

## BELGIAN CAVE ENTRANCE AND ROCK-SHELTER SEQUENCES AS PALAEOENVIRONMENTAL DATA RECORDERS: THE EXAMPLE OF WALOU CAVE

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(4 figures)

**ABSTRACT.** Despite abundant sites and numerous archaeological excavations, the knowledge of Belgian cave entrance and rock-shelter sequences is still poor from a geological point of view. A systematic program of detailed stratigraphic recordings associated with different analyses was recently undertaken in close collaboration with researchers from different disciplines. The objective was to better understand the sedimentary dynamics of these fillings and to test their potential as recorders of Quaternary climatic variations. The microstratigraphic study of the Walou Cave sequence illustrates this approach. Several clear climatic signals were identified. The validity of these signals and the type of environment were confirmed by palynology. Furthermore, tephrostratigraphy together with the excellent correlation with the loess sequence of Middle Belgium gave this exceptional recording a coherent chronostratigraphic context, supported by radiocarbon and thermoluminescence dates as well as archaeology and palaeontology. These results lead to interesting prospects for research work in this type of environment, e.g. understanding better the context of the numerous prehistoric occupations that distinguish Belgian caves.

**Keywords:** Upper Pleistocene, Belgium, loess, lithostratigraphy, tephrostratigraphy, palynology, pedogenesis, palaeoenvironment.

### 1. Introduction

Numerous caves are accessible to men within the Paleozoic limestones of Belgium (Ek, 1995). The filling of these cavities generally date back to the Upper Pleistocene and can provide important data on the palaeoenvironment. For the last 30 years endokarstic deposits have been the subject of several multidisciplinary studies in which geology plays an important role (see synthesis in Blockmans *et al.*, 1999). These studies resulted in the development of a model integrating sedimentary dynamics and palaeoenvironmental information (Quinif & Bastin, 2005, this volume).

On the other hand, the geology of Belgian cave entrance and rock-shelter deposits is poorly known, in spite of the excavation of more than 300 prehistoric sites in the last 175 years. The striking contrast between the number of sites studied and the dearth of geological information can be explained in two ways. First, most of the major cavities have been emptied from the 19<sup>th</sup> century onwards,

when Belgium played an important role in the birth and further development of prehistory and palaeoanthropology (Otte & Michel, 1984; Toussaint, 2001). The work of such seminal figures as Schmerling (1833-1834) or Dupont (1872) and those of their successors resulted in the accumulation of archaeological, palaeoanthropological and palaeozoological data from both cave entrances and rock-shelters. Unfortunately, considering these excavations were conducted so long ago, the stratigraphic and palaeoenvironmental context of the sites was barely studied. Second, for the last 35 years, modern excavations have been carried out in Belgian caves by multidisciplinary teams willing to associate palaeoenvironment with the dynamics of research, but geological studies have frequently been neglected. With very few exceptions (such as "Trou Jadot": Toussaint *et al.*, 1993), only limited studies were conducted (for instance Remouchamps Cave, Ek *et al.*, 1974), with neither continuous stratigraphic surveys nor detailed sedimentary studies. Only palaeozoology and palaeobotany were used on a regular basis to study

the palaeoenvironment. No real attempt at stratigraphic correlations between different sites was ever made. This resulted in the absence of an overall understanding of the problematics. The lack of interest from most Belgian geologists for the Quaternary in general and for this sedimentary environment in particular partly explains the current situation despite a real demand from archaeologists.

In this context, a systematic program of detailed stratigraphic analysis conducted in several sites (e.g. the caves of Walou, Sclayn, Trou Al'Wesse, Goyet and La Naulette) has been undertaken by one of us (SP) in the course of PhD studies. This work is complemented by various sedimentological and micromorphological analyses and is conducted in conjunction with researchers from different disciplines. The objectives are: determining the sedimentary dynamics of the sequences, identifying the palaeoenvironmental and chronostratigraphic potentialities, testing the correlations between sites with the help of sequence stratigraphy and, if possible, ultimately elaborating a reference sequence for this particular sedimentary environment. This paper presents the first results of this research through the analysis of the sequence of Walou cave.

## 2. Methodology and distinctive features of the studied sedimentary environment

Microstratigraphy, consisting in precise recordings of geometric features of the deposits, lithofacies and post depositional phenomena, is the basis of our methodology. The studied sites are surveyed regularly, integrating as many sections as possible. Stratigraphy governs the validity of the results of all the other approaches involved in the study of this kind of sequence since it allows a precise location of the archaeological and anthropological data and of the different samples used in the palaeoenvironmental study (fauna, flora, sedimentology, etc.). Stratigraphy also helps monitor the sedimentary development by following the lateral variation of facies and thickness. This approach leads to a better understanding of the dynamics of the system. Field observations are clarified and complemented by laboratory analyses (e.g. granulometry, heavy mineral study, micromorphology, magnetic susceptibility).

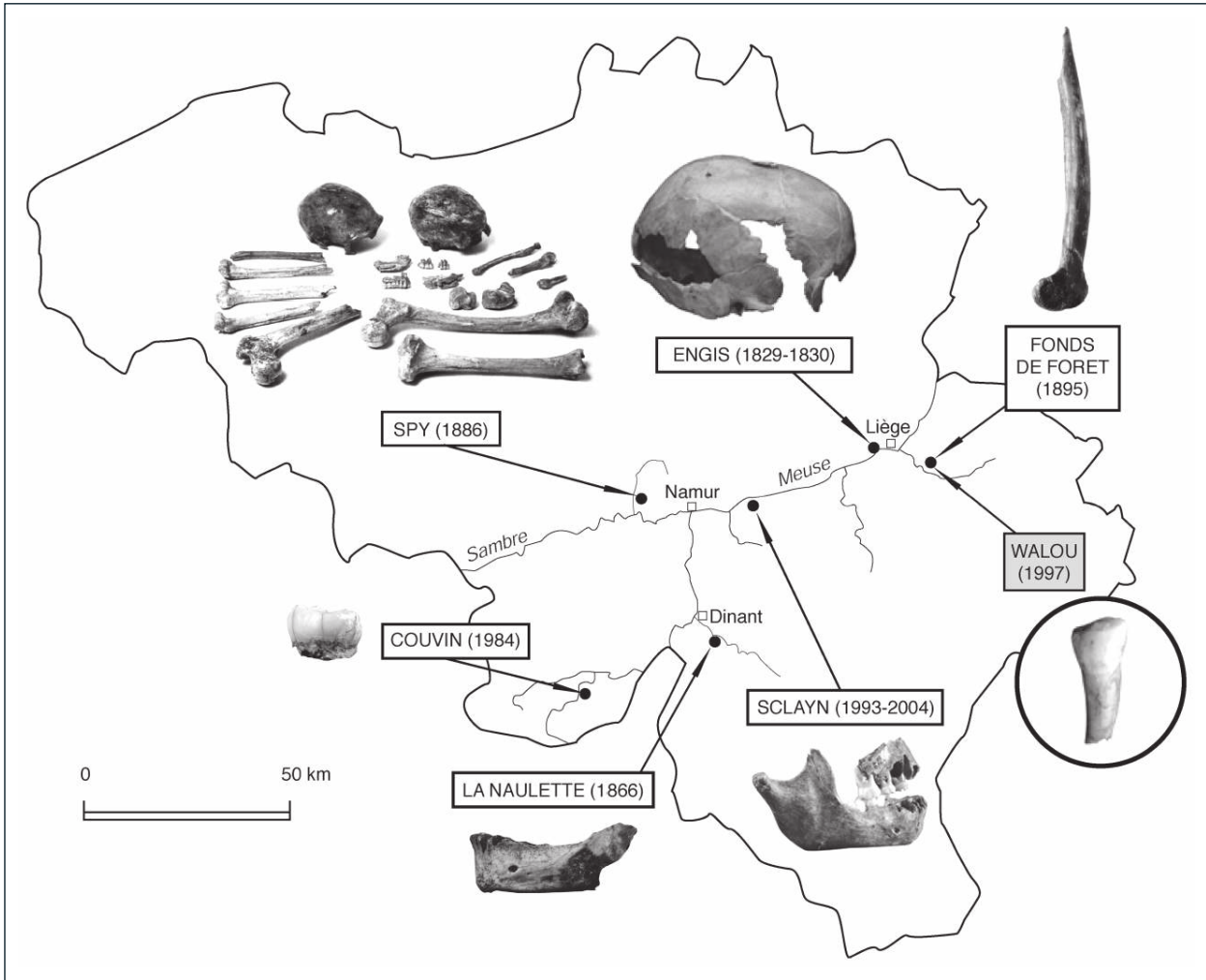
Cave entrances and rock-shelters offer a number of advantages to the study of the Quaternary. First, a large number of stratigraphic sections are easily accessible on these sites due to frequent archaeological excavations. Second, climatic variations, the basis of Quaternary stratigraphy, are theoretically recorded in these deposits. The paleosols, sedimentary structures, secondary carbonates (e.g. loess dolls, speleothems), weathering and degree of roundness of limestone blocks, loess deposits, cryoturbation, and gelifraction can be studied through a detailed geological survey. Third, palaeoenvironmental data collected during geological analysis can be tested through independent analysis by other disciplines, such as palaeobotany and

palaeozoology. The excellent bone preservation in karstic environments is a major asset. Fourth, chronology can be determined in several ways. (1) Different dating methods are available: radiocarbon on bones or charcoal, U/Th on speleothems, thermoluminescence (TL) on burnt limestones or burnt flints, etc. (2) Tephrostratigraphy is also helpful, with three well known tephras in the Upper Pleistocene of Belgium (Juvigné, 1993). (3) To a lesser extent, palaeontology and palaeoanthropology offer useful chronological indicators. (4) Archaeology can also, indirectly, provide more or less accurate chronological information due to the frequency of human occupations, the speed at which cultural evolution took place (mainly for the last 35,000 years) and the relatively good understanding of the succession and chronological extension of cultural phases in Belgium (Cahen & Haesaerts, 1984; Cauwe *et al.*, 2001).

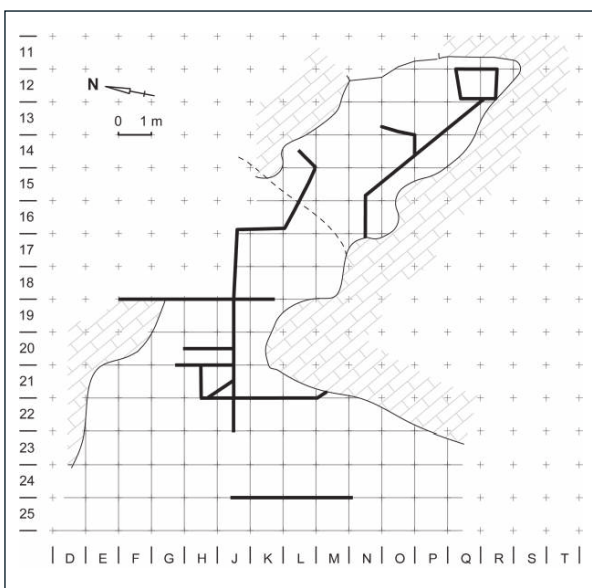
One last advantage is the composition of the non-carbonated fine fraction of Belgian cave entrance and rock-shelter fillings: it is mainly made of reworked loess (Ek *et al.*, 1974; Gullentops & Deblaere, 1992; Pirson, 1999). Walou cave is not an exception (Chen *et al.*, 1988; Juvigné & Renson, 1998). The specific location of these sequences, sedimentary traps directly exposed to outside processes, allows the recording of palaeoenvironmental information, notably through pedological phenomena (paleosols, secondary carbonates), just like in loess sequences. Despite the obvious differences between the two sedimentary environments, the possibility of correlating the studied deposits with the pedostratigraphic loess sequence of Middle Belgium should be tested. As this loess sequence provides the most complete record for Upper Pleistocene in Belgium (Haesaerts, 1974), a reliable correlation offers not only another way to check the palaeoenvironment data collected during geological analysis in caves but also invaluable chronostratigraphic tie points through pedostratigraphic, tephrostratigraphic and lithological data.

## 3. Walou cave

Walou Cave (Trooz, province of Liège, Belgium; Figs 1 & 2) is a major Palaeolithic site whose deposits exhibit an important stratigraphic sequence and evidence of numerous archaeological occupations. The site is located on the Magne River, a small tributary of the Vesdre River, and is set in Viséan limestones (Ghysel *et al.*, 1996). Excavated on two occasions, the first campaign was conducted from 1985 to 1990 by the *Société wallonne de Paléontologie* (SoWaP), under the direction of Michel Dewez (Dewez *et al.*, 1993). A primary analysis of the stratigraphy (Collcutt, 1993) and a few sedimentary analyses (Chen *et al.*, 1988; Lacroix, 1993) were conducted at this time. Recently, a palaeoenvironmental synthesis and a chronostratigraphic interpretation of the SoWaP excavations were presented (Pirson & Toussaint, 2002 : 94). The second campaign,



**Figure 1.** Location of Walou Cave amongst six other sites which have yielded pleistocene hominid remains in Belgium (cf. Toussaint *et al.*, 2001).



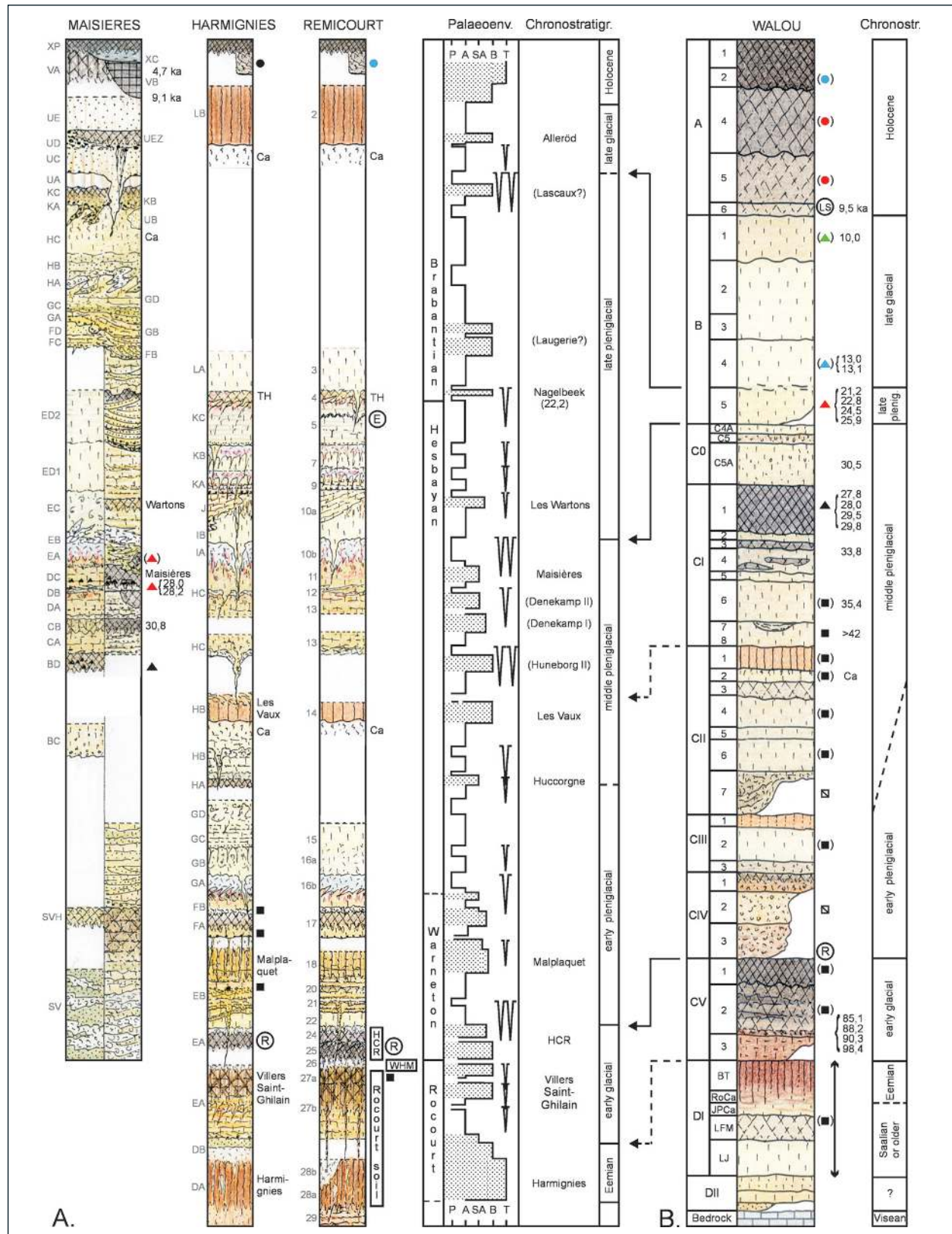
**Figure 2.** Plan of the site with location of the studied sections (bold) and of the cave entrance (dashed line).

funded by several grants from the *Ministère de la Région wallonne*, was conducted from 1996 to 2004 by Christelle Draily (Draily, 1998, 2004). The importance of the site was reinforced by the discovery of a Neandertal tooth in a Mousterian context (Draily *et al.*, 1999). This discovery made Walou the seventh Belgian cave to yield Middle Palaeolithic hominid remains (Toussaint *et al.*, 2001; Fig. 1). A monograph (in progress) will present the relevant data from the various disciplines involved. The 1996–2004 stratigraphic sequence as well as its correlation with Collcutt’s stratigraphy have already been presented (Pirson *et al.*, 2004). By comparison with the SoWaP data, the recent excavation permitted a finer sequencing of the lithostratigraphy particularly for the inferior units (C and D of Collcutt). The new sequence, approximately 10 m in depth, includes 10 sedimentary units.

**3.1. Lithostratigraphy**

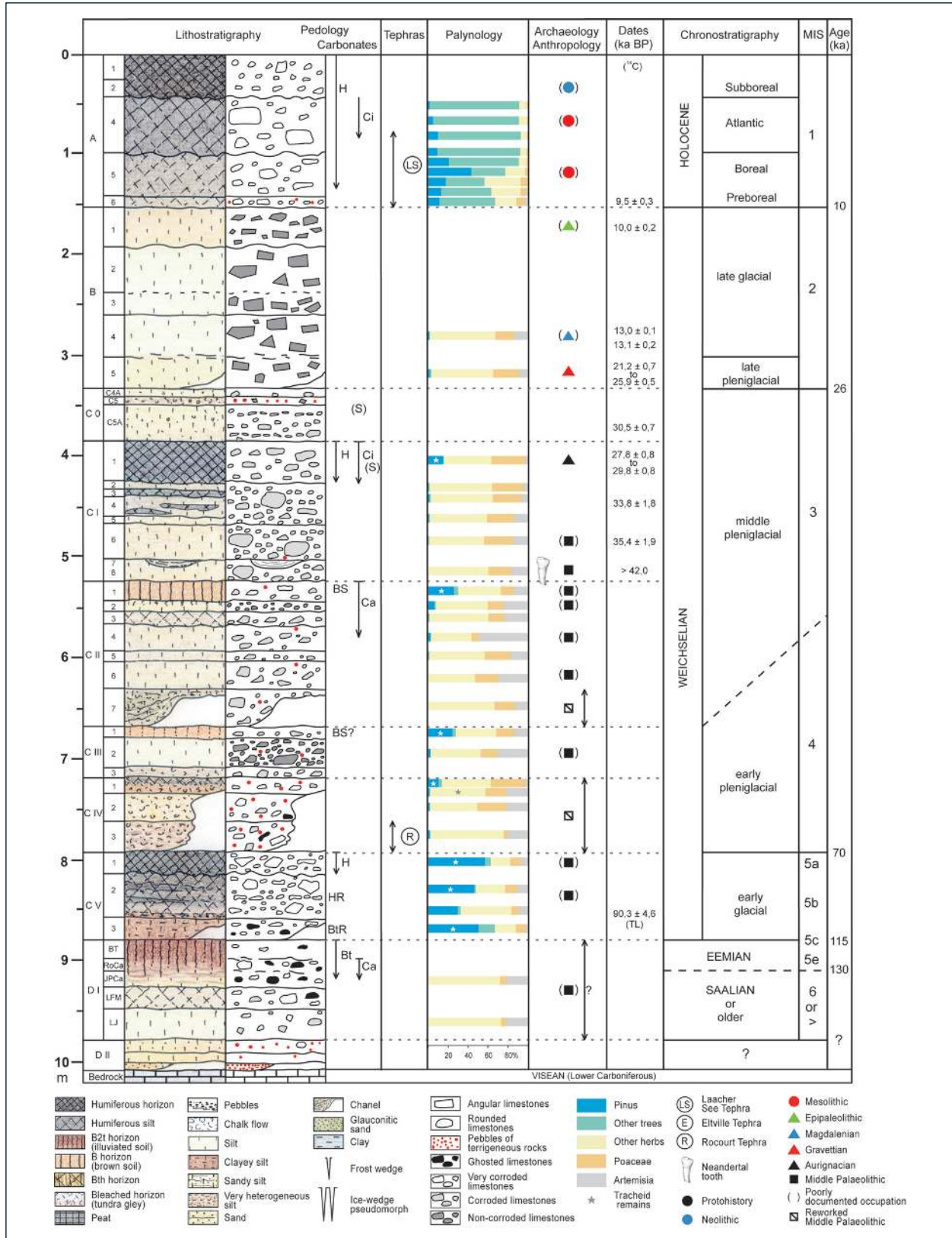
The following discussion provides a synthesis of the lithostratigraphic description of the Walou sequence





**Figure 3.** Comparison between (B) the pedosedimentary record of Walou Cave and (A) that of three major loess sequences from Belgium (from Haesaerts, 2004): Maisières-Canal (province of Hainaut), Harmignies (province of Hainaut) and Remicourt (province of Liège). The dates (in ka BP) are all radiocarbon dates, except for the bottom of unit CV-2 (thermoluminescence on burnt limestone). The Walou record only presents the fine fraction. For the coarse fraction, see Fig. 3.

Abbreviations: Ca = carbonate concretions; TH = tongued horizon of Nagelbeek; P = periglacial; A = arctic; SA = subarctic; B = boreal; T = temperate; WHM = Whitish Horizon of Momalle; HCR = Humiferous Complex of Remicourt. Graphic symbols: see Fig. 3.



**Figure 4.** The new stratigraphic sequence of Walou Cave. Most of the data from units A and B are from Dewez *et al.* (1993). For palynology, the percentage of each taxa are calculated in accordance with the total number of pollen grains of terrestrial plants. Palynological data of unit A are from Heim (1993). Abbreviations: H = humiferous soil; HR = reworked humiferous soil; BS = brown soil; Bt = illuviated horizon; BtR = reworked illuviated horizon; Ci = carbonate cement in the matrix; Ca = carbonate concretions; S = small speleothem; MIS = possible correlation with the marine oxygen isotopic stages.



(Pirson *et al.*, 2004) from the bottom of the deposits to the top (Figs 3B & 4). All the layers are matrix supported. Except when mentioned, the deposits are massive, without any internal stratification. The sedimentary bodies in the cave and on the terrace are generally following a gentle slope (ca. 5–10° for units DI to C0; ca. 15–20° for units B and A), either leading to the hillslope connected with the alluvial plain of the Magne River or to the back of the cave where the karstic system continues beyond the excavation area. The limestone clasts show most of the time a preferential orientation parallel to the slope.

Unit DII is poorly documented. This unit consists of very truncated residual layers, with very few limestone clasts and sometimes with many allochthonous elements (pebbles of terrigenous rocks).

Unit DI starts with two layers of pale yellow to light brown silt with limestone blocks (DI-LJ and DI-LFM). They are topped by three horizons denoting a strong pedogenesis (horizons DI-JPCa, DI-RoCa and DI-BT): strongly corroded or ghosted limestone clasts, numerous carbonated concretions, reddish patches and stripes developing towards the top into a compact reddish clayey silt, with a well-developed subangular blocky structure and clay coatings on the surfaces of the structural plans.

Units CV to CI are characterised by an abundance of coarse elements, mainly limestone clasts that are, unless stated otherwise, weakly corroded and slightly rounded. CV unit is composed of 3 layers. CV-3 is a reddish-brown silt with carbonate concretions in a secondary position and with limestone clasts showing a very variable degree of corrosion. It develops in a small channel structure. This is the result of the reworking of underlying unit DI. CV-2, a roughly stratified humic silt with strongly corroded and powdery limestone clasts, is probably a reworked humic paleosol. This layer contains charcoal concentrations and some lenses of rubified material at its bottom. CV-1 is a very dark brown compact silt with a well-developed granular structure and dark brown argillohumic coatings. This layer is an in situ humic paleosol. The limestone clasts exhibit the same degree of alteration as CV-2.

Unit CIV consists of a series of cut-and-filled layers in an important channel structure eroding the underlying layers. It is present across all the site. The walls of this structure are very irregular. The matrix of the fill is made of heterogeneous to very heterogeneous silts, orangey-brown to dark brown, with subrounded fragments, reworked from the anterior deposits. A stabilization with a slight humification can be observed locally at the top of the sequence.

CIII and CII units show some similarities. They both start with a heterogeneous and erosive layer (CIII-3 and CII-7) reworking the top of the underlying unit; CII-7 develops locally into a deep channel structure and presents some laminations. These are followed by one or more layers of grey beige to yellowish silt (CIII-2, CII-6 to CII-4, CII-2) that correspond to the reworking of the first allochthonous loess recorded in the sequence; locally, a layer of grey brown silt is present in the record (CII-3).

In CIII-2, undulating structure in the limestone clasts has been observed, with an irregular pattern. Laminated sediments have been reported locally, in CII-6 and in a small gully on top of CIII-2. Units CIII and CII both end with a layer of compact clayey silt, reddish-brown to orangey-beige, evoking a partly reworked small paleosol. In the case of CII-1, the presence of in situ secondary carbonates covering limestone blocks at the CII-2/CII-1 interface indicates that one portion of the pedological profile is still undisturbed.

Unit CI comprises a succession of layers of pale beige-grey, reddish-brown or dark brown silt, globally heterogeneous (CI-8 and CI-6 to CI-2). Locally, a small channel (CI-7) develops at the top of CI-8, with a stratified, silty filling poor in coarse elements. Evidence of a reworked paleosol can be seen at the top of CI-6 and in CI-4 and CI-3. Unit CI ends with a thick horizon of compact, dark brown, clayey silt (CI-1) which is highly porous (biogalleries). This horizon exhibits a well-developed, conchoidal structure with humic coatings and is an in situ humic paleosol, consistent with a climatic improvement. The presence of some small, in situ speleothems at this level (Collcutt, 1993) corroborates this interpretation.

C0 unit was not observed during the 1996–2004 excavations. The unit includes layers C0-C1 to C0-C5 of Collcutt (1993). C0-C1 to C0-C3 are burrows (Dewez, 1986) and are not included in the sequence. C0-C5A and C0-C4A are composed of orangey-yellow silt. C0-C5A is rich in small platy limestone clasts and reworked fragments from CI-1. Limestone elements are often organised in subhorizontal but undulating pattern. A small speleothem exists at the top of this layer. C0-C4A is locally slightly stratified and comprises some rounded limestones. C0-C5 is a heterogeneous deposit containing some angular limestone blocks and varied allochthonous rocks.

B unit is geometrically and lithologically different from the underlying units. Collcutt (1993) describes an angular unconformity between units B and C, which we also observed. During the recent excavations, an important channel, with irregular walls, gullying towards the top of DI, has been discerned at the bottom of unit B. This unit's very heterogeneous fill at the bottom substantiates the reworking of the underlying layers. As for lithology, the pure yellow silt, rather poor in limestone blocks which characterises the major part of unit B is clearly different from the anterior deposits. Moreover, these limestones are angular and non-corroded. Collcutt mentions locally a weak matrix lamination as well as thin slope-parallel lenses of limestone debris and microfauna. B1 and B5 layers were not well exposed during the recent researches. Collcutt (1993) described these as slightly more orange. This author reports cryoturbation in B1 and rhizoliths in the whole B unit. According to Collcutt, most of these rhizoliths originate from unit A, but some clearly come from the B2/B1 boundary, which might indicate a truncated paleosol. Decimetric bioturbations (krotovinas) from unit A can be seen in layer B1.

Finally, unit A consists of several layers of silt which become progressively darker towards the top, the colour ranging from orangey-brown to very dark brown. A granular structure gets progressively stronger towards the top while bioturbations are more and more frequent. The limestone clasts, more numerous than in unit B, are rounded and corroded to very corroded. Layer A3, interpreted as an anthropogenic structure (Collcutt, 1993), is not included in the sequence.

### 3.2. Tephrostratigraphy

The characteristic minerals of two tephra have been identified at Walou: those of the Laacher See Tephra and those of the Rocourt Tephra.

The Laacher See Tephra is a well known volcanic fallout dated from around 11,000 BP (Bogaard & Schmincke, 1985). It has been found in several locations in Belgium (Juvigné, 1993). At Walou, minerals from this tephra were located in layers A4 to A6 by Lacroix (1993) during the SoWaP excavations; they were in secondary position. The presence of this tephra at the bottom of unit A was confirmed by Renson and Juvigné, during C. Draily's excavations (Renson *et al.*, 2002).

The Rocourt Tephra has also been located at several Belgian sites. The dates for this Tephra range between 62 ka and 106 ka (Juvigné, 1993). However, its position in several loess sequences tends to situate it at the end of early glacial (Haesaerts *et al.*, 1999 ; Pirson *et al.*, 2004). Minerals from the Rocourt Tephra were located for the first time at the site of Walou by Lacroix (1993) in small concentrations in units B and CI. The extension of the excavations towards the lower layers allowed Renson and Juvigné to obtain better results: a maximal concentration was found in the lower part of Collcutt's C unit (Renson *et al.*, 2002). The new and more precise sequencing of this part of the record as well as the stratigraphic complexity of the area where most volcanic minerals were found necessitated new analyses. From that context, a new precisely positioned series of samples was obtained in the new stratigraphy. The first results, based on the examination of about ten samples taken by large and continuous scrapings, were recently presented (Pirson *et al.*, 2004). The maximum concentration of the Rocourt Tephra minerals was observed at the bottom of unit CIV.

### 3.3. Origin of the sediments and sedimentary dynamic

The autochthonous fraction, i.e. the limestone coarse elements and the carbonated fraction of the matrix, is originating from the walls and roof of the cave. The allochthonous coarse fraction is made of fluvial pebbles reworked from alluvial sediments preserved on the plateau. The non-carbonated sandy fraction of the matrix has probably the same origin. On the contrary, allochthonous pebbles and sand from DII could come from the karstic system. The non-carbonated silty fraction is of

loessic origin, as demonstrated by grain size and heavy mineral analysis (Chen *et al.*, 1988 ; Juvigné & Renson, 1998). Secondary carbonates are generated by pedological activity. Sediments from the plateau reached the site partly through the cave mouth and partly through a shaft connecting with upper levels of the system.

Apart from rockfall, stabilisation phases linked to pedogenesis and cryoturbation, the site filling is dominated by slope processes. Wash processes are attested by the laminated sediments observed in some layers. Major erosion phases are probably due to the melting of frozen ground (thermokarst). Given the significant slope, the periglacial context, the preferential orientation of limestone clasts and the silty matrix, solifluction must have played an important role (Bertran & Texier, 1995; Bertran, 2004). However, no clear structures, like those reported in the stone-banked lobe type solifluction (Bertran *et al.*, 1995 ; Bertran, 2004) have been noticed.

### 3.4. Palaeoenvironment, chronostratigraphy and comparison with the loess sequence

Data on the Upper Pleistocene gathered over the last 50 years in the loessic domain of north-western Europe (Gullentops, 1954 ; Paepe & Vanhoorne, 1967 ; Paepe & Sommé, 1970 ; Haesaerts, 1974, 2004 ; Haesaerts *et al.*, 1981, 1999 ; Haesaerts & Mestdagh, 2000) permitted the elaboration of a well-documented pedostratigraphic reference sequence. The palaeoclimatic interpretation is mainly based on the analysis of paleosols, periglacial phenomena and sedimentary units (Haesaerts, 1974 ; Haesaerts & Van Vliet-Lanoë, 1981). The same methodology applied to the Walou deposits, together with the available data from the study of tephra, heavy minerals of the silt fraction and micromorphology, yield the interpretation presented below and allows a comparison with the loess reference sequence (Fig. 3A). This palaeoenvironmental and chronostratigraphic interpretation deduced from geological data as well as the comparison with the loess sequence will then be tested by the other disciplines (§3.5.).

The strong pedogenesis of the top of unit DI can be ascribed to interglacial conditions. The well-developed clay coatings, observed macroscopically and confirmed in thin section, indicated the presence of a leached soil B2t horizon. The strong corrosion of the limestone elements and the presence of secondary carbonates is consistent with this interpretation. This illuvial horizon is similar to the "Rocourt Soil" which was defined by Gullentops (1954) on top of pre-Weichselian loess in Middle Belgium. This soil is a pedocomplex which consists of several pedogeneses highlighted at Harmignies, Kesselt, Rocourt and Remicourt (Haesaerts & Van Vliet, 1974 ; Mestdagh & Haesaerts, 1998 ; Haesaerts *et al.*, 1999 ; Haesaerts & Mestdagh, 2000). Complementary micromorphological study of the top of unit DI at Walou will have to focus on the presence of several illuvial phases. In the open air sequence, the 'Rocourt Soil' is topped by a humic pedo-

complex (“Humiferous Complex of Remicourt”, or HCR: Haesaerts *et al.*, 1999) in which the Rocourt Tephra is found (Gullentops, 1954; Juvigné, 1977; Haesaerts *et al.*, 1999; Haesaerts & Mestdagh, 2000). At Walou, a humic complex (CV) was observed above DI and the Rocourt Tephra was located at the bottom of CIV. However, the recently highlighted complexity of the early glacial in the loess succession of Belgium (Haesaerts *et al.*, 1999; Haesaerts & Mestdagh, 2000) emphasizes the need to exercise caution in making any hasty correlations. Nevertheless, the presence of the B2t (top of DI), of the humic complex (CV) and of the Rocourt Tephra (bottom of CIV) allow the attribution of this part of the Walou sequence to Eemian and early glacial. This hypothesis is reinforced by the silt mineralogy of DI, poor in amphibole and garnet, indicating a pre-Eemian age (Juvigné & Renson, 1998; Renson *et al.*, 2002).

Unit CIV developed in a channel which locally reached a depth of 1 m. The irregular and sub-vertical walls of this channel suggest a melting structure. This structure may be associated with periglacial climatic conditions with deep frozen soil. The periglacial conditions carried on in unit CIII as indicated by the erosive phase of layer CIII-3 and by the first allochthonous loess recorded at Walou in layer CIII-2. Local undulating structure of limestone clasts reported in CIII-2 could be ice-induced. The small paleosol CIII-1 evoked the return of interstadial conditions. By comparison with the record of the onset of the loess succession preserved above the Humiferous Complex of Remicourt in Hesbaye, units CIV and CIII can validly be ascribed to the beginning of the Weichselian lower pleniglacial.

Unit CII, with its reworked loess, is indicative of the return of periglacial conditions. This unit ends with a new paleosol reflective of a marked climatic improvement. The abundance of secondary carbonates and the clayey facies of CII-1 allowed a comparison with the “Les Vaux Soil” noticed at Harmignies (Haesaerts & Van Vliet, 1974) and Remicourt (Haesaerts *et al.*, 1997) in the middle pleniglacial. This soil shows close similarities with the Bohunice Soil (Valoch, 1976) with a date range between 40,000 BP to 42,000 BP in Central Europe (Haesaerts & Teyssandier, 2003). The pedogenesis of “Les Vaux Soil” may also be contemporary with the upper part of the Moershoofd interstadial defined in the Netherlands between ca. 40,000 BP and ca. 42,000 BP (van der Hammen, 1995).

Heterogeneous silts from unit CI also suggest middle pleniglacial. The strong humic paleosol at the top of CI may correspond to the humic pedogeneses of Maisières-Canal which range between ca. 33,000 BP and ca. 28,000 BP (Haesaerts, 2004). Unit C0 probably belongs to the end of middle pleniglacial. According to Collcutt (1993), the undulating pattern of limestone elements reported in C0-C5A may be ice-induced.

The angular unconformity at C/B interface and the lateral channel indicate a strong erosion. This erosion phase can

be related to those of Harmignies (unit J) and Remicourt (unit 10a) under the upper pleniglacial loess cover (Haesaerts, 1974; Haesaerts & Van Vliet-Lanoë, 1981: 309; Haesaerts *et al.*, 1999, fig. 12). In the open air sequence, this erosion phase is contemporaneous with or slightly subsequent to the important tundra gley with its large, ice-wedge polygons, which ends the middle pleniglacial. This tundra gley is found in a number of sequences as far as central Europe where it is radiocarbon dated to around 26,000 BP (Haesaerts, 1985). Besides, the morphology of the channel at the bottom of unit B, with its vertical and irregular walls, evokes a melting structure associated with a deep frozen soil similar to the structure of CIV channel.

The pure, yellowish silt of unit B indicates a substantial aeolian supply and allows a good correlation with the open air sequence. Such an accumulation is attested to during the upper pleniglacial, between ca. 25,000 BP and ca. 20,000 BP (Haesaerts, 1974, 2004). According to the model of Juvigné (1978), the heavy mineral composition of the silt fraction is in good agreement with this interpretation (Juvigné & Renson, 1998). However, the silt of unit B is in secondary position; Collcutt interpret the laminations he observed locally as wash processes. Thus, the lithostratigraphy is not sufficient to ascertain whether unit B arose during the upper pleniglacial or during the late glacial.

The important pedological phase, the stratigraphic position, and the presence of reworked minerals from the Laacher See Tephra relate unit A to the Holocene.

### 3.5. Comparison with the other disciplines

Figure 4 shows the excellent correlation between the palaeoenvironmental and chronostratigraphic interpretation presented above and the data from the other disciplines.

The geology-deduced palaeoenvironmental interpretation is totally compatible with the palynological data. The first pollen analyses were conducted during the SoWaP excavations (Heim, 1993). They concerned the equivalents of units A, B and CI. Whereas the results for unit A, attributed to the Holocene (see below), are consistent, those for units B and CI remain puzzling. In order to both verify the results of units B and CI and extend the palynological study to the rest of the sequence, new analyses were carried out in 2004 by M. Court-Picon within the framework of C. Draily's excavations (Pirson *et al.*, 2004). Thirty nine samples have been treated following a physico-chemical procedure of pollen extraction developed at the Royal Belgian Institute of Natural Sciences and based on Bastin's (1990) method. When possible, a minimum of 400 pollen grains from terrestrial plants was counted (aquatic, hygroet hydrophilous taxa, undetermined, intrusives, spores and non pollinic microfossils excluded: Berglund & Ralska-Jasiewiczowa, 1986). The mean of counted pollen grains by sample is 404, with a minimum of 106 and a maximum



of 935; only two samples contained less than 300 grains. Forty five taxa have been identified: 17 trees and shrubs, 26 herbaceous taxa and filicales as well as 2 algae. Amongst the vascular plants, 13 taxa have been identified at the family scale, 26 at the genus scale and 1 at the pollinic type scale. The complete diagram and comments will be presented in the monograph in progress. The strict correlation between palynology and the pedosedimentary record as well as the qualitative aspect of the assemblages demonstrate the reliability of the pollen signal. In units B to DI the climatic improvements are mainly highlighted by significant *Pinus* peaks. Although the *Pinus* pollen grains can be transported over long distances, the autochthonous nature of this taxon is proven at Walou by the occurrence of *Pinus* charcoal in unit CV and of tracheid remains in units CV, CIII-1, CII-1 and CI-1 (Fig. 4). Each paleosol observed in the sequence is characterised by a more or less rich spectrum of pine pollen, whereas the reworked loess deposits show an assemblage of rich, herbaceous taxa with a predominant steppic feature.

Inferences derived from the microfauna found during the SoWaP excavations (units CI, B and A) completed and reinforced the interpretation presented above. For example, layer CI-1 (C6 of Collcutt) contained an interstadial microfauna (Cordy, 1993), layers B4 to B2 yielded very cold associations (Cordy, 1991) and layers A6 to A2 revealed species characteristic of the Holocene (Turmes, 1996). Moreover, according to Cordy (1991), preliminary results of the microfaunal analysis may be indicative of supplementary interstadial phases at the top of B4, in B5 and in CI-C8. The palaeontological data from the 1996-2004 excavations (microfauna: M. Turmes; macrofauna: B. De Wilde) will be presented in the monograph in progress.

The chronostratigraphic position deduced from the comparison with the loess sequence and supported by tephrostratigraphy fits well with research results of the other disciplines (Fig. 4). Sixteen radiocarbon dates from several different layers were obtained during the two excavation campaigns (see the synthesis in Draily, 1998). In addition, four TL dates were obtained by N. Debenham on burnt limestones associated with heaps of charcoal and rubified material from the bottom of layer CV-2. Statistically, these dates are not significantly different and probably correspond to a single event the best estimate of which is given by the weighted mean ( $90,3 \pm 4,6$  ka). The numerous Middle Palaeolithic to Neolithic human occupations are also fully compatible with the geological interpretation. In unit B (Dewez *et al.*, 1993), the archaeological data and the radiocarbon dates complete the geological information: layer B5 belongs to upper pleniglacial while layers B4 to B1 belong to late glacial. Thus, there is an important hiatus between B5 and B4. Finally, palaeontological analysis confirms that unit A belongs to the Holocene. The data from micropalaeontology (Turmes, 1996) and palynology (Heim, 1993) refine the chronostratigraphic framework: layers A6 to A2 aligned with Preboreal to Sub-Boreal.

These results indicates that the correlation between cave entrance and rock-shelter sequences and the loess reference sequence is possible in Belgium, despite the differences between the two sedimentary environments. The abundance of silt with a loessic origin is in that context a major asset.

#### 4. Conclusion and prospects

The Walou results emphasized the importance of the geological approach in the study of palaeoenvironments and the assessment of chronostratigraphic position for cave entrance and rock-shelter sequences. This approach thus favorably complements the results of the other disciplines. The microstratigraphic study of the Walou sequence highlighted a number of clear climatic markers, particularly those recorded by pedological and sedimentary processes. The significance of these markers is substantiated by the palynological data which, moreover, helps specify the types of vegetation characteristic of the different stages of the filling process.

In addition, tephrostratigraphy in conjunction with the excellent correlation with the loess sequences of Middle Belgium gives this exceptional record a coherent chronostratigraphic framework which finds support in radiocarbon and TL dates, archaeology and palaeontology. The integration of our results with the data collected during the SoWaP excavations (Dewez *et al.*, 1993 ; Turmes, 1996) indicated the sedimentary record of Walou spans from the Holocene down to the Pre-Weichselian and includes the late glacial, pleniglacial, early glacial and probably Eemian. Walou cave presents the most complete and best documented Upper Pleistocene sequence available for all the Belgian caves.

One of the direct consequences of our results is a better chronological framework for the numerous archaeological occupations of Walou, mainly for Middle Palaeolithic occurrences. More specifically, this approach also concerns the Neandertal tooth from layer CI-8. If one agrees with the age of 40-42 ka proposed for "Les Vaux Soil", this tooth can reasonably be dated between ca. 36,000 BP and ca. 40,000 BP.

Future research will have to focus on several directions. At Walou, the detailed comparison of the results gathered to date with the data from microfauna and macrofauna, as well as the completion of micromorphological and magnetic susceptibility analyses, should make it possible to improve on the palaeoenvironmental interpretation. Sedimentary dynamics, barely approached here, will have to be examined by comparing field data with the results from different analyses (such as granulometry or heavy mineral study). The origin and depositional mode of the sediments as well as the significance of the stratigraphic gaps will have to be emphasised.

The same methodology adopted at Walou will have to be applied to other depositional records found in the same

sedimentary environment. This approach will permit the confirmation of the reproduction of these geology-deduced palaeoenvironmental signals on a regional level. The correlation between the different records will lead to the development of a reference sequence for cave entrances and rock-shelters. The first attempts at correlation between the main lithostratigraphic units of several cave and rock shelter sequences are encouraging (Pirson, 2002; Pirson & Toussaint, 2002). A more detailed correlation between the deposits of Walou and those of other sequences, such as Scladina Cave, is also promising. In the long run, accurate interpretations of sedimentary dynamics, palaeoenvironment, and chronostratigraphy will lead to interesting applications for the other disciplines involved in the study of these types of deposits, particularly archaeology, palaeoanthropology and paleontology. For example, they could contribute to a better understanding of the context of the numerous prehistoric finds in Belgian caves. Geology is fundamental to the accuracy of site interpretation and analysis. Therefore, geologists should actively participate throughout the process of site excavation. Moreover, the elaboration of a reference sequence could also allow the re-examination of stratigraphic data from past excavations.

## 5. Acknowledgements

We would like to thank Joël Eloy (*Découverte géologique de Comblain-au-Pont et environs*), Louis Bruzzese and Sylviane Lambermont (*Association wallonne d'Etudes mégalithiques*) as well as Eric Dermience (*Royal Belgian Institute of Natural Sciences*) for their technical assistance. We also express our deepest gratitude to Cheryl Roy (*Malaspina University-College, British Columbia, Canada*), Jean-François Lemaire (*Association wallonne d'Etudes mégalithiques*) and Philippe Pirson for their valuable help in translating the manuscript into English. We want to thank Yves Vanbrabant (*Geological Survey of Belgium*) and an anonymous reviewer for helpful comments. Last but not least, we gratefully acknowledge Etienne Juvigné (*University of Liège*) who welcomed one of us (SP) in his laboratory and acted as a guide in the Rocourt Tephra problematics.

This work was made possible by funding to SP through an Action 2 project from the Belgian Science Policy. The 1996-2004 archaeological excavations at Walou were supported by the *Direction de l'Archéologie du Ministère de la Région wallonne*.

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Manuscript received on 17.04.2005 and accepted for publication on 15.05.2006.