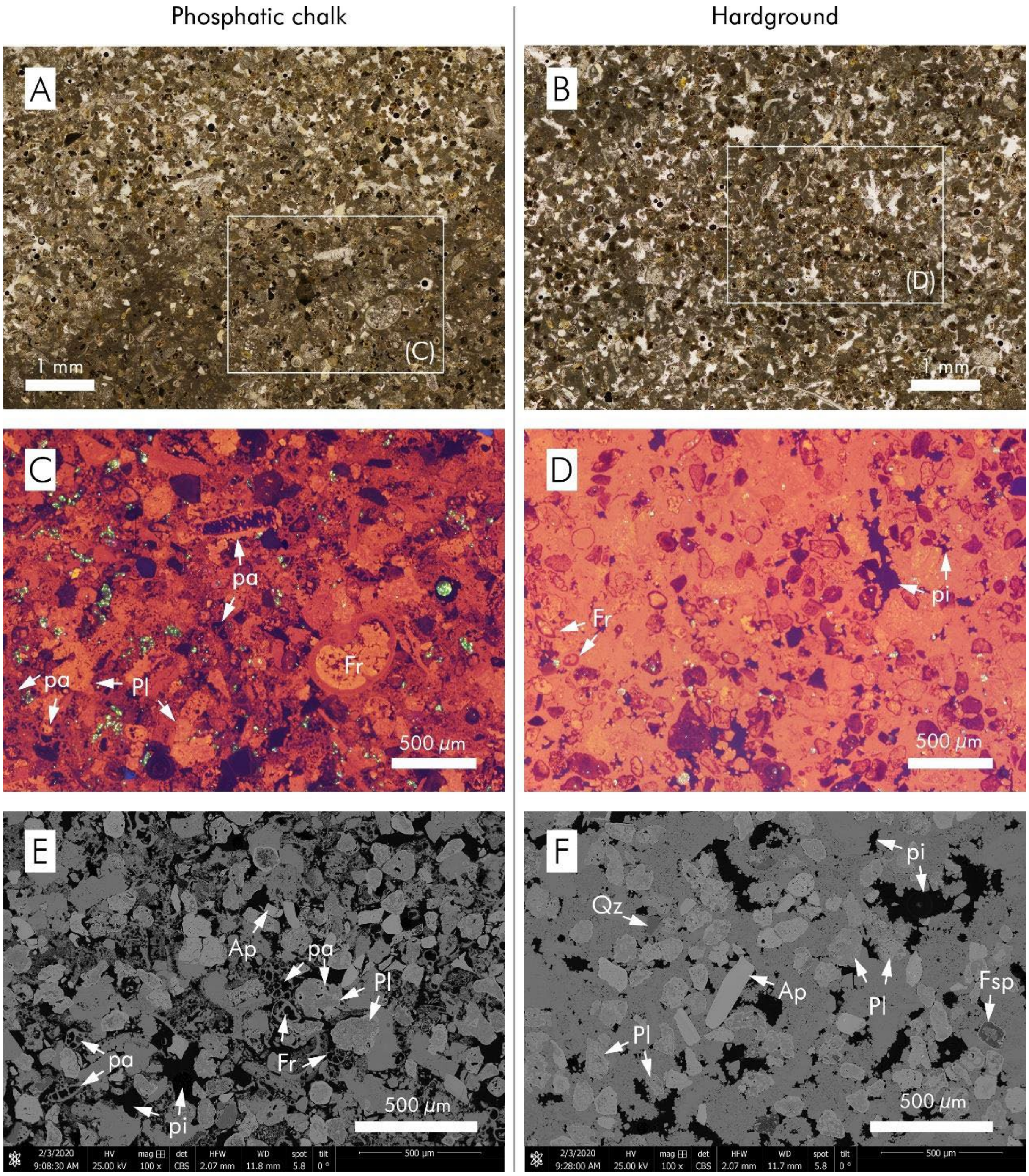


Figure 6: Thin section study of phosphatic chalk (left column) and hardground level (right column) samples: (a-b) transmitted light microscope images; (c-d) cathodoluminescence (CL) photomicrographs; (e-f) back-scattered electrons (BSE) images. Abbreviations: Ap- apatite; Fsp - feldspar; Fr - foraminifera; pa - intragranular porosity; pi - intergranular porosity; Pl - pellets; Qz - quartz. (Georgievia, 2022)