Chapter 4

THE PALAEOENVIRONMENTAL CONTEXT AND CHRONOSTRATIGRAPHIC FRAMEWORK OF THE SCLADINA CAVE SEDIMENTARY SEQUENCE (UNITS 5 TO 3-SUP)

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1. Introduction

Since the first professional excavations in 1978 (see Chapter 2), numerous studies regarding palaeoenvironment and chronostratigraphy have occurred at Scladina Cave. This chapter presents a synthesis of these analyses, focusing on the layers concerning the Neandertal child (Scladina I-4A) problem, i.e., layers from sedimentary units 5 to 3-SUP (see Chapter 3). Several analyses are still in progress or will start in the very near future (e.g., palynology, heavy mineralogy, and dating); therefore, the results delineated below solely represent the progress of current scientific endeavours at Scladina Cave.

Most of the available data were obtained before the stratigraphic reappraisal began in 2003 (Pirson et al., 2005; Pirson, 2007; see Chapter 3). In the former stratigraphic record, the deposits that are addressed in this chapter were divided into 4 distinct layers (layers 5, 4B, 4A, and 3; Figure 1a). Since the stratigraphic revision, the same deposits now encompass more than 25 layers, which are grouped into 8 main units (units 5, 4B, 4A-AP, 4A-IP, 4A-CHE, 4A-POC, 3-INF, and 3-SUP; Figure 1b). This situation limits the possibility for detailed comparisons between the 2 data sets (see Chapter 3). In order to avoid confusion, whether the data is from the former stratigraphic record (e.g., 'former Layer 4A') or from the current one (e.g., 'Layer 4A-KG') will be systematically specified.

An attempt at integrating all the disciplines involved in palaeoenvironment and chronostratigraphy is presented below, first for the palaeoenvironmental context and then for the chronostratigraphic framework.

2. Palaeoenvironmental context

The most numerous results dealing with the palaeoenvironment of the Scladina Cave sequence come from palaeobotany and palaeozoology.

Palynology was the subject of several papers in the 1980s-1990s (Schneider in Otte et al., 1983; Bastin & Schneider, 1984; Bastin et al., 1986; Schneider, 1986[a], 1986[b]; Bastin, 1990, 1992). Y. Quinif (2006) recently published some of B. Bastin's unpublished data. Finally, M. Court-Picon and F. Damblon undertook new palynological studies within the framework of the Scladina stratigraphic reappraisal (Pirson, 2007; Pirson et al., 2008), complemented by some anthracological data obtained by F. Damblon (Pirson, 2007; Pirson et al., 2008).

A few papers also deal with small mammal remains (Cordy in Bastin et al., 1986; Cordy, 1988, 1992) and macrofauna (Gautier in Otte et al., 1983; Cordy, 1984, 1988; Cordy in Bastin et al., 1986; Simonet, 1992; Patou-Mathis, 1998[a]; Lamarque, 2003). These faunal results only refer to the former stratigraphic record; the study of the material unearthed after the stratigraphic reappraisal is still in progress. Macrofaunal data are complemented by archaeozoological data (Patou-Mathis, 1998[b]; Patou-Mathis & López-Bayón, 1998; Abrams et al., 2010, 2014).

A synthesis of the palaeontological data was presented in the first monograph for Scladina Cave (Cordy & Bastin, 1992).

Geologic inquiry also yields information about the climatic changes in the Scladina sequence. The first palaeoenvironmental interpretations that were deduced from stratigraphy and sedimentology gave very little reliable data. While Haesaerts (1992) remained very careful, insisting on the lack of reference for cave entrance sequences in Belgium, the palaeoenvironmental reconstruction of Gullentops & Deblaere (1992) was based on a model of sedimentogenesis in cave entrances which is no longer valid (see Pirson, 2007). In 1999, sampling for a magnetic susceptibility study of sediment from Scladina took place. It yielded interesting

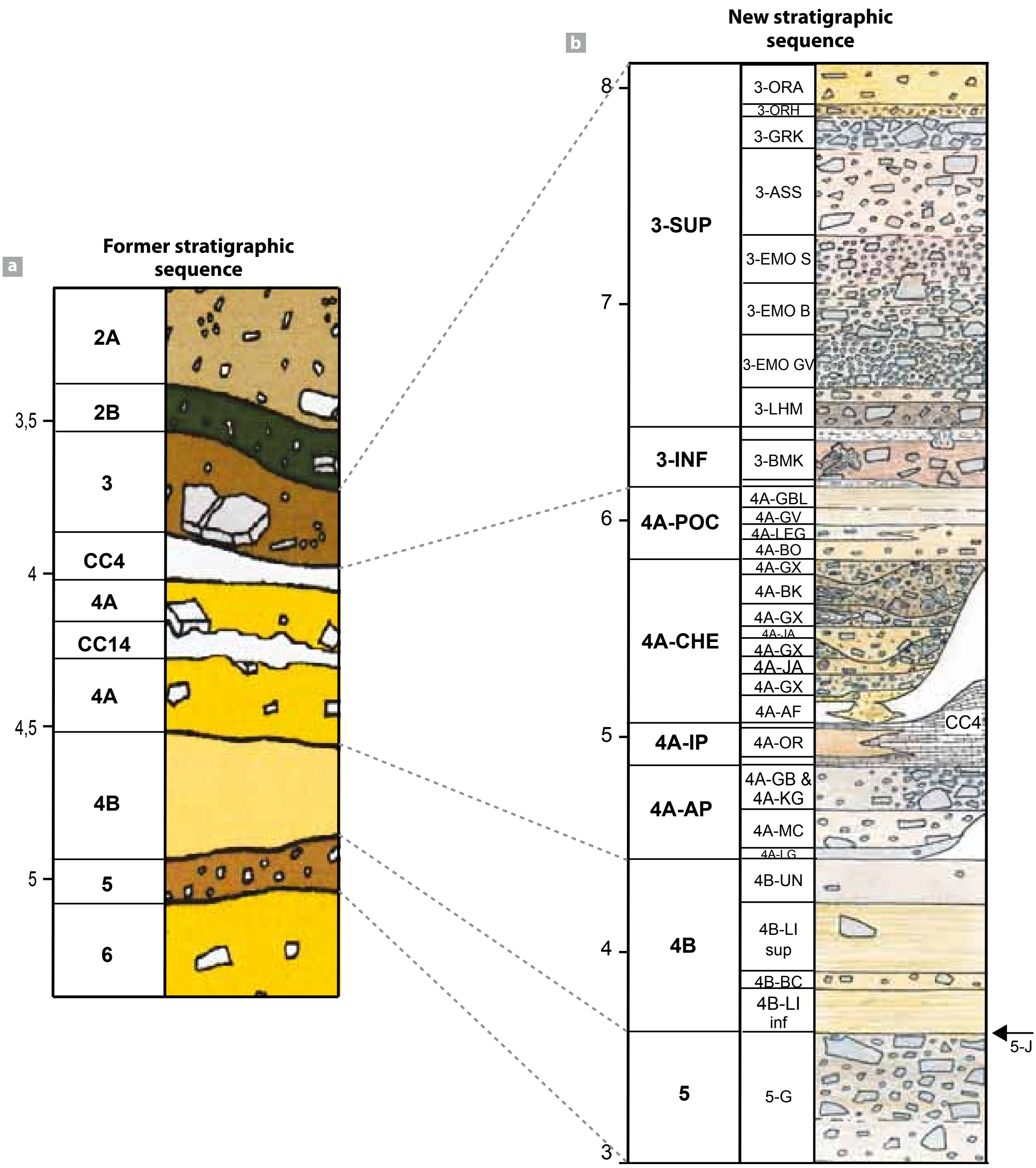


Figure 1: The former stratigraphic sequence of Scladina Cave (a; after Bonjean, 1998) compared with the new stratigraphic sequence of Scladina Cave (b; after Pirson, 2007).

palaeoenvironmental information (Ellwood et al., 2004; Figure 2), which was overall in excellent agreement with palaeontological data. Finally, quite recently, a detailed study of the sedimentary and post-sedimentary processes in the Scladina sequence allowed a set of well-documented climate changes to be evidenced (Pirson, 2007; Pirson et al., 2008).

All the available palaeoenvironmental information for units 5 to 3-SUP is presented below, from the oldest to the youngest (see Figure 3).

2.1. Unit 5

Unit 5 is comprised of 2 distinct layers: 5-G and 5-J (see Chapter 3; Figure 1b).

The presence of a linear fabric (*sensu* Bertran (dir.), 2004) affecting limestone fragments in Layer 5-G suggests the influence of solifluction (Pirson, 2007), which is a slow downslope displacement of sediments involving 2 processes linked with ground ice formation (frost-creep and gelifluction; Bertran (dir.), 2004). This sedimentary process is typical of periglacial environments and therefore has a clear climatic signature.

A cold climate is further attested by the presence of a thick (4-10 mm) platy structure that developed in Unit 6A, Layer 5-G being the upper part of the cryosol (see Chapter 3). This kind of feature indicates deep frost (Van Vliet-Lanoë, 1988). In Middle Belgium loess sequences, a thick platy structure is regularly observed and is interpreted as evidence for the continuous growth of ice lenses (i.e., during several years) in the upper part of permafrost (Haesaerts & Van Vliet-Lanoë, 1981; Haesaerts, 1983; Van-Vliet-Lanoë, 1988).

The new palynological study (Court-Picon & Damblon in Pirson, 2007; Pirson et al., 2008) obtained from Layer 5-G suggests cold steppic conditions with a relatively open landscape (15-20% AP) in which tree genera indicate boreal environment (*Pinus*, *Juniperus*, *Betula*). Very low frequencies of *Quercus* are also recorded.

Comparing these new results with those available in the literature is possible because the now-understood Unit 5 is not very thick and contains only a few layers. Therefore, the equivalence between Unit 5 and former Layer 5 is well controlled and easily translatable.

Palaeontological data (palynology, small mammals, and macrofauna) from former Layer 5 suggest the existence of a cooling by a decrease of the tree cover compared to the underlying former Layer 6. Small mammals evidence the return of arctic taxa (Cordy, 1992). In the upper half of former Layer 5, palynology indicates steppic conditions (<10% AP; Bastin, 1992); however, small mammals and large herbivores show the persistence of forest taxa (up to 25%: Cordy, 1992; Simonet, 1992) and the bottom of former Layer 5 still yields 50% AP, including some mesophilous trees (Bastin, 1992) that could be related to the low *Quercus* content from the new palynological data.

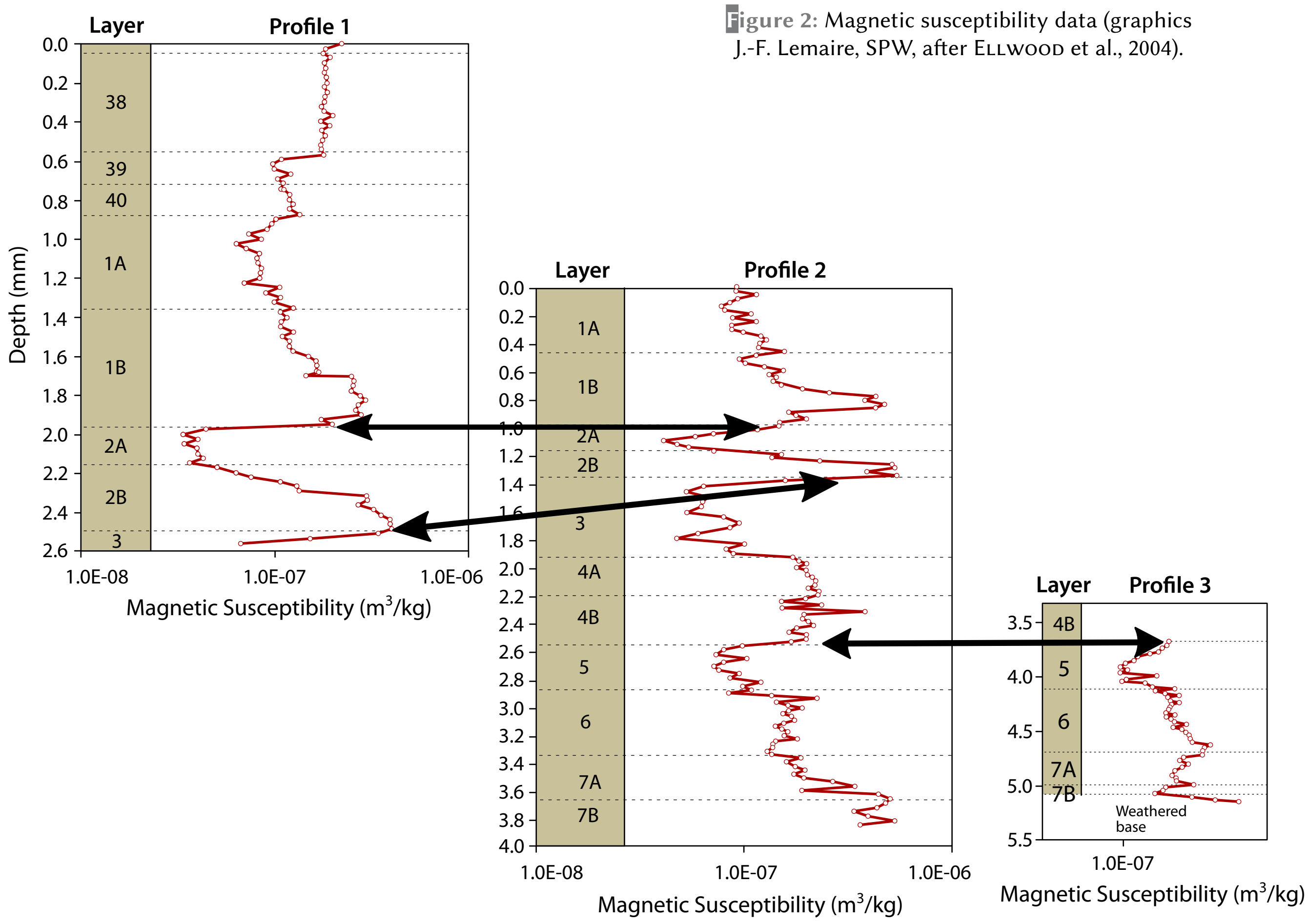


Figure 2: Magnetic susceptibility data (graphics J.-F. Lemaire, SPW, after Ellwood et al., 2004).

The magnetic susceptibility signal also suggests the existence of a cooling in former Layer 5 (Ellwood et al., 2004; Figure 2).

2.2. Unit 4B

Unit 4B is composed of 2 main layers: 4B-LI and 4B-UN (Figure 1a). Locally, other layers have been recognized; some are interbedded with 4B-LI, while Layer 4B-UF corresponds to a lateral variation of 4B-UN (see Chapter 3).

Depositional and post-depositional processes identified in Unit 4B (Pirson, 2007; see Chapter 3) do not yield any climatic information; the fall of large stone slabs, run-off, settling, and dessication cracks are ubiquitous processes (Bertran (dir.), 2004).

On the other hand, new palynological data from Unit 4B indicates arid open steppic conditions (Court-Picon & Damblon in Pirson, 2007; Pirson et al., 2008). The 6 samples from layers 4B-LI and 4B-BC are largely dominated by steppic plants (<5% AP); the trees are mainly represented by *Pinus* and *Juniperus*. The top of Unit 4B, only documented by a single sample from Layer 4B-UN, shows a slight rise of the conifers (ca. 20%), almost exclusively *Juniperus*. Spores of algae increase in frequency. Thus, Layer 4B-UN could represent the beginning of the major climatic improvement recorded in Sedimentary Complex 4A (§ 2.3).

The connection between these new geological and palynological data and the data from the literature is globally possible. The palynological signal from former Layer 4B (Bastin, 1992) is very close to what was recently obtained from Unit 4B (5-10% AP, *Pinus* dominating the trees). Small mammals indicate a similar trend on the cave terrace (Layer V gris), with the disappearance of temperate forest taxa, insectivores, and bats, and the strong return of the collared lemming (Cordy, 1992). On the contrary, the magnetic susceptibility signal indicates different conditions: a climatic improvement in both former layers 4B and 4A (Ellwood et al., 2004). New analyses should be undertaken in order to better understand this apparent contradiction.

Large mammals from former Layer 4B are difficult to use for climatic reconstruction because they were originally mixed and studied together with the objects from former Layer 4A, creating the 'former Layer 4' assemblage (Simonet, 1992). The probable equivalent of former Layer 4B on the terrace (Layer V gris) is deprived of any faunal remains (Simonet, 1992). In addition, former Layer 4B, excavated inside the cave after Simonet's study (i.e., between 1991 and 2003), as well as the different layers from the newly defined Unit 4B (layers 4B-UN, 4B-LI, etc.) that were excavated after the stratigraphic reappraisal (i.e., since 2003), are both extremely poor in macrofaunal remains. Therefore, it is probable that most of the large mammal remains labelled 'former Layer 4' come from former Layer 4A (cf. § 2.3.2).

2.3. Sedimentary Complex 4A

The correlation of both old and new data is much more delicate for Sedimentary Complex 4A. While the former stratigraphic system included only 1 layer (i.e., Layer 4A; Figure 1a), the stratigraphic reappraisal demonstrated a much greater complexity: 4 major units, encompassing more than 10 layers (Figure 1b; Pirson et al., 2005; Pirson, 2007; see Chapter 3). Strong lithological and geometrical variations have been identified, including the presence of an important gully structure. Given this context, former and new palaeoenvironmental results will be presented separately.

2.3.1. New results

2.3.1.1. Unit 4A-AP

Unit 4A-AP is comprised of 3 distinct layers, including (from bottom to top): 4A-LG, 4A-MC, and 4A-KG (Figure 1b). A fourth layer, 4A-GB, corresponds to a possible lateral equivalent of 4A-KG (see Chapter 3).

The sedimentary processes recognized in Unit 4A-AP (debris flow and/or run-off: Pirson, 2007; see Chapter 3) do not allow the identification of any specific climatic condition.

A single sample (from Layer 4A-KG) has been studied in the framework of the new palynological analyses (Court-Picon & Damblon in Pirson, 2007; Pirson et al., 2008). The amount of trees, especially *Pinus* and *Juniperus*, is much higher than in underlying layers (ca. 65%), while various malacophyll temperate taxa appear (*Quercus* and *Ulmus*). The presence of charcoal remains of *Quercus*, *Populus*, and *Prunus* in Layer 4A-KG (Pirson et al., 2008) confirms the local presence of mesophilous taxa. Algae levels peak in this layer. All of this suggests a clear climatic improvement in Layer 4A-KG, which could correspond to the beginning of the major climatic improvement recorded in the overlying Unit 4A-IP.

2.3.1.2. Unit 4A-IP

Unit 4A-IP contains 2 major lithologies. The first is a thick stalagmitic floor labelled CC4 that was identified during the early stages of excavation (e.g., Bastin et al., 1986; Gullentops & Deblaere, 1992). The second lithology is comprised of some silty deposits locally interbedded inside Speleothem CC4 (Figure 1b). These silty deposits are grouped into 3 distinct layers that have been distinguished in different areas of the cave (4A-OR, 4A-SGR, and 4A-YS; see Chapter 3).

Stalagmitic floors are classically used in palaeoenvironmental reconstructions of caves. They indicate climatic improvements (e.g., Quinif et al., 1994). Given the important thickness of CC4 and its large spatial distribution in the cave, this stalagmitic floor probably indicates a major climatic improvement. The silty deposits interbedded in CC4 (Layer 4A-OR and lateral equivalents) were laid down by run-off processes (Pirson, 2007) and therefore do not directly record any climatic information.

The existence of a strong climatic improvement in CC4 is further supported by a recent palynological study (Court-Picon & Damblon in Pirson, 2007; Pirson et al., 2008). Unit 4A-IP is represented by several pollen spectra from Stalagmitic Floor CC4 and from Layer 4A-OR.

The spectra from CC4 clearly point to forest conditions (50 to 80% AP) with relatively high percentages of various temperate malacophyll trees like *Ulmus*, *Quercus*, *Fraxinus*, and *Carpinus* coexisting with *Pinus* and *Picea*. The presence of sclerophyllous liana *Hedera* (up to 10%) is worth mentioning. The analyses have also provided evidence for a mass of woody microremains from vessels and tracheids. High amounts of monolete fern spores were also identified and are most probably linked to the increase of humidity around the cave. 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 determined with regard to other data.

On the contrary, the pollen spectra from Layer 4A-OR yielded much less tree pollen (ca. 25–35%), which is only boreal (*Pinus*, *Juniperus*, and *Betula*). Almost no temperate taxa were identified. They seem to correspond to a forest-steppe or even to cold steppic conditions. Further investigation is necessary to understand the apparent contradiction between CC4 and 4A-OR pollen assemblages. Nevertheless, a set of charcoal remains from malacophyll temperate taxa is preserved in Layer 4A-OR (*Quercus*, *Fraxinus*, and a Malaceae; F. Damblon in Pirson, 2007; Pirson et al., 2008), in good agreement with the pollen record of CC4. This demonstrates the local presence of malacophilous taxa during Unit 4A-IP.

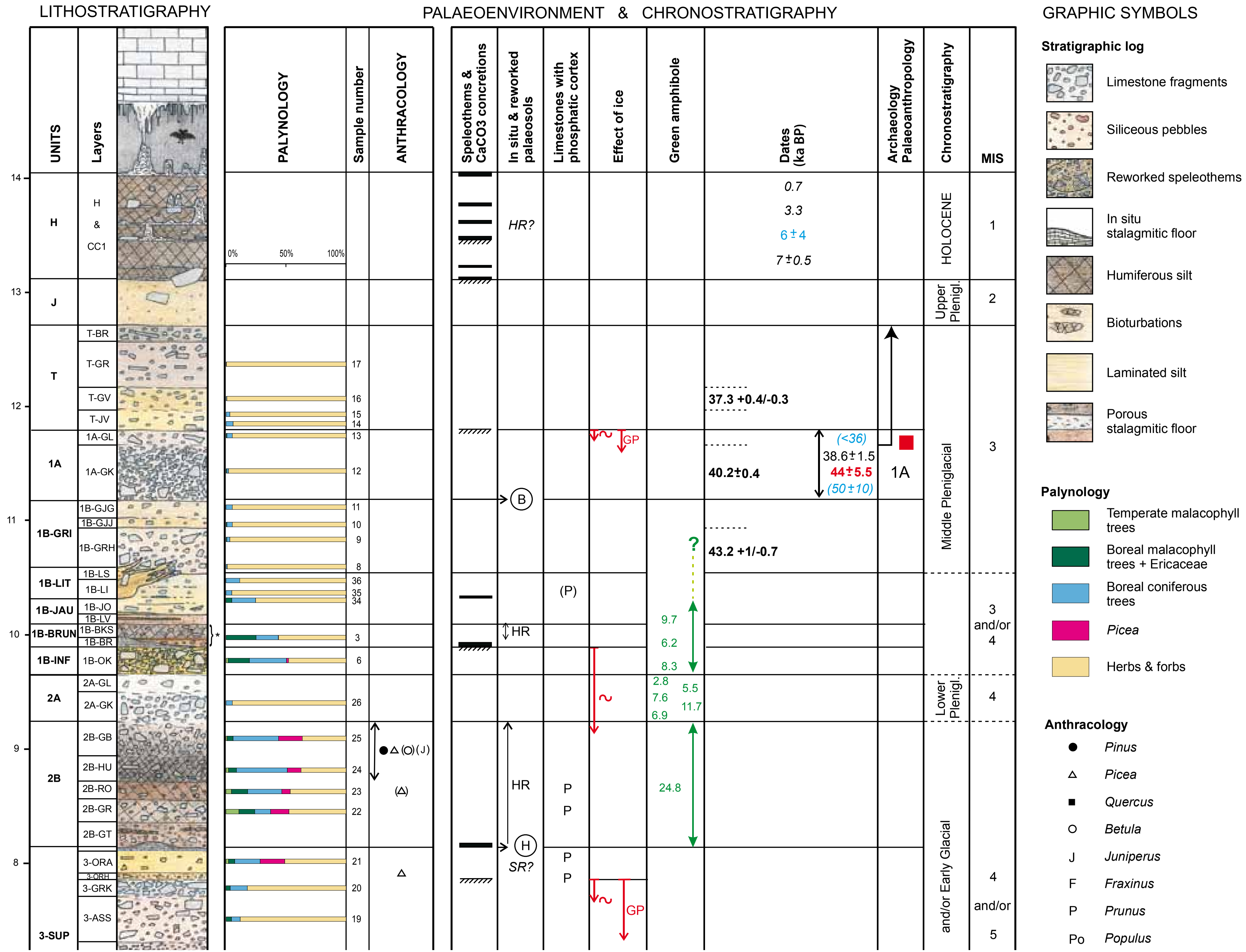
Figure 3 (next two pages): Scladina Cave's stratigraphic log including a synthesis of the palaeoenvironmental and chronostratigraphical data.

Green amphibole: the percentage of green 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 obtained in Groningen, 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 (TL) and on sediment (IRSL);
— green: coupled 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: suggested chronostratigraphic interpretation of the Scladina sequence based upon all the available analyses.

MIS: suggestion of correlation with the marine oxygen isotopic stages.



LITHOSTRATIGRAPHY
PALAEOENVIRONMENT & CHRONOSTRATIGRAPHY
GRAPHIC SYMBOLS
UNITS
Layers
PALYNOLOGY
0%
50%
100%
Sample number
ANTHRACOLOGY
Speleothems & CaCO3 concretions
In situ & reworked palaeosols
Limestones with phosphatic cortex
Effect of ice
Green amphibole
Dates (ka BP)
Archaeology Palaeoanthropology
Chronostratigraphy
MIS
14
13
12
11
10
9
8
H
J
T
1A
1B-GRI
1B-LIT
1B-JAU
1B-BRUN
1B-INF
2A
2B
3-SUP
H & CC1
T-BR
T-GR
T-GV
T-JV
1A-GL
1A-GK
1B-GJG
1B-GJJ
1B-GRH
1B-LS
1B-LI
1B-JO
1B-LV
1B-BKS
1B-BR
1B-OK
2A-GL
2A-GK
2B-GB
2B-HU
2B-RO
2B-GR
2B-GT
3-ORA
3-ORH
3-GRK
3-ASS
17
16
15
14
13
12
11
10
9
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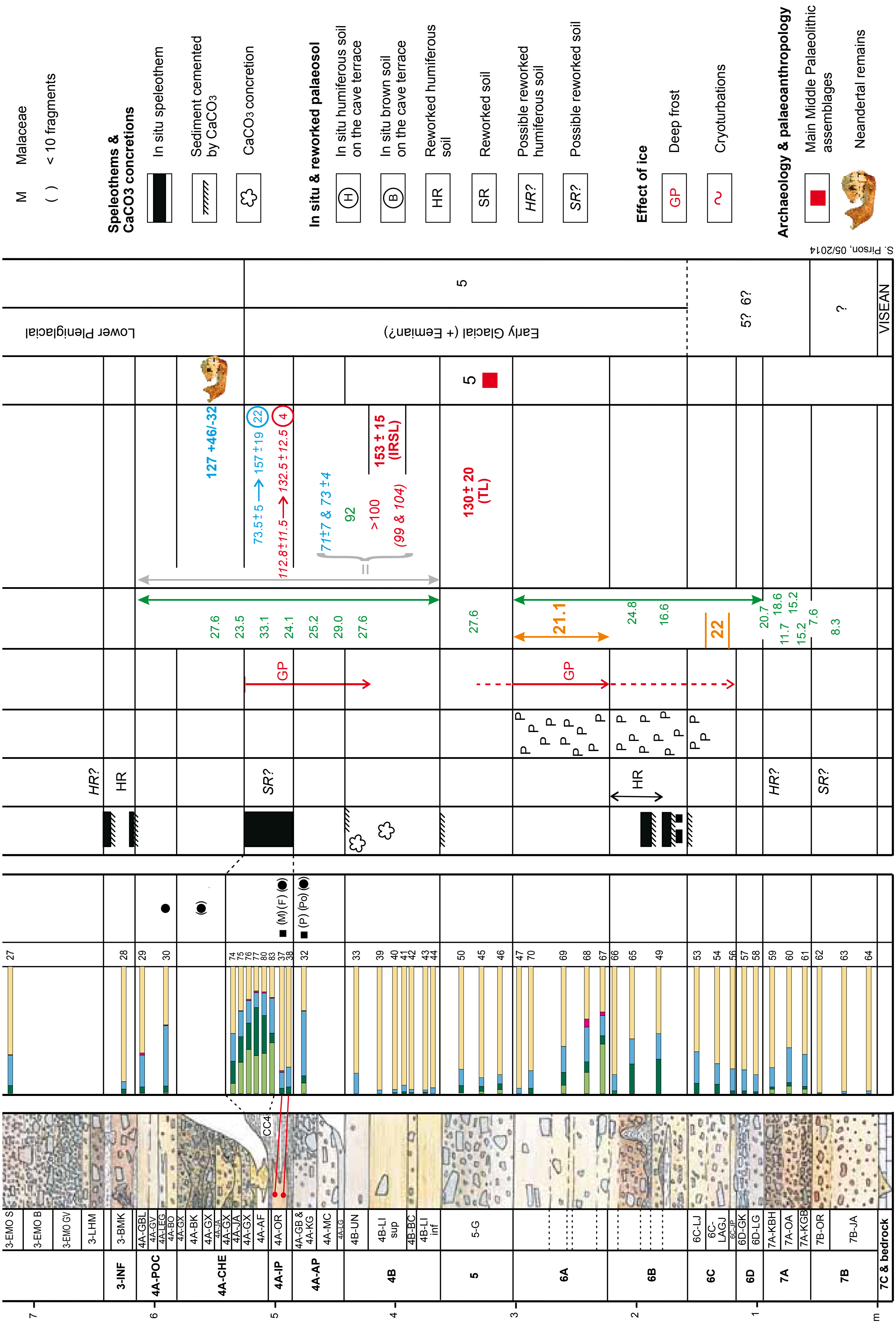
36
35
34
3
6
26
25
24
23
22
21
20
19
● Δ (O) (J)
(Δ)
Δ
HR?
B
HR
HR
H
SR?
(P)
P
P
P
P
GP
GP
9.7
6.2
8.3
2.8
7.6
6.9
5.5
11.7
24.8
?
0.7
3.3
6 ± 4
7 ± 0.5
37.3 +0.4/-0.3
40.2±0.4
43.2 +1/-0.7
(<36)
38.6±1.5
44±5.5
(50±10)
1A
HOLOCENE
Upper Plenigl.
Middle Pleniglacial
Lower Plenigl.
and/or Early Glacial
1
2
3
3 and/or 4
4
4 and/or 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
Δ Picea
■ Quercus
O Betula
J Juniperus
F Fraxinus
P Prunus
Po Populus


M 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
Main Middle Palaeolithic assemblages
Neandertal remains
S. Pirson, 05/2014
Lower Pleniglacial
Early Glacial (+ Eemian?)
VISEAN
127 +46/-32
73.5±5 → 157 ±19
112.8±11.5 → 132.5±12.5
71±7 & 73 ±4
>100
(99 & 104)
153 ± 15 (IRSL)
130 ± 20 (TL)
3-INF
4A-POC
4A-CHE
4A-IP
4A-AP
4B
5
6A
6B
6C
6D
7A
7B
7C & bedrock
CC4

2.3.1.3. Interface between units 4A-IP and 4A-CHE

The sediment from units 4A-IP and 4A-AP, as well as the sediment from the top of Unit 4B (Layer 4B-UN), are both affected by a thick platy structure (4-6 mm), indicating a deep frost episode (cf. § 2.1 & Figure 3).

2.3.1.4. Unit 4A-CHE

Unit 4A-CHE consists of a series of cut-and-filled layers in a complicated gully structure (Figure 1b) that has eroded the underlying layers down to the top of Unit 6A. The sediment from Unit 4A-CHE is very heterogeneous; several lithologies have been recognised (see Chapter 3). No climatic information is directly recorded in this complicated unit. Nevertheless, the existence of a cryosol at the interface between units 4A-IP and 4A-CHE, as well as some specific sedimentary features (Pirson, 2007; see Chapter 3), suggest that this gully could correspond to the degradation of a deep frozen soil (melting structure).

No palynological data is available from this unit. The presence of some fragments of *Pinus* charcoal in 4A-CHE (F. Damblon in Pirson, 2007; Pirson et al., 2008) does not have any firm significance given the very erosive character of this unit, which reworked the underlying deposits where *Pinus* charcoal have been recognised (Pirson, 2007; see Chapter 3).

2.3.1.5. Unit 4A-POC

Unit 4A-POC is comprised of 4 distinct layers, including (from bottom to top): 4A-BO, 4A-LEG, 4A-GV, and 4A-GBL (Figure 1b; see also Chapter 3).

Once again, the sedimentary dynamics of the deposits from 4A-POC are dominated by run-off processes and do not allow the identification of any specific climatic conditions. The few palynological spectra obtained from this unit suggest boreal conditions, underlined by steppic herbs and large amount of *Pinus* (30–50% AP), complemented by scattered pollen of malacophyll trees, mainly *Betula* (Court-Picon & Damblon in Pirson, 2007; Pirson et al., 2008). Monolete spores of ferns suggest local humidity around the cave. Local presence of *Pinus* is demonstrated by anthracology (Pirson et al., 2008).

2.3.2. Former results

The sediments from the upper part of former Layer 4 (generally labelled 4A or V ocre: Gullentops & Deblaere, 1992; Haesaerts, 1992; Bonjean, 1998) yielded palynological data that indicated forest conditions (60–95% AP) dominated by *Corylus* and *Pinus* but with high values for mesophilous trees (e.g., *Tilia*, *Quercus*, and *Ulmus*), as well as high amounts of ferns (Bastin, 1992). These pollen assemblages from former layers 4A and V ocre are compatible with those from the palynological study of sedimentary Unit 4A-AP.

Pollen assemblages from Stalagmitic Floor CC4 (and its lateral equivalent CC14; see Chapter 3) indicate temperate forest conditions: 65–90% AP, most of the time dominated by *Corylus* and *Pinus* but including locally high percentages of *Ulmus* (up to 60%) or *Carpinus* (up to 20%), together with low values of *Tilia*, *Quercus*, *Fraxinus*, *Picea*, *Hedera*, or *Ilex* (Bastin, 1992). Monoletes ferns are also well represented in this part of former Layer 4. The palaeoenvironmental conditions are therefore very similar to those deduced from the new palynological and anthracological analyses from CC4 (see § 2.3.1.2).

Small mammals from former Layer 4A also record a rather temperate environment: a strong presence of temperate forest taxa (up to 60%) and temperate open taxa, an important return of chiroptera and insectivores, as well as the disappearance of arctic taxa (Cordy, 1992).

The available data from the large mammals of former Layer 4A were studied together with those from 4B ("Layer 4" of Simonet, 1992). However, as 4B is extremely poor in macrofaunal remains (see § 2.2), the presence of more than 75% forest taxa (with 50% being *Dama dama*) amongst the large herbivores from the "Layer 4" assemblage (Simonet, 1992) is probably related to the temperate conditions of 4A.

The magnetic susceptibility signal suggests the presence of a climatic improvement in both former layers 4B and 4A (Ellwood et al., 2004; see § 2.2).

2.4. Sedimentary Complex 3

As for former Layer 4A, palaeoenvironmental results from former Layer 3 are delicate to accurately position in the new stratigraphic record.

From a single layer in the former stratigraphic record, this part of the sequence now includes 2 major units encompassing about 10 layers, several of which are likely lateral equivalents (Figure 1b; see also Chapter 3). Former and new results will therefore be presented separately.

2.4.1. New results

2.4.1.1. Unit 3-INF

Unit 3-INF is very poorly exposed at the site and is therefore still not well understood. It is characterized by dark brownish sediment, suggesting the reworking of humic material from the cave terrace (Pirson, 2007; see Chapter 3). This unit could therefore record a reworked interstadial palaeosol, and thus a climatic improvement. The local presence of an unsound stalagmitic floor both at the bottom and the top of this unit supports this hypothesis. However, from a palynological point of view, the only available spectrum indicates a relatively open environment (10–30% AP). The identified trees are almost exclusively boreal taxa (*Pinus*, *Juniperus*, and *Betula*).

2.4.1.2. Unit 3-SUP

The bottom of this unit (Layer 3-LHM) is again composed of dark brownish sediments suggesting the reworking of humic material, possibly a palaeosol (Pirson, 2007). These deposits are probably related to those from Unit 3-INF.

The major part of Unit 3-SUP is characterized by an episode of torrential flow and run-off (layers 3-EMO and 3-ASS). It was overlain by a debris flow (Layer 3-GRK). No climatic signature is recorded in these deposits (Pirson, 2007; see Chapter 3). The 3 available pollen spectra from this part of the sequence suggest a steppic environment with some boreal trees (10–30% AP, with *Pinus*, *Juniperus*, and *Betula*; Court-Picon & Damblon in Pirson, 2007; Pirson et al., 2008).

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 (layers 3-ORH and 3-ORA), conditions seem to have started to change. A climatic improvement, continuing in Unit 2B, is recorded by studies under several disciplines (geology, palynology, and anthracology; Pirson, 2007; Pirson et al., 2008; Figure 3).

2.4.2. Former results

Palaeontological investigation has yielded some palaeoenvironmental indicators for former Layer 3. Palynology recorded a decrease in trees, although they still remained well represented (50–60% AP); *Pinus* or *Corylus* are the dominant taxa, with local occurrence of *Tilia* (up to 10%) and high amounts of monolete fern spores (Bastin, 1992). Small mammals also indicate rather contrasting conditions (Cordy, 1992). Herbivores are represented by 40% forest taxa, including 10% *Dama dama* (Simonet, 1992). All in all, the published palaeontological data from former Layer 3 suggests a contrasting environment, with a mixture of taxa from temperate forest and colder environments.

The magnetic susceptibility signal, while rather irregular, suggests a global cooling event when compared to underlying former Layer 4A (Ellwood et al., 2004; Figure 2).

As mentioned above, these former data are difficult to interpret because how they correspond with the different layers of the newly defined units 3-INF and 3-SUP is unknown. Depositional mixing between different layers that have distinct palaeoenvironmental signatures is likely.

2.5. Palaeoenvironmental synthesis

All the available palaeoenvironmental data are summarized in Figure 3. Despite the problems due to the difference between former and current stratigraphic records, the overall convergence of the palaeoenvironment results from all the available disciplines is worth mentioning, as already emphasized by J.-M. Cordy & B. Bastin (1992). Consistency also appears at a single-discipline level, as illustrated by the reproducibility of the palynological results from distinct sedimentary profiles or from distinct analysts, i.e., former results from B. Bastin (1992) and new results from F. Damblon and M. Court-Picon (in Pirson et al., 2008). The viability of the existence of these recorded climatic fluctuations is thus strengthened.

The results recently obtained in the fields of geology and palynology allow the construction of a consistent palaeoenvironmental framework for the new Scladina stratigraphic sequence. Palynology appears to be more complete, as most of the sedimentary processes do not exhibit any climatic signals. However, the understanding of sedimentary dynamics helps interpreting the palaeobotanical results while post-depositional processes provide information about climatic events for periods without sediment accumulation (e.g., frost action or the formation of authigenic phosphates). These 2 approaches therefore appear as highly complementary. The available anthracological data supplements and strengthens the palynological results, demonstrating the local (or at least regional) presence of some of the tree taxa.

Despite the specific character of stratigraphic records in caves, which often involves a highly discontinuous sedimentation rate, these concordant palaeoenvironmental results further demonstrate the high potential of Belgian cave entrance sedimentary sequences as recorders of Quaternary climatic changes, as already stated for the Walou Cave sequence (Pirson et al., 2006).

3. Chronostratigraphic framework

3.1. Former chronostratigraphic interpretations

Several chronostratigraphic interpretations of the Scladina sequence are available in the literature, reflecting different steps in the evolution of this type of research. They are mainly based on 3 distinct elements: palaeontology, radiometric dates, and magnetic susceptibility.

A few scientists have based their chronostratigraphic framework upon palaeontology through the classical climatostratigraphical approach (e.g., Bastin, 1992; Cordy, 1992; Cordy & Bastin, 1992; Simonet, 1992; Bonjean, 1998). The most important scheme, on which almost all the others are referring to, is that of Bastin (1992). This scientist considered that the stratigraphic sequences of Scladina Cave and underlying Sous-Saint-Paul Cave are in continuity, with the exception of a small hiatus. He recorded palynological data from the top of the sedimentary sequence of Sous-Saint-Paul Cave (Layer VIII) that he interpreted as a "true signature of the beginning of the Eemian […] and not any other interglacial" (Bastin, 1992: 62[1]). Therefore, all the subsequent climatic fluctuations were interpreted by reference to this system: the end of Eemian in former Layer 7A, after a small hiatus; Saint Germain I in former Layer 6; and Saint Germain II in former Layer 4A. However, this system is no longer valid (Pirson, 2007; Pirson et al., 2008). The succession of taxa that Bastin recorded in Layer VIII is indeed typical of the beginning of an interglacial (or an interstadial of an early glacial) but not only from the Eemian (e.g., Tzedakis, 1993; Reille et al., 1998; de Beaulieu et al., 2006). In addition, several arguments suggest that the sedimentary filling of the 2 caves (Scladina and Sous-Saint-Paul) is separated by an important hiatus (Haesaerts, 1992; Pirson, 2007).

Dating specialists who have provided data for the Scladina sequence rarely risk interpreting their own results in terms of chronostratigraphy. They deliver raw data, sometimes carefully suggesting some scenarios, and frequently warn against the problems inherent in the different dating methods. For instance, M. Gewelt et al. (1992) restricted themselves to merely indicate the divergence between the palynological interpretation and the radiometric results, without taking sides, or even inferring that palynology-based interpretation is more valid. The high imprecision of most of the available dates in the sequence, especially for the lower half, does not allow for a reliable and accurate chronostratigraphic framework.

The chronostratigraphic interpretation based upon the magnetic susceptibility signal, proposed by Ellwood et al. (2004), does not appear convincing. These researchers consider that the sedimentary filling of Scladina Cave is characterized by a rather slow sedimentation rate comparable to that of marine sediments, and stated that this sedimentation rate is constant, the sequence thus being deprived of any important hiatuses. Following these principles, they consider the magnetic susceptibility curve as representative of a continuous succession of climate changes. Then, they position the available dates on this curve and extrapolate the age of the identified climatic events. This way of understanding sedimentogenesis in cave entrances is in total contradiction with recent studies of cave sedimentary processes (e.g., Campy & Chaline, 1993; Ferrier, 2002; Bertran, 2006; Texier, 2007). The inadequacy of the slow continuous sedimentation rate model is even more obvious when looking at the recent reappraisal of the filling history of Scladina Cave (Pirson, 2007; see Chapter 3).

The major conclusion is that the arguments employed so far that place the whole Scladina sequence in Upper Pleistocene are not reliable. Bastin's palynological demonstration situating the Eemian is no longer valid. Other palaeontological disciplines yield interesting palaeoenvironmental

[1] "*véritable signature du début de l'Eemien (…) à l'exclusion de tout autre interglaciaire*"

indications (§ 2), but do not provide any accurate chronostratigraphic information. The dates from the lower part of the sequence (units 7B to 3) do not provide the answer either, as they are compatible with the positioning of part of the sequence in the late Middle Pleistocene. In fact, given the available data from the literature, nothing firmly excludes part of the Scladina sequence from the Middle Pleistocene.

3.2. Scladina sequence chronostratigraphic framework: current status

As a consequence of the problems stated above, the chronostratigraphic framework of the Scladina sequence had to be reconsidered (Pirson, 2007; Pirson et al., 2008). Several analyses are still in progress in order to test and refine the new chronostratigraphical scheme, which remains rather inaccurate in the present state of research. The following data, integrating both former and new data in the light of the new stratigraphic framework, must therefore be considered as a preliminary synthesis.

3.2.1. Dates

3.2.1.1. Published 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). All the reliable dates are presented in Figure 3. They can be divided into 2 groups: units 5 to 4A-POC in the lower part of the sequence, and units 1B-GR to H in the upper part. The other dates were considered as aberrant by their authors (e.g., Otte et al., 1983; Gewelt et al., 1992) and have therefore been discarded here.

In the lower part of the sequence, despite the numerous results, very few layers provided radiometric data. Most of the available dates come from Sedimentary Complex 4 and particularly from Stalagmitic Floor CC4. All these dates are rather inaccurate (Figure 3). Standard deviations frequently reach 20 ka and are often coupled with a strong variability of dates for single events, or for single objects (e.g., a single stalagmitic floor sample provided several dates with an important scattering; Gewelt et al., 1992; Bonjean, 1998). Another problem is the lack of a precise stratigraphic position for the dated samples in comparison with the new stratigraphic record (see Chapter 3). Therefore, because of all these problems, the available dates cannot be used to either build an accurate chronological framework or to test and refine the chronostratigraphic framework deduced from the other disciplines. They can support several distinct hypotheses: from a strict radiometric point of view and taking the standard deviations into account, the dates obtained from the top of Sous-Saint-Paul sequence, from Unit 5, and from Sedimentary Complex 4 (including the date obtained directly on the Neandertal mandible) are overlapping. Stalagmitic Floor CC4 could, according to the numerous dates (synthesis in Bonjean, 1998 and Pirson, 2007; see also Figure 3), either record all MIS 5, only MIS 5a and/or MIS 5c, or even late MIS 6. The thermoluminescence date obtained on burnt flint from Unit 5 (130 ± 20 ka BP; Huxtable & Aitken, 1992) as well as the gamma spectrometry date performed on the Neandertal mandible (127 +46/−32 ka BP; Falguères & Yokoyama in Toussaint et al., 1998) are also compatible with several scenarios from MIS 6 to MIS 5, or even MIS 4 for the hominid mandible taking 2σ into account. Finally, the dates obtained from the top of Sous-Saint-Paul sequence, which should be older than Scladina sequence (see § 3.2.2), do not increase the precision, as they provided a similar chronological interval ranging from late Middle Pleistocene to early Upper Pleistocene: 130 ± 18 ka BP from Layer XII at the bottom of the sequence; 177 ± 17 to 93 ± 4 ka BP from Layer VIII at the top of the sequence (Gewelt et al., 1992).

In the upper part of the Scladina sequence, the published dates from former Layer 1A are neither particularly accurate nor precisely positioned in the new stratigraphic record. The few dates available for Unit H (Figure 3), either radiocarbon dates on calcite or U/Th date on an in situ speleothem, clearly point to a Holocene age, which is further supported by other data (§ 3.2.5).

3.2.1.2. New dates

Luminescence dating

In July 2006, a sample for luminescence dating was collected from Layer 4B-LI. The IRSL signal from coarse-grained alkali feldspars (40–60 microns) was used for dating the depositional age of this layer. The IRSL technique already tested on Middle Pleistocene loess sequences of Romania

(Balescu et al., 2003) and NW France (Balescu, 2004; Balescu & Tuffreau, 2004) was applied. The optical signal was recorded using a Corning 7-59/Schott BG39 blue transmitting filter combination (300-500 nm). The equivalent doses (ED) were determined using the additive gamma dose method on multigrain aliquots. The feldspars were stored for 1 year after laboratory irradiation in order to avoid the effect of short-term fading. Preheating at 160°C for 9 hours was done prior to taking IRSL measurements. The ED value is estimated at 420 ± 29 Gy. The external and internal contributions to the dose rate were estimated from the concentrations of U, Th, and K measured by neutron activation. The total dose rate for this sample is 3.24 ± 0.26 Gy/ka (see Balescu et al., 2003 for further methodological details). The *apparent* IRSL age obtained is 129 ± 13 ka BP. A correction for long-term fading (Mejdahl, 1988) has been applied using the apparent mean life (t_2 = 516 ka) estimated on infinitely old alkali feldspars from a Tertiary or Early Quaternary (?) deposit lying on top of the plateau, nearby the cave. It yielded a *corrected* IRSL age of 153 ± 15 ka BP (see Balescu et al., 1997 for further details on the correction protocol).

This IRSL result suggests a MIS 6 age for Unit 4B-LI, consistent with the high green amphibole content of the layer (see § 3.2.4.1). This loess was thus deposited during MIS 6 outside or near the entrance of the cave. However, it was later reworked over a short distance within the cave, probably under very dim light conditions; therefore, the estimation of the age of the deposition of Layer 4B-LI is not possible to obtain from the IRSL result alone, it needs the integration of the results from other disciplines (see § 3.2.4.1).

Radiocarbon dating

In November 2006, new ^{14}C dates were obtained from the upper part of the sequence (Pirson, 2007; Pirson et al., 2008). They considerably improve the chronology. In particular, 3 new ^{14}C dates obtained in layers 1B-GRH (GrA-32581: 43,150 +950/−700 BP), 1A-GK (GrA-32635: 40,210 +400/−350 BP), and T-GV (GrA-32633: 37,300 +400/-300 BP) lead to define a rather accurate chronostratigraphic framework for this part of the stratigraphy, which can be attributed to MIS 3. Some already published dates (Gewelt et al., 1992; Bonjean, 1998) are compatible with these new results, although they are less accurate. This allows the age of Middle Palaeolithic material from former Layer 1A to be refined to between 40 and 37 ka BP (Abrams et al., 2010; Bonjean et al., 2011).

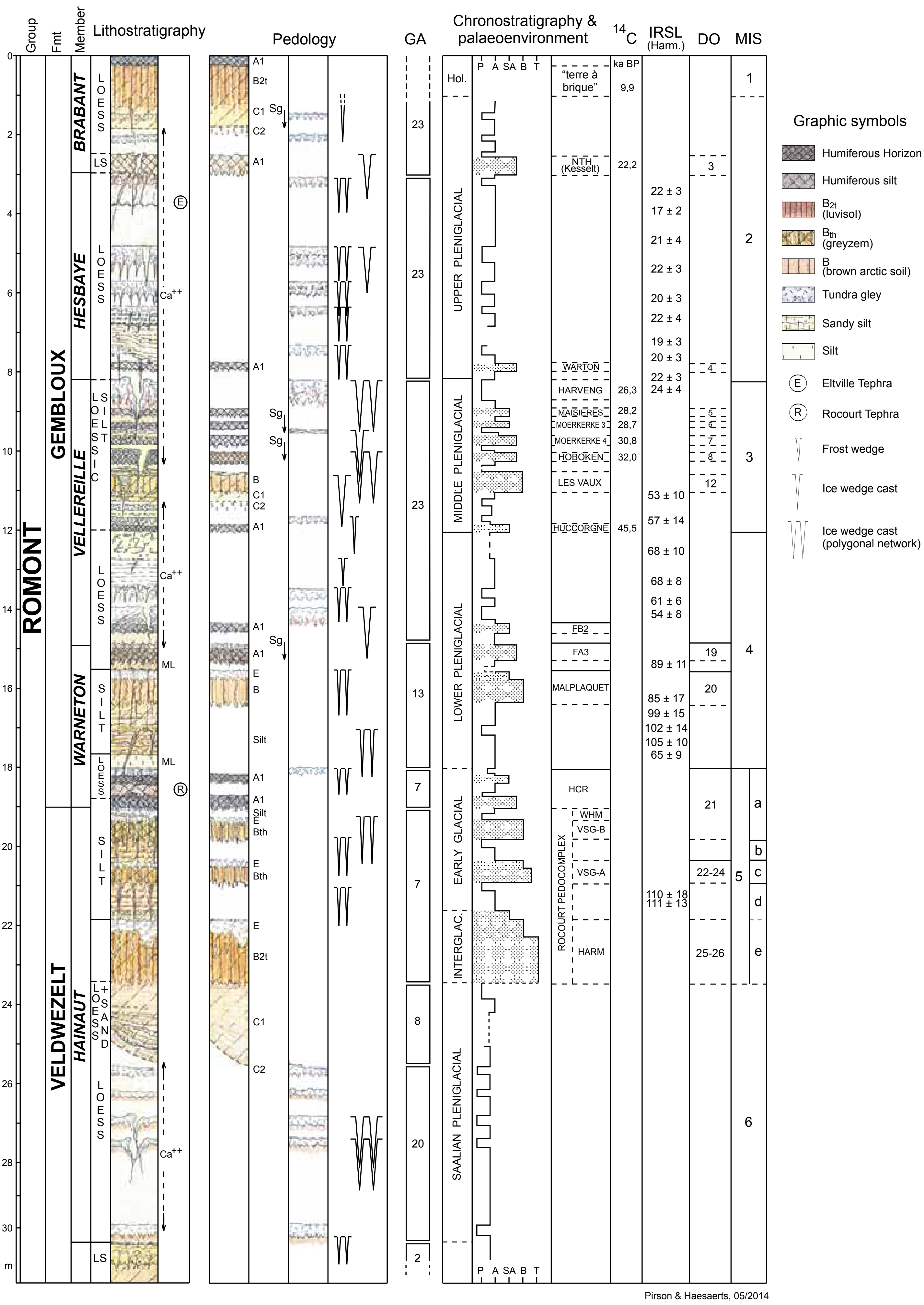
3.2.2. Biostratigraphy

The ursids are the dominant taxa in the faunal collections from the Caves of Sclayn. The only bears recognized so far in the Scladina deposits are *Ursus spelaeus* and *Ursus arctos* (Simonet, 1992; Patou-Mathis, 1998[a]). From a biostratigraphical point of view, the presence of *U. spelaeus* indicates that the Scladina sequence could span between the end of Middle Pleistocene and Upper Pleistocene (e.g., Argant & Philippe, 2002), which remains rather inaccurate. However, Simonet (1992) did not study Unit 7B, and in Unit 7A the bear remains were too poor to "carry out a fruitful study[2]" (Simonet, 1992: 132).

On the other hand, in the sequence from Sous-Saint-Paul Cave (Simonet, 1992; Nieuwlaet, 2007; Goubel, 2011), the ursid remains showed features from both *Ursus spelaeus* and *Ursus deningeri*. The transition between these 2 species is known to be gradual, following a mosaic-like evolutionary path (Argant & Philippe, 2002; M. Germonpré, pers. comm.). Therefore, interpreting this information is difficult. Regardless, this tends to confirm the existence of a major hiatus between the Sous-Scladina and Scladina sequences (i.e., between Sous-Saint-Paul Layer VIII and Scladina former Layer VII/7A). In Belgium, very few data are available on bear evolution. Moreover, the sequences, which are accurately dated from the end of Middle Pleistocene and from the beginning of Upper Pleistocene, are very rare. In La Belle-Roche Cave, *Ursus deningeri* is present but in much older deposits (at least 500 ka; Cordy et al., 1992, 1993; see also Pirson & Di Modica, 2011). In the sequence of Walou Cave,

[2] "*réaliser une étude fructueuse*"

Figure 4 (facing page): The Middle Belgium loess reference sequence. Sg = segregation ice; GA = % of green amphibole in the silty fraction (values = average % from Table 1); P = polar; A = arctic; SA = sub-arctic; B = boreal; T = temperate; NTH = Nagelbeek tongued horizon; HCR = Humiferous Complex of Remicourt; WHM = Whitish horizon of Momalle; VSG-B and VSG-A = Villers-Saint-Ghislain B and A Soils; HARM = Harmignies Soil; IRSL: infrared optically stimulated luminescence (Harmignies, after Frechen et al., 2001); DO = Dansgaard-Oeschger events; MIS = marine oxygen isotopic stages.



Group
Fmt
Member
Lithostratigraphy
Pedology
GA
Chronostratigraphy & palaeoenvironment
14C
ka BP
IRSL (Harm.)
DO
MIS
ROMONT
GEMBLOUX
VELDWEZELT
BRABANT
HESBAYE
VELLEREILLE
WARNETON
HAINAUT
LOESS
LS
SILTSTIC LOESS
SILT
LOESS + SAND
E
R
Ca++
ML
A1
B2t
C1
C2
Sg
B
E
Bth
Silt
23
13
7
8
20
2
Hol.
UPPER PLENIGLACIAL
MIDDLE PLENIGLACIAL
LOWER PLENIGLACIAL
EARLY GLACIAL
INTERGLAC.
SAALIAN PLENIGLACIAL
P A SA B T
"terre à brique"
NTH (Kesselt)
WARTON
HARVENG
MAISIERES
MOERKERKE 3
MOERKERKE 4
HOBOKEN
LES VAUX
HUCCORGNE
FB2
FA3
MALPLAQUET
HCR
WHM
VSG-B
VSG-A
HARM
ROCOURT PEDOCOMPLEX
9,9
22,2
26,3
28,2
28,7
30,8
32,0
45,5
22 ± 3
17 ± 2
21 ± 4
22 ± 3
20 ± 3
22 ± 4
19 ± 3
20 ± 3
22 ± 3
24 ± 4
53 ± 10
57 ± 14
68 ± 10
68 ± 8
61 ± 6
54 ± 8
89 ± 11
85 ± 17
99 ± 15
102 ± 14
105 ± 10
65 ± 9
110 ± 18
111 ± 13
3
4
5
6
7
8
12
19
20
21
22-24
25-26
1
2
3
4
5
a
b
c
d
e
6
m
Graphic symbols
Humiferous Horizon
Humiferous silt
B2t (luvisol)
Bth (greyzem)
B (brown arctic soil)
Tundra gley
Sandy silt
Silt
Eltville Tephra
Rocourt Tephra
Frost wedge
Ice wedge cast
Ice wedge cast (polygonal network)
Pirson & Haesaerts, 05/2014

in the deposits attributed to the end of MIS 6 and to MIS 5 (Pirson et al., 2006; Pirson, 2011), bear species were confined to *Ursus spelaeus* (De Wilde, 2011).

The other species found in Scladina, including small mammals, have not yet been studied from a strict biostratigraphical point of view.

3.2.3. Archaeostratigraphy

Archaeological data does not greatly aid in the chronostratigraphic problem of the Scladina sequence. Still, some information can be gathered.

In former layers 5 and 1A, Mousterian lithic material has been unearthed (e.g., Otte et al. (dir.), 1998; Loodts & Bonjean, 2004; Di Modica, 2010; Bonjean et al., 2011; see also Chapter 2). Recently, Mousterian artefacts were found in Layer 1A-GL and in Unit T. By comparison with the rare reliable chronological data that are available for the end of Middle Palaeolithic in Belgium (Toussaint, 1988; Otte et al., 1998; Flas, 2006; Pirson et al., 2006; Toussaint et al., 2010; Pirson, 2011; Pirson et al., 2012), and if the dated material from Unit T is not reworked, the deposits from Unit T downwards should be older than ca. 40-35 ka BP.

The top of the Scladina sequence has yielded some rare Upper Palaeolithic remains in secondary position (Otte, 1998), as well as anatomically modern human bones suggesting a multiple burial that is Holocene in age (Otte et al., 1983: 141).

3.2.4. Comparison with the loess sequence

The data gathered within the last 60 years about Upper Pleistocene in the Middle Belgium loess belt has led to the construction of a well-documented pedostratigraphic sequence (e.g., Haesaerts et al., 1999, 2011[a]; Haesaerts, 2004; Pirson, 2007; Pirson et al., 2009). This loess sequence is actually the most complete record for Upper Pleistocene in Belgium and therefore acts as a reference sequence. It is presented in Figure 4.

In Belgium, the non-carbonated fine fraction from cave entrance deposits is almost entirely made of silt with a loessic origin (Ek et al., 1974; Chen et al., 1988; Pirson, 1999; Pirson & Draily, 2011). This is also true for Scladina deposits (Gullentops & Deblaere, 1992; Haesaerts, 1992; Pirson, 2007) and allows detailed correlations between these karstic sequences and the loess reference sequences from Middle Belgium (Pirson et al., 2006; Pirson, 2007, 2011). In the case of Scladina Cave, the most useful tool for comparison with the loess sequence is the mineralogical signature of the silt fraction. A few other data (lithological and pedological markers) complete the system.

3.2.4.1. Heavy mineralogy

In the loess sequences from middle Belgium and northwestern France, one of the most useful minerals for chronostratigraphic reconstructions is green amphibole (e.g., Juvigné, 1978; Balescu, 1988; Meijs, 2002). The available green amphibole (GA) data for Middle and Upper Pleistocene are rather numerous (e.g., Gullentops, 1954; Juvigné, 1978; Balescu & Haesaerts, 1984; Balescu, 1986, 1988; Meijs, 2002; Balescu, 2004; Balescu & Tuffreau, 2004). The integration of all the GA data, which can be accurately positioned in the detailed loess reference sequence of Middle Belgium (see Pirson, 2007), led to the synthesis presented in Table 1.

Several researchers have studied the heavy mineralogy of the silt fraction at Scladina (Gullentops & Deblaere, 1992; Balescu in Haesaerts, 1992; Balescu in Pirson, 2007; Pirson, 2007). The comparison between the GA distributions in Scladina (Figure 3) and in the Belgian loess belt (Figure 4 & Table 1) indicates that with a GA fraction of 12 to 33%, former layers 7A to 2B carry the signature of either late Saalian or Weichselian loess (MIS 6 or MIS 4-2; Haesaerts,

Table 1 (facing page): Synthesis of the green amphibole data from the Middle Belgian loess belt (after Pirson, 2007; data from Gullentops, 1954; Juvigné, 1978; Balescu, 1988; Meijs, 2002). The lithostratigraphic divisions are based on the new lithostratigraphic scale of Middle Belgium Loess (from Haesaerts et al., 2011[a]). MIS = marine oxygen isotopic stages; A-loess to E-loess: nomenclature of Pleistocene loess following Meijs (2002); NTH = Nagelbeek tongued horizon; HCR = Humiferous Complex of Remicourt; N1 to N5 = 5 'Nassboden' (tundra gleys) in the lower MIS 6 loess (lower B-loess); Harveng, Les Vaux, Huccorgne, Malplaquet, Rocourt pedocomplex, Hees pedocomplex, Montenaken pedocomplex, and Pottenberg pedocomplex: major pedological units (see Meijs, 2002 and Haesaerts et al., 2011[a]). Mean values: average GA values (in %) calculated from the available data from the literature; N = number of samples; Range of % = minimal and maximal values.

Chronostratigraphy		MIS	Lithostratigraphy			Mean values	N	Range of %
HOLOCENE		1	GEMBLOUX FORMATION	Brabant Member	Luvisol	23	14	16.2 to 34
UPPER PLEISTOCENE	Upper Pleniglacial	2			Decalcified A-loess			
					Calcareous A-loess			
					NTH			
				Hesbaye Member	A-loess	23	8	17 to 27
	Middle Pleniglacial	3		Vellereille Member	Harveng	23	11	16 to 35
					Les Vaux			
					Huccorgne			
	Lower Pleniglacial	4			A-loess			
				Warneton Member	FA3	13	5	8 to 19
					Malplaquet			
					A-loess			
	Early Glacial	5a to 5d			Humic complex of Remicourt (CHR)	7	6	5 to 8
			VELDWEZELT FORMATION	Hainaut Member (top)	Rocourt pedocomplex	7	23	3.1 to 18
	Eemian	5e						
MIDDLE PLEISTOCENE		6			Upper B-loess	8	8	4.2 to 11
				Hainaut Member (bottom)	N5	20	15	11 to 32
					Lower B-loess			
					N4			
					Lower B-loess			
					N3			
					Lower B-loess			
					N2			
					Lower B-loess			
					N1			
					Lower B-loess			
		7		Vlijtingen Member	Hees pedocomplex	2	8	0.7 to 2.7
		8			C-loess			
					Humic complex			
		9		Riemst Member	Montenaken pedocomplex	1	3	0.4 to 0.9
		10			D-loess			
		11		Op de Schans Member	Pottenberg pedocomplex	0.4	1	0.4
		12			E-loess			

1992; PIRSON, 2007). The attribution of this part of the sequence to MIS 7 can be discarded because GA content is too high. In addition, the presence of low GA values in the overlying deposits (Unit 2A) as well as interglacial or early glacial conditions in former layers 6 and 4A (§ 2) rule out the Weichselian hypothesis. The silts with high GA values from Scladina sedimentary units 7A to 2B must therefore result from the reworking of late Saalian loess (MIS 6), which is corroborated by the IRSL date from Layer 4B-LI (see § 3.2.1.2). The late MIS 6 loesses, which have low GA content, are thus absent in Scladina, as in some loess sections from northwestern France (Cagny-la-Garenne, Sourdon or Sangatte: BALESCU, 1986). In this context, temperate conditions recorded in units 6B-6A and in former Layer 6 (PIRSON et al., 2008; see also § 3.2.5) point to a MIS 5 age and indicate that from Unit 6B upward, the sequence can be positioned in Upper Pleistocene. Units 7A to 6C, with rather high GA concentrations (12–22%), should be positioned either in MIS 6 or in MIS 5. This data set indicates that most of the Scladina stratigraphic sequence belongs to the Upper Pleistocene. The part of the sequence that could belong to Middle Pleistocene amounts to units 7B to 6C. The GA values from former Layer 7B must be considered with caution because of the probable mixing between loess and the alluvial sediments reworked from the plateau.

The decrease of GA in former Layer 2A (ca. 3–12%) suggests, together with other data (§ 3.2.4.2), a new allochthonous loessic input in the sequence. Compared to the Belgian loess sequence, this silt with low GA content observed above silt with high GA content must correspond to loess from either late MIS 6 or early MIS 4, or even late MIS 6 loess reworked during MIS 5. This, combined with its stratigraphic position above sediments with an interglacial or early glacial signature, suggests an early MIS 4 age. However, no important allochthonous loessic inputs are recorded in early MIS 4 in the Belgian loess-belt, and very few GA data are available in this part of the loess sequence. Therefore, further analyses are required.

3.2.4.2. Lithological markers

Two aeolian inputs attributable to the Upper Pleistocene could be recorded as reworked loessic material in the Scladina sequence. Unit 2A probably records the first allochthonous Upper Pleistocene loessic deposit in the sequence; several arguments led to the proposition of the positioning of Unit 2A in Weichselian Lower Pleniglacial (PIRSON, 2007; PIRSON et al., 2008). The second allochthonous loessic input is represented by the deposits from Unit J. Given their position in the stratigraphic sequence of Scladina, as well as the comparison with other sequences either in a loessic context (e.g., HAESAERTS et al., 1997; HAESAERTS, 2004) or in a cave entrance context (Walou Cave: PIRSON et al., 2006; *Trou Al'Wesse*: PIRSON, 1999; Abri supérieur of Goyet: TOUSSAINT et al., 1999), they are interpreted, in the current state of research, as probably resulting from the reworking of Weichselian Upper Pleniglacial loess (MIS 2; PIRSON, 2007).

3.2.4.3. Pedological markers

The highly humiferous sediment from Unit 2B has been interpreted as the result of the reworking of an important humiferous palaeosol, suggesting a strong interstadial (PIRSON, 2007; PIRSON et al., 2008). This hypothesis is further supported by palynological and anthracological data (PIRSON et al., 2008), as well as by magnetic susceptibility data (ELLWOOD et al., 2004). The stratigraphic position of Unit 2B and the correlation with the loess reference sequence indicate that this unit could correspond to the Humiferous Complex of Remicourt, a key marker of the Belgian loess belt (HAESAERTS et al., 1999, 2011[a], 2011[b]). In this case, Unit 2B would belong to the end of Weichselian Early Glacial (Figure 4). The GA content from Unit 2A is consistent with this attribution (compare Figure 3, Figure 4 & Table 1). The high GA values from Unit 2B are not a problem since the humic soil could have been developing on OIS 6 colluvial material (as already suggested by the GA distribution in underlying units). If the presence of the Rocourt Tephra in Unit 2B was confirmed (although it is still hypothetical; PIRSON, 2007), the correlation between Unit 2B and the Humiferous Complex of Remicourt would be demonstrated, as this tephra is classically found in this humic complex in the Belgian loess belt (e.g., GULLENTOPS, 1954; HAESAERTS et al., 1997; JUVIGNÉ et al., 2008; POUCLET et al., 2008; PIRSON & JUVIGNÉ, 2011).

The important climatic improvement recorded in Unit 1B-BRUN could be positioned at the bottom of Weichselian Lower Pleniglacial. It would then be an equivalent to the Malplaquet soil of the loess reference sequence, correlated by Haesaerts (2004) with the Dansgaard-Oeschger event 20 (DO 20) from the Greenland ice records (Dansgaard et al., 1993; Grootes et al., 1993). Weak GA values observed in former Layer 1B (6–10%; Figure 3) are consistent with this hypothesis, with this mineral becoming much more abundant in the major loessic input from Velereille Member (16–35%, with a mean value of ca. 23%; Figure 4 & Table 1).

On the cave terrace, below the cave porch, an in situ brown soil has been observed on top of former Layer 1B (Haesaerts, 1992). Given its nature and stratigraphic position, it could correspond to Les Vaux soil described in the Middle Belgian loess reference sequence in Harmignies (Haesaerts & Van Vliet, 1974) and Remicourt (Haesaerts et al., 1997) from the Weichselian Middle Pleniglacial (Figure 4). As far as its facies and stratigraphic position are concerned, Les Vaux soil exhibits close similarities with the Bohunice soil described in Moravia (Valoch, 1976) and the Willendorf Interstadial described in Austria (Haesaerts, 1990; Haesaerts & Teyssandier, 2003). These pedological markers represent a single interstadial event dated between ca. 42,000 and ca. 40,000 BP in the Middle Danube Basin. This correlation is further supported by the new radiocarbon dates bracketing the top of 1B-GRI between 43 and 40 ka BP. The existence of an equivalent to the Les Vaux soil has also been proposed for 2 other Belgian cave entrance sequences: Walou Cave (Pirson et al., 2006; Pirson, 2011) and the Trou de l'Abîme in Couvin (Toussaint et al., 2010), which both yielded Neandertal remains. In these 2 caves, the correlation with the Les Vaux soil is also supported by new radiocarbon data. According to Haesaerts (2004), Les Vaux soil can be correlated with the DO 12 from the Greenland records.

3.2.5. Climatostratigraphy

The palaeoenvironmental data from the Scladina sequence has been presented for units 5 to 3-SUP in § 2; this is not the place to present a synthesis of the whole sequence (see Pirson, 2007; Pirson et al., 2008). Figure 3 shows a summary of Scladina palaeoclimatic record.

No chronostratigraphical information can be directly drawn from this data set. Nevertheless, it evidences a succession of climatic events that cannot be positioned anywhere in the Pleistocene. The significance of some of the climatic changes recorded in Scladina still has to be completed by further analyses, specifically through palynological analyses from speleothems.

Palaeozoological and palaeobotanical data clearly show the existence of major climatic improvements in former layers 6 and 4A and in new units 6B/6A and 4A-AP/4A-IP. 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*, and Chiroptera: Cordy, 1992). These elements suggest the attribution of units 6B, 6A, 4A-AP, and 4A-IP (especially Speleothem CC4) to an interstadial of an early glacial or even to an interglacial without establishing whether or not they belong to either MIS 5 or another interglacial complex from the Middle Pleistocene. The chronostratigraphic interpretation can be refined if this information is compared to the heavy mineralogy data from the silt fraction (§ 3.2.4.1); units 6B/6A and 4A-AP/4A-IP could then be attributed to either the Eemian or Weichselian Early Glacial. However, it is not possible in the present state of research to precise the attribution of these 2 major climatic improvements inside MIS 5. Furthermore, the beginning and the end of MIS 5 are difficult to position in the Scladina sequence. The beginning of MIS 5 (stage 5e, Eemian) could be either missing or recorded in units 6B/6A. As for the end of MIS 5, the best current hypothesis positions Unit 2A in the Weichselian Lower Pleniglacial (MIS 4), with Unit 2B recording the end of MIS 5a.

Because of its low GA content, the major climatic improvement of Unit 1B-BRUN could belong to the Weichselian early Lower Pleniglacial (§ 3.2.4.3). The brown soil evidenced on the terrace seems to correspond to Les Vaux soil, which is further supported by the new radiocarbon dates (§ 3.2.4.3). The rest of the sequence records cold, steppic conditions. The stratigraphic position of these deposits, between Les Vaux soil and the Weichselian Upper Pleniglacial (Unit J), indicate that they belong to the Weichselian Middle Pleniglacial.

Finally, the Holocene age of Unit H is demonstrated by its stratigraphic position on top of the sequence, by some dates (§ 3.2.1), by palynology (Bastin, 1992), as well as by geology (stalagmitic floors and important biological activity in the sediments; Pirson, 2007).

3.3. Chronostratigraphic synthesis

All of the results that contribute to the chronostratigraphic framework of the Scladina sequence have been reconsidered; henceforth, most of the Scladina deposits can confidently be positioned in the Upper Pleistocene. The most accurate and reliable information comes from the combination of climatostratigraphy and the correlation with the Middle Belgium loess sequence. Data from other disciplines are compatible with this chronostratigraphic scheme.

However, the chronostratigraphic framework currently remains rather inaccurate. Several hypotheses can be considered, for instance those concerning the location of the beginning and end of MIS 5. The most reliable framework in the present state of research is presented in Figure 3. Considering all disciplinary approaches, the 2 units that indicate temperate forest conditions (i.e., Stalagmitic Floor CC4 in Unit 4A-IP and units 6B/6A) must be situated inside MIS 5. Whether they represent MIS 5e and 5c, or MIS 5c and 5a, or some other combination is still unknown.

4. Conclusions and prospects

The new palaeoenvironmental results from the Scladina Cave sequence, obtained from the reappraised stratigraphic record, indicate a very good concordance between palynology, anthracology, and geology. Furthermore, these new results correlate with the data from literature based on the former stratigraphic record. The reproducibility of the results and therefore the viability of the recorded climatic fluctuations are thus strengthened.

With the high complexity of the climatic signal recorded in Scladina, the site appears to be an exceptional reference for the Upper Pleistocene in Belgium, together with the Walou Cave sequence (Pirson et al. (dir.), 2011; Draily et al. (dir.), 2011). Apart from a few rare loess sequences from Middle Belgium (e.g., Haesaerts, 2004; Pirson et al., 2009), no other sedimentary record in Belgium is as complex. These results demonstrate that rapid climatic events can be recorded in cave entrance sequences in Belgium.

However, the lack of precision of the Scladina chronostratigraphic framework is a concern when positioning fluctuations in the sequence inside the climatically complex Upper Pleistocene (e.g., Dansgaard et al., 1993; Grootes et al., 1993). A better knowledge of the chronostratigraphic framework is therefore necessary. Several analyses in progress should improve the chronostratigraphic framework. Locating the Rocourt Tephra is essential; this tephra is a very good chronostratigraphical marker in Belgium (Juvigné et al., 2008; Pouclet et al., 2008) and has been proven to be very useful in cave sequences (Pirson et al., 2006; Pirson & Juvigné, 2011). New dating in carefully selected layers, especially in the lower part of the sequence (notably U/Th dates on speleothems), is another key point. New heavy mineral analyses will also be very useful, since very good results have recently been obtained for the Upper Pleistocene in several key loess sequences from Middle Belgium (Spagna et al., in preparation).

Other analyses that aim to refine the palaeoenvironmental data from Scladina Cave are also in progress. One of the priorities is the obtention of complementary palynological data, notably from speleothems other than CC4 (mainly those from Unit 6B), in order to try to determine their palaeoenvironmental signature and thus refine the climatostratigraphic signal. Analysis of the faunal material recently excavated in the new stratigraphic record would also contribute to improve the climatostratigraphical data.

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