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FAMENNIAN

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(9 figures, 4 tables)

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ABSTRACT. The name of the Famennian stage originated in the 19th century from the Famenne region in southern Belgium. After the pioneering work of Dumont, d'Omalius d'Halloy, Gosselet and Mourlon, a renewed interest in the 1960's focused mainly on the lithological, sedimentological, paleontological and palynological characteristics of the Famennian. This resulted in a refined litho- and biostratigraphical framework for the Lower Famennian Famenne Shales and the Upper Famennian Condroz Sandstones in Belgium. The most obvious finding was the distinct diachronous character of the Condroz Group. The present review paper extends this stratigraphical framework into the neighbouring Avesnois (Northern France) and Aachen (Northwestern Germany) areas: it proposes a lithostratigraphical correlation between the units identified within the individual tectonic units. An overview is given of the main lithological-sedimentological characteristics, depositional environments (for both the siliciclastics and the carbonates) and prevailing paleogeographical-paloeclimatological conditions, during the Famennian stage in Belgium and adjacent areas.

KEYWORDS: Famennian, Belgium, Avesnois, Northwestern Germany

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1. Introduction

In Belgium, the Famennian is exposed or has been encountered in five distinct tectonic settings (Fig. 1): a) the autochtonous Namur Synclinorium with its prolongation into the Hainaut area; b) the allochtonous Dinant Synclinorium, c) the Theux tectonic window in the Stavelot-Venn Massif; d) the Vesdre Nappe which extends into the Aachen area; e) and the subsurface of the Campine Basin in north-eastern Belgium where the Famennian has been encountered only in boreholes. Both the Namur and Dinant Synclinoria extend into the Avesnois region of northern France. All of these units (and depocenters) surround the London-Brabant Massif as part of the former Old Red Continent. They reached their present-day tectonic configuration during the Asturian orogenic phase. The Dinant and Namur Synclinoria are separated by the Midi-Eifel-Aachen Overthrust, the importance of which still remains a matter of debate: it accounts for 10-15 km of basin shortening according to Michot (1980) *versus* more than 100 km according to the tectonic nappe concept of Bless *et al.* (1983). Adopting the latter model would have an immediate implication for the palinspastic paleogeographical reconstruction of the Famennian lithostratigraphical units. The Famennian is more complete and best developed in the Dinant Synclinorium. In contrast, it is rather incomplete or even lacking due to erosion or non-deposition events in the other areas (*e.g.* the northern limb of the Namur Synclinorium, the Hainaut area and especially in the Campine Basin, NE-Belgium), as shown in figure 3.

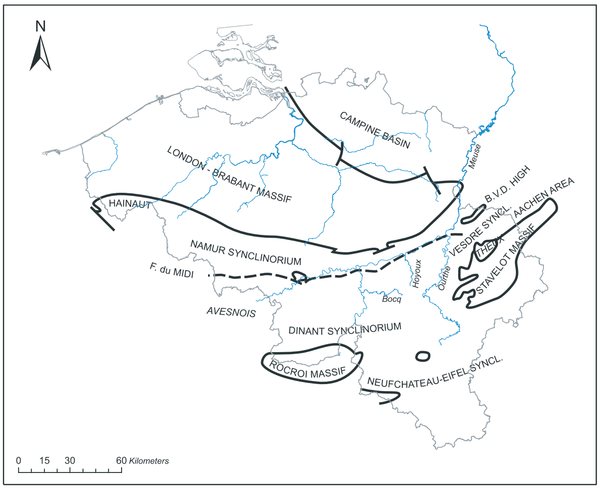


Figure 1. Location map of the studied areas. B.V.D. = Booze – Le Val Dieu High

2. Name

Famennian (English), Famenniaan (Dutch), Famennium (German), Famennien (French).

3. Age

(Gradstein *et al.* 2004)
Top: 359.2 ± 2.5 my
Base: 374.5 _+ 2.6 my

4. Authors

The name "Famennian" was first introduced by Dumont (1855, legend of the "Carte géologique de l'Europe": Faménien ou Dévonien supérieur) when referring to a shaly and sandy (Dumont, 1848) "Condruzian System". The evolution in concept of subdividing the Famennian Stage is summarized in Table 1 (modified after Dreesen, 1976), starting with the pioneering work of Dumont (1832) and ending with the latest concepts of Bouckaert *et al.* (1968) and Thorez & Dreesen (1986).

5. Historical type area

The name of the Famennian stage originated in the 19th century from the Famenne region in southern Belgium. This geographical region corresponds to a shaly depression located South and East of the Meuse river, in between the Condroz area (folded sandstone-limestone succession) in the North and the limestone ridge (La Calestienne) and the succeeding Lower Paleozoic Ardennes hills in the South (Fig. 2). The name Famenne refers to its Latin name "famina", pointing to the poor soil conditions of the area.

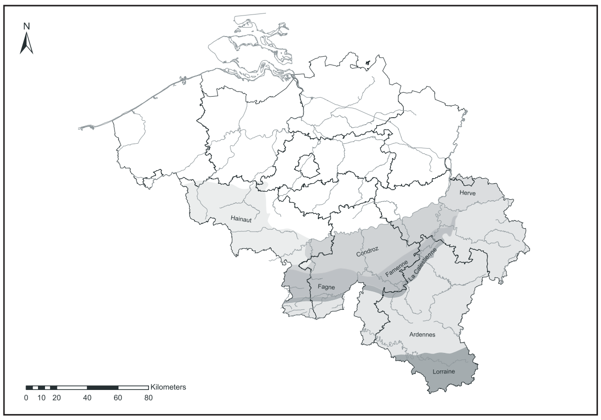


Figure 2. Location of the Famenne area, the name of which is at the origin of the Famennian Stage.

6. Description

The Famennian Stage (Uppermost Devonian) corresponds in Belgium to a sedimentary sequence of up to 600 m of predominantly siliciclastic shelf sediments inserted in between Upper Devonian (Frasnian) and Lower Carboniferous (Tournaisian) shelf carbonates. With time, a lithofacies shift occurred from predominantly pelitic sediments in the early Famennian, (the Famenne Shales) to predominantly sandy sediments during the late Famennian (the Condroz Sandstones). Fossiliferous nodular shales represent the transitional beds from the underlying Matagne Shales (Frasnian), whereas the Latest Famennian (Strunian) stromatoporoid limestones of the Comblain-au-Pont Fm mark the start of the extensive shallow-marine shelf carbonate sedimentation of the succeeding Lower Carboniferous (Tournaisian) stage, starting with the Hastière Limestone (Figs 2 & 3).

7. Historical background

Dumont (see chapter 4., Authors) correlated his Condruzian system with the Condroz Psammites *s.l.* of d'Omalius d'Halloy (1868). The latter unit then still included the uppermost Frasnian shales at the base, and the Etroeungt "Assise" at the top. The "standard" stratigraphical scheme of the Upper Famennian "Condroz Psammites" was first established by Mourlon (1875-1886) in the Ourthe valley, which is south of Liege in the north-eastern corner of the Dinant Synclinorium. Mourlon introduced and described several new stratigraphical units, in ascending order: the Esneux, Souverain-Pré, Montfort and Evieux "assises". These units were then all well exposed in the railroad cuts along the Rivage-Liège track and, in the then, numerous active sandstone quarries. The names of the "assises" were taken from small towns and villages along the Ourthe river, where the lithological units were well exposed. Later on, Mourlon (1885) studied coeval lithological units in different geographical areas. He then proposed a lithostratigraphical correlation with the southern part of the Dinant Synclinorium and even with the Avesnois area of northern France, where a shalier facies predominated. Gosselet (1878, 1879, 1880) recognized also important lateral facies changes when he correlated the sandy Condroz Psammites of the Condroz and the Entre-Sambre-et-Meuse regions (northern limb of the Dinant Synclinorium) with the dominantly shaly facies of the Fagne area in northern France. In the latter area, the Sains Shales that occur above the Senzeille and Mariembourg Shales, were then considered as coeval deposits of the Condroz Psammites (= micaceous sandstones) (Fig. 2). The exact lithostratigraphical position of the Souverain-Pré "assise" has been discussed by Dreesen (1976). Since the work by Bouckaert *et al.* (1968) the Souverain-Pré formation has become incorporated into the Condroz Sandstone Group. Figure 3 is a more detailed

Subdivision	Reference
UPPER QUARTZO-SHALE SYSTEM	*Dumont (1830)*
CONDROZ PSAMMITES s.l.	*d' Omalius d' Halloy (1839)*
QUARTZO-SHALY CONDRUZIAN SYSTEM	*Dumont (1839)*
FAMENNE SHALES | CONDROZ PSAMMITES	*d' Omalius d' Halloy (1858)*
FAMENNIAN STAGE	*Dumont (1855)*
FRASNIAN SHALE + LIMESTONE | FAGNE SHALES | CONDROZ PSAMMITES | ETROEUNGT LIMESTONE	*Gosselet (1860)*
FAMENNE SHALES | CONDROZ PSAMMITES	*Mourlon (1873)*
LAYGRED SHALES | PSAMMITES | ETROEUNGT SHALE + LIMESTONE	*Gosselet (1879)*
CONDROZ PSAMMITES: ESN ASSISE, SVP ASSISE, MFT ASSISE, EVX ASSISE	*Mourlon (1880)*
LOWER FAMENNIAN (SEN ASSISE, MAR ASSISE) | UPPER FAMENNIAN (SAINS ASSISE, ETROEUNGT ASSISE)	*Gosselet (1880)*
LOWER FAMENNIAN Fa 1 (SEN Fa 1a, MAR Fa 1b, ESN Fa 1c) | Fa 2 (SVP a, b) | Fa 3 (MFT a, EVX b, c, d, HAS e, CLP f)	*Mourlon (1882)*
Fa 1 (SEN Fa 1a, MAR Fa 1b, ESN Fa 1c) | Fa 2 (SVP Fa 2a, MFT Fa 2b, EVX Fa 2c, CLP Fa 2d)	*1st Map Legend (1892)*
LOWER FAMENNIAN (SEN Fa 1a, MAR Fa 1b-c) | UPPER FAMENNIAN (MFT Fa 2a, EVX Fa 2b)	*5th Map Legend (1900)*
LOWER FAMENNIAN (SEN Fm 1a, MAR Fm 1b, ESN + SVP Fm 1c) | UPPER FAMENNIAN (MFT Fm 2a, EVX Fm 2b)	*Geological Survey of Belgium (1952)*
LOWER FAMENNIAN | SVP MIDD. FAM | UPPER FAMENNIAN	*Sartenaer (1957)*
Fm 1 (LOWER ASS. Fm 1a, MIDDLE ASS. Fm 1b, UPPER ASS. Fm 1c) | Fm 2 (LOWER ASS. Fm 2a, UPPER ASSISE Fm 2b)	*Beugnies (1965)*
LOWER FAMENNIAN (Fa 1a, Fa 1b) | UPPER FAMENNIAN (ESN Fm Fa 2a, SVP Fm Fa 2b, MFT Fm Fa 2c, EVX Fm Fa 2d) | STRUNIAN (CLP Fm Tn 1a)	*Bouckaert, Streel & Thorez (1968)* *Thorez & Dreesen (1986)*
LOWER FAMENNIAN (SEN Fm, MAR Fm) | MIDDLE FAMENNIAN (ESN Fm AYE Fm, SVP Fm) | UPPER FAMENNIAN ((*), (*)) | UPPERMOST FAM. (CLP)	*Thorez & Dreesen (1986)* *Thorez & Dreesen (2002)* *(Dinant synclinorium, Belgium)*
FAMENNE GROUP | CONDROZ GROUP (*)	*this paper*

Abbreviation	Locality
SEN	Senzeille
MAR	Mariembourg
ESN	Esneux
AYE	Aye
SVP	Souverain-Pré
MFT	Montfort
CLT	Comblain-La-Tour
CIN	Ciney
HAV	Haversin
EVX	Evieux
BEV	Beverire
HAS	Hastière
CLP	Comblain-Au-Pont

Table 1. Historical evolution of the lithostratigraphical subdivision of the Famennian Stage. Asterisks in the lowermost boxes refer to the most recent subdivision depicted in Fig.3.

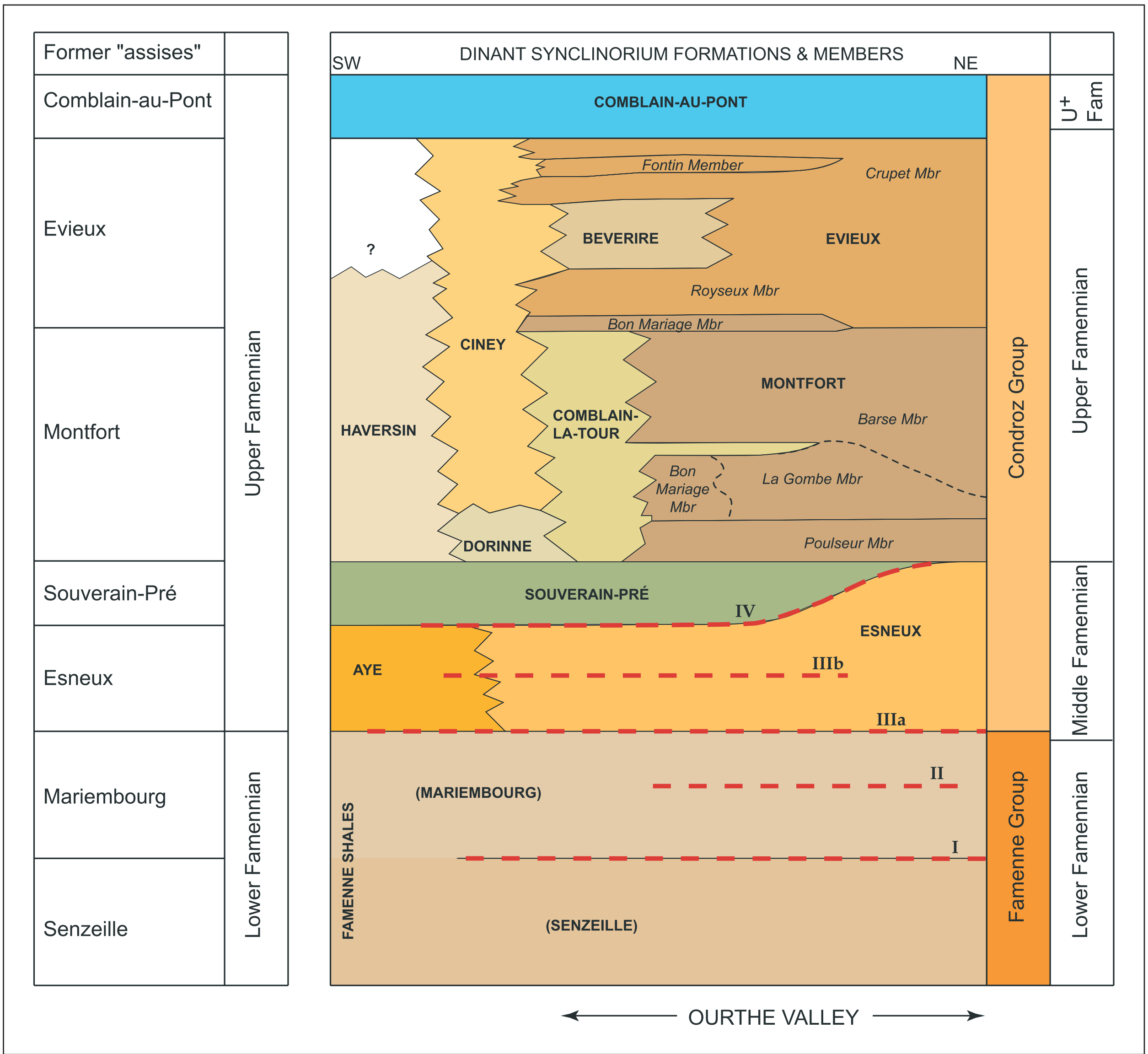


Figure 3. Detail of the lowermost box in Table 1 showing further lithostratigraphical subsdivsion of the Famennian Stage within the Dinant Synclinorium. Dashed red lines correspond to successive oolitic ironstone levels (event-stratigraphical marker beds).

correlation scheme for the Famennian formations in the Dinant Synclinorium and represents an enlargement of the inset at the very bottom of Table 1.

Altough an international agreement has yet not been reached to define the bases of substages within the Famennian stage, a subdivision into 4 substages has been internationally adopted: from base to top the Lower, Middle, Upper and Uppermost (Strunian?) Famennian (Streel *et al.*, 1998 & 2005). A proposal for a conodont-based definition of these substages is still under consideration by the International Subcommission on Devonian Stratigraphy (Streel, 2005). However, it is adopted here as a chronological subdivision to replace the old subdivisions of 2 or 3 substages and the now obsolete stratigraphic units represented by the Fa or Fm symbols (Table 1, Fig. 3).

8. Lithology and lithostratigraphy

In the Dinant Synclinorium, the Lower Famennian Famenne Group encompasses the shaly Senzeille and Mariembourg Fms (Fig. 4): the latter grade laterally into the Lambermont (*pars*) and Hodimont Fms in the Namur Synclinorium (southern flank), in the Vesdre Nappe and in the Theux Window. Although the Senzeille and Mariembourg Fms can be distinguished on the base of a combination of lithological and macropaleontological criteria (e.g. rhynchonellid brachiopod index species) this distinction has not been made on the published sheets of the new geological map of Wallonia. On the other hand, the Senzeille and Mariembourg Fms merge in a southwestern direction into one single unit, called the Fa-

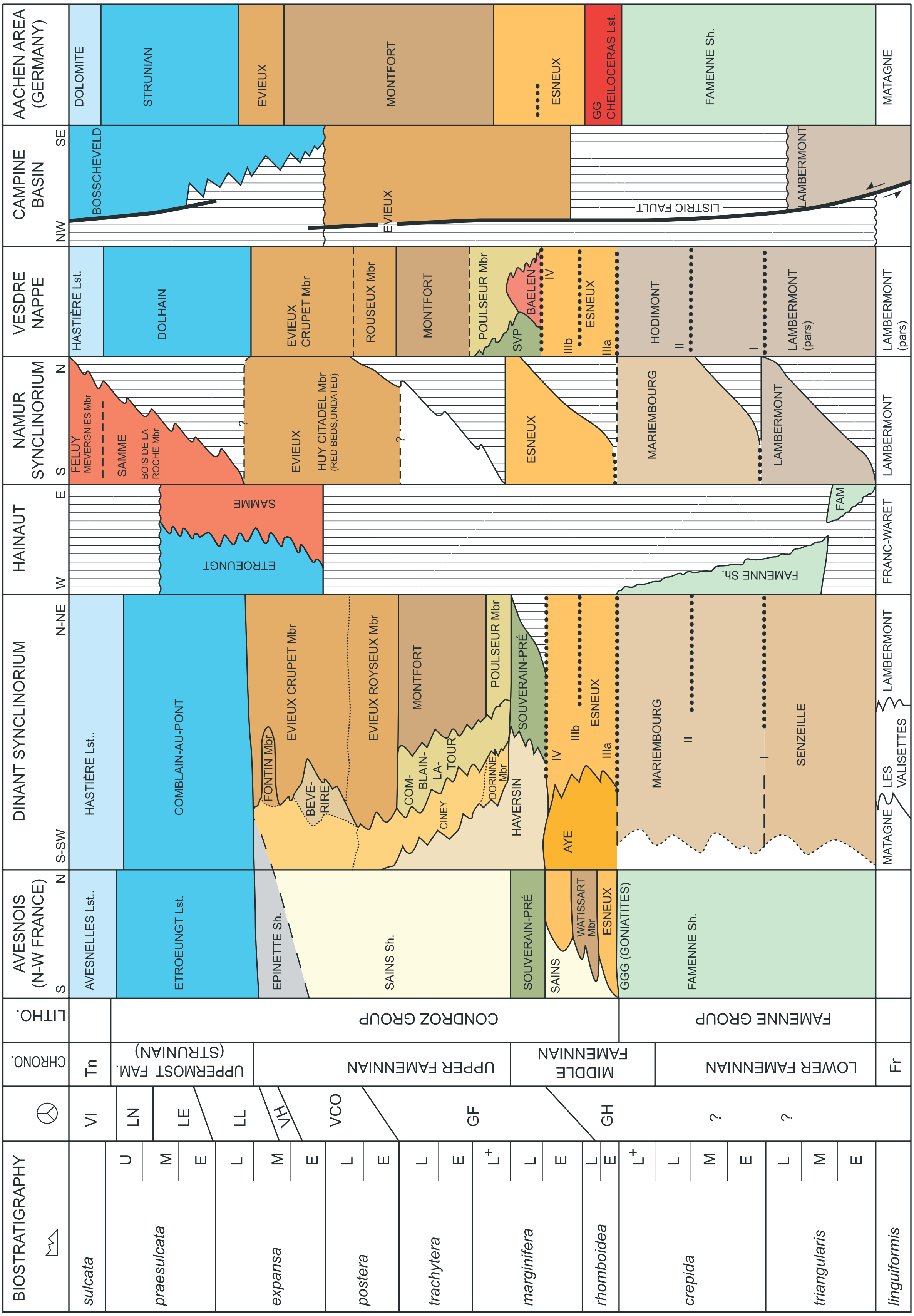


Figure 4. Lithostratigraphical scheme of the Famenne and Condroz Groups in the different tectonic units of Belgium, incorporating the Avesnois (northern France) and Aachen areas (western Germany). Correlations are based on conodont and miospore zonal markers (left). Black dotted lines correspond to oolitic ironstone levels

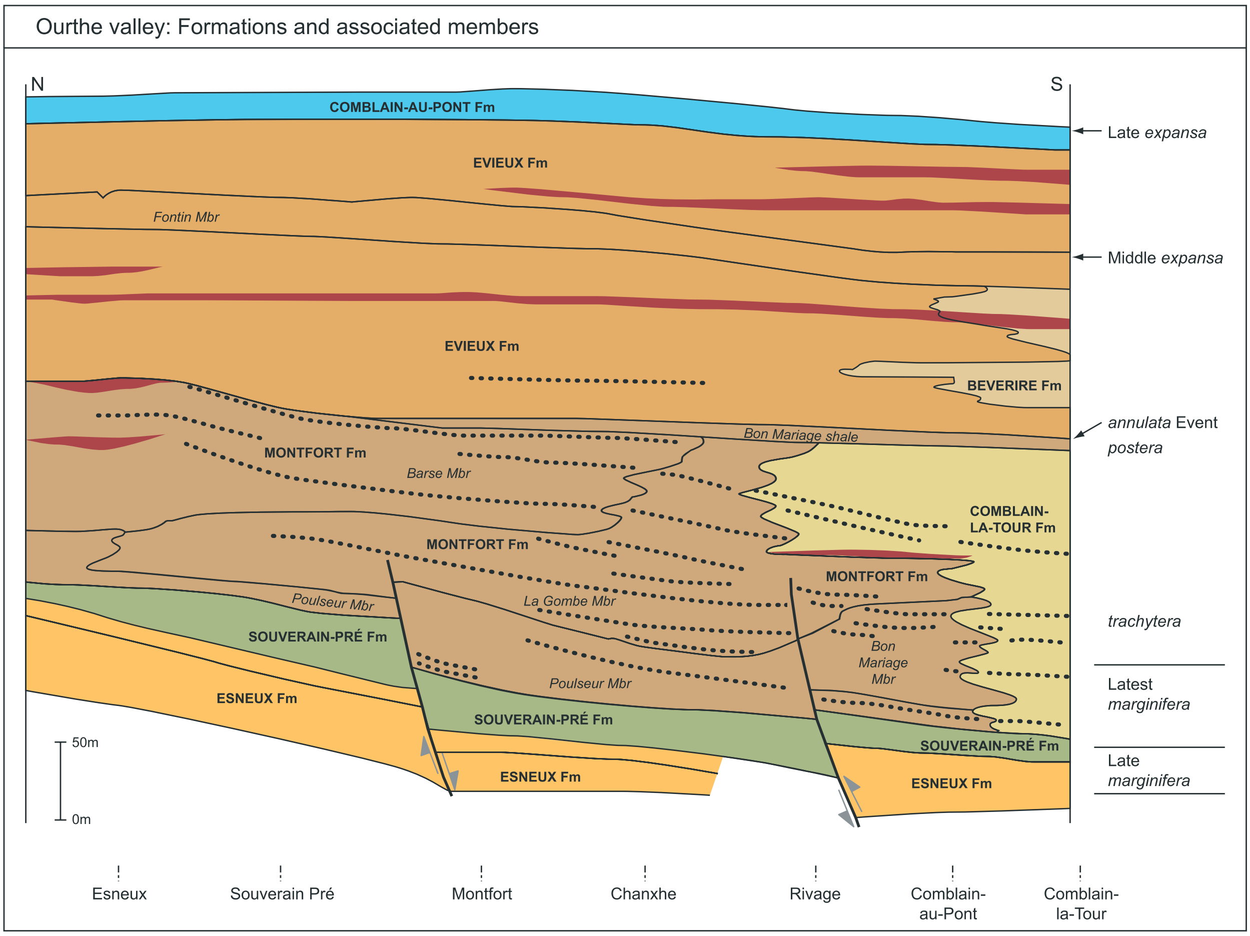


Figure 5. Lithostratigraphical scheme (after a palinspastic reconstruction of about 18 km) of the Condroz Sandstone Group in the "classical" Ourthe valley (S of Liège). This section extends from the town of Esneux in the N to the town of Comblain-la-Tour in the S. Black dotted lines represent conspicuous ball-and-pillow levels ("pseudonodules"). Thick red lines correspond to red beds.

menne Shales, typical of the Avesnois area (Fig. 4). Here, the latter Famenne Shales contain nodular and lenticular limestones near their top, yielding conodonts of the *marginifera* zone: hence this upper level can be correlated with the Souverain-Pré Fm in the Ourthe valley (Bouckaert *et al.*, 1977). Moreover, a goniatite-bearing nodular and lenticular limestone interval within the Famenne Shales in the same area, allowed further biostratigraphical correlation with the *Cheiloceras* Limestone of the Aachen region (NW-Germany) (Fig. 4).

The Upper Famennian Condroz Group is best developed, and shows the most complete suite of succeeding formations, in the eastern part of the Dinant Synclinorium (Fig. 3): here, the Montfort Fm grades into the coeval Comblain-la-Tour, Ciney and Haversin Fms, according to a NNE - SSW section. The Haversin Fm in turn passes laterally and in a southwestern direction into the Sains Shales (Avesnois area, northern France). The Evieux Fm is conspicuously interfingering with the Beverire Fm. Its uppermost part is also interrupted by a short transgressive event, the restricted marine or peritidal Fontin Mbr, whereas a thin black shale interval near the boundary of the Montfort and Evieux Fm (in the Ourthe and Bock valleys) matches another transgressive event, that can probably be correlated with the *annulata* event (Walliser, 1996). Despite the lack of good biostratigraphical control, a thick series of red beds (up to 200 m) provisionally named here as the Huy Citadelle Fm (southern flank of the Namur Synclinorium) (Fig. 4), seems to be coeval of the Evieux Fm. In the Namur Synclinorium, the Samme Fm is partly coeval with the Comblain-au-Pont Fm from the Dinant Synclinorium, but it extends vertically into the Lower Carboniferous Hastière Limestone. In the Campine Basin, the Condroz Sandstone Group (according to borehole data) seems to be represented only by the Evieux Fm. Here, the latter formation is clearly diachronous with respect to the adjacent tectonic units (Laenen, 2003) (Fig. 4). In the Aachen area (NW-Germany), peculiar red-stained goniatite-bearing nodular shales and limestones (the so-called *Cheiloceras* Limestone) occur at or near the transition of the Lower Famenne Shales and the Esneux Fm. This level grades laterally (to the W) into an oolitic ironstone bed and can be traced further westward into the Vesdre and Dinant

Synclinoria (Sartenaer, 1957b; Dreesen, 1987, 1982b). In the Avesnois area, a coeval Cheiloceratid goniatite bearing interval is present as well (Bouckaert *et al*, 1977). Moreover, analogous *Cheiloceras*-bearing marker horizons have been encountered at the same stratigraphical level in different sedimentary basins throughout the Rheno-Hercynian realm (Dreesen, 1989). The Watissart Mbr is a local and rather unusual sandy member of the Esneux Fm in the westernmost part of the Dinant Synclinorium (Silenrieux-Walcourt and Grandrieu-Beaumont area; Dumoulin & Marion, 1997; Dumoulin, 2001) and in the adjacent Avesnois area (Northern France, Waterlot *et al.*, 1967): here, grey quartzitic sandstones ranging in thickness from tens of centimetres to metres were recognized for the first time by Gosselet (1880). They were initially identified as "Grès de Cerfontaine", and later as "Grès de Watissart" by Beugnies (1965) and Waterlot *et al.* (1967). However, because of the lack of detailed sedimentological and biostratigraphical data, the lithostratigraphical relationships of the Famennian of the Avesnois area with coeval deposits in the adjacent areas in Belgium are still unclear. Figure 5 represents the stratigraphical framework for the Condroz Group in the "classic" Ourthe valley: in this valley Mourlon (1875-1886) made his pioneering geological observations leading to the first detailed (litho)stratigraphical scheme of the Condroz Sandstones, differentiating the succeeding (superposed) lithostratigraphic units or "assises" of Esneux, Souverain-Pré, Montfort and Evieux. Later on, these "assises" became partly replaced by formal formations with corresponding names. More recently, new coeval formations have been introduced, including the Beverire and Comblain-la-Tour Fms (Bouckaert *et al.*, 1968). Of particular interest is the occurrence of thin oolitic ironstone beds (Figs 3 & 4) in the Famennian. These appear at distinct stratigraphical levels in the Lower and Middle Famennian and represent excellent lithostratigraphical marker beds (levels I, II, IIIa, IIIb & IV of Dreesen, 1982a and b). They are interpreted by the authors as transgressive system tracts. Some ironstone beds can be traced over great distances throughout the sedimentary basin, even out of Belgian territory into the Aachen and Avesnois areas. Moreover, they represent good event-stratigraphical markers that can even be correlated with volcano-sedimentary events in the Rhenish basin (Dreesen *et al.*, 1986a and b; Dreesen, 1987). Based on geochemical evidence (REE) the source of the iron has been related to volcanic activity (Laenen et al, 2002).

9. Sedimentology and palaeogeography

The present authors have summarized and graphically highlighted the most relevant lithological, sedimentological and depositional environmental parameters for each of the identified units in tables (Tables 2, 3 & 4). The latter tables give a quick overview of the dominant lithological and sedimentological characteristics and subsequent depositional settings, allowing a clear distinction of each formal lithostratigraphical unit of the Belgian Famennian Stage. The Lower Famennian argillaceous sediments represent relatively open marine conditions: they were deposited mainly offshore, on a shallow epicontinental platform, out of the reach of the longshore currents that redistributed the mainly coarser siliciclastics. Paleoecological evidence from conodont biofacies analysis supports the above interpretation (Dreesen & Thorez, 1980). The Senzeille and Mariembourg Fms are, respectively, composed of olive-green to greyish green shales and grey to purplish (violet) shales and sandy shales, locally enclosing thin siltstone and fine-grained sandstone beds, as well as nodular or lenticular limestones. Rhynchonellid brachiopods are very common and particular key-species are very helpful in the field for mapping and discriminating between the two shaly formations. Oolitic ironstone marker beds occur within the Famenne Group in most of the investigated tectonic units. The latter Clinton-type oolitic ironstones are composed of lenticular limestones (packstones / grainstones) enriched with various ferruginized allochems. The shaly Hodimont Fm (Laloux *et al.,* 1996) of the Vesdre Nappe is coeval with the Mariembourg Fm of the Dinant and Namur Synclinoria, but it encloses more siltstone beds (decimetric to metric beds). The Hodimont Fm contains numerous nodular and lenticular limestones or coquinas (brachiopod-rich wackestones and packstones). In the Aachen area, a particular red-stained goniatite-bearing nodular mudstone/wackestone, the "*Cheiloceras* Kalk", occurs near the Lower/Upper Famennian transition. The latter limestone can be traced into the adjacent Vesdre Nappe (Sartenaer, 1957b) and Dinant Synclinorium and grades laterally into ironstone level IIIa (Dreesen, 1982b).

The sediments of the Condroz Group originated during an important progradation of deltaic complexes and a redistribution of the reworked siliciclastic sediments by strong longshore currents onto a shallow epicontinental platform. As a result, a whole spectrum of alluvial, estuarine, restricted marine (lagoonal) and shallow marine siliciclastic depositional settings has developed. The coarser clastics are predominantly well-sorted fine-grained sandstones (mean 45-120 µm) that are chiefly composed of quartz and feldspars. Due to the relative abundance of feldspars, these sandstones can be classified as (micro)arkosic sandstones (Thorez, 1969). The thickness of these (micro-) arkosic sandstones and siltstones varies from a few dm up to several metres, depending on their depositional setting. The sandstones exhibit a large variety of colours as well. Besides a broad spectrum of predominantly siliciclastic sediments (shales, siltstones and sandstones), the Condroz Group contains subordinated carbonate rocks including dolostones and limestones, as well as mixed carbonate-siliciclastic rock types. Their relative frequency depends largely on the type of depositional setting. All of the dolostones (mostly a few cm, excep-

LITHOSTRATIGRAPHY	LITHOLOGY Ss	Si	Sh	Dm	Ds	pAn	SS(D)	SSD	si(Ca)	Lim	As	Vs	Dolc	OI
Comblain-au-Pont Fm		abundant	abundant							abundant				
Evieux Fm *Fontin Mbr*	abundant	abundant	frequent	rare					frequent	rare	rare	rare	rare	
Evieux Fm *Crupet Mbr*	abundant	frequent	rare	rare		rare					rare	rare		
Evieux Fm *Royseux Mbr*	abundant	rare	rare	abundant		rare		rare				rare	rare	
Beverire Fm	rare	abundant	rare						rare	rare				
Montfort Fm *Barse Mbr*	abundant	rare	rare		abundant		abundant	abundant			rare			
Montfort Fm *La Gombe Mbr*	abundant	rare	rare		rare		rare	rare						
Montfort Fm *Bon Mariage Mbr*	rare	abundant	rare						rare					
Comblain-La-Tour Fm	rare	abundant	frequent						frequent	rare				
Comblain-La-Tour Fm *Poulseur Mbr*	abundant	abundant	rare						rare					
Ciney Fm	abundant	abundant	rare						rare					
Ciney Fm *Dorinne Mbr*	rare	abundant	rare						rare					
Haversin Fm	rare	abundant	rare						frequent	frequent				
Souverain-Pré Fm		rare	rare						frequent	abundant				rare
Souverain-Pré Fm *Baelen Mbr*		rare	rare						rare	abundant				
Esneux Fm	rare	abundant	rare							rare				rare
Aye Fm		rare	abundant							rare				rare
Mariembourg Fm / Senzeille Fm	rare	rare	abundant							rare				rare
Hodimont Fm		abundant							rare	rare				rare

abundant frequent rare

Table 2. Occurrence, stratigraphical distribution and relative frequency of characteristic lithological features of the Condroz Sandstone Group, especially in the Dinant Synclinorium. Ss = micro-arkosic sandstone, Si = arkosic siltstone, Sh = shale, Dm = evaporitic dolostone with a massive structure (lack of internal stratification), Ds = straticulated (micaceous) para-autochthonous evaporitic dolomite, SS(D) = dolomitic arkose (contamination by dolomite less than 25%), SSD = sandy dolomite, the dolomite content of which ranges from 25% to 65%, (Ca)Si = calcareous siltstone, Lim = limestones, AS: aridisol, VS = (generally reddened) vertic fluvial paleosol (paleofluvial entisol), Dolc = dolcrete, OI = oolitic ironstones.

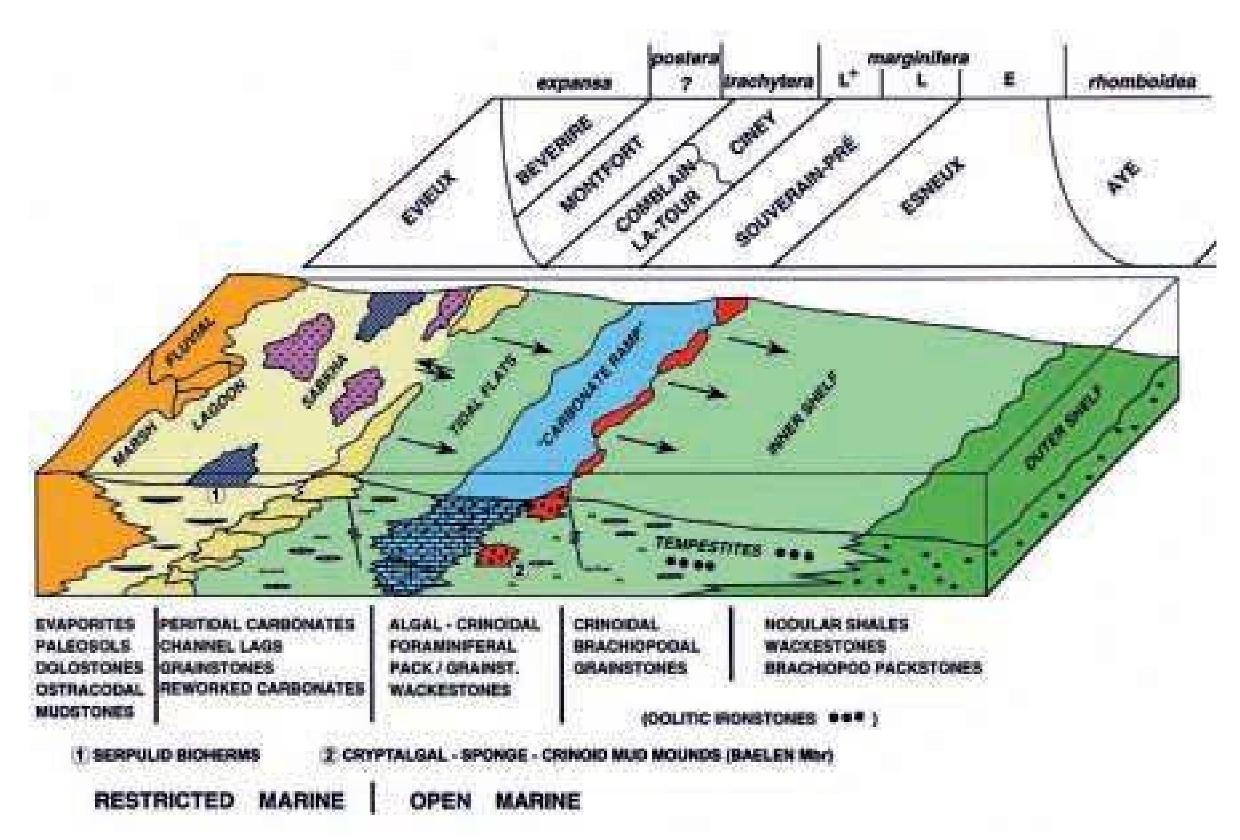


Figure 6. Cartoon depicting the major carbonate microfacies characteristics of restricted marine and open marine limestones within the Condroz Sandstone Group (after Dreesen & Thorez, 1994). 1 and 2 refer to exceptional autochtonous limestone deposits: 1. serpulid bioherms of the Fontin Mbr in the Evieux Fm, and 2. mud mounds of the Baelen Mbr of the Souverain-Pré Fm. The upper part of the figure shows the prograding lithofacies and the stratigraphic succession (from right to left) of the corresponding formations with time (*rhomboidea* through *expansa* conodont zones). Arrows point to transport direction of storm surges and tidal currents generating tempestites and allowing mixing of carbonate allochems.

tionally one metre thick) have been interpreted as the result of shallow water evaporation in restricted marine settings or emerging lagoonal ponds. Dolomite is also a characteristic component of paleosols, including dolcretes (dolomitic calcretes) and aridisols: these occur at or near the boundary between the succeeding Montfort and Evieux Fms in the Ourthe and Hoyoux valleys (Thorez, 2002). The progradation of siliciclastic facies during the Famennian is punctuated by the episodic occurrence of bioclastic limestones. Generally the latter occur as nodular or thin lenticular, millimetre to many centimetre thick beds interstratified within shales, siltstones and sandstones. These sometimes densely fossiliferous limestones provide valuable biostratigraphic data and paleoecological information on the prevailing depositional conditions (carbonate microfacies). Not only the host siliclastic sediments but also the enclosed limestones of the Famenne Shales, and especially those of the Condroz Sandstone Group, show a broad spectrum of depositional settings. These are depicted in Figure 6.

The limestones can be grouped into two major categories, according to the origin of their biogenic components: autochthonous limestones and parautochthonous-allochtonous limestones (Dreesen & Thorez, 1994). Autochthonous limestones are rather exceptional: they are restricted to particular paleogeographical-paleotectonic settings of the Condroz shelf. Three genuine autochthonous carbonate deposits have been described so far in the Condroz sandstone Group: the Fontin Mbr, the Baelen Mbr and the stromatoporoid boundstones ("biostromes") of the Comblain-au-Pont and coeval Etroeungt Fms. These autochthonous limestones are related to transgressive events, possibly also to eustatic events (Thorez & Dreesen, 1997; Sandberg et al, 2002). The carbonate Fontin Mbr of the Evieux Fm consists of dark-coloured restricted-marine or lagoonal, ostracodal mudstones and algal-peloidal wackestones, locally enclosing small serpulid (microconchid) carbonate build-ups (Dreesen & Jux, 1995). The red- to pink-coloured Baelen Mbr of the Souverain-Pré Fm (in the Vesdre Nappe) consists of relatively deeper water, open-marine cryptalgal-sponge-crinoidal mud mounds displaying characteristic "stromatactis" structures (Dreesen & Flajs, 1984; Dreesen *et al.*, 1985a). The mud mounds developed below wave base but they intermit-

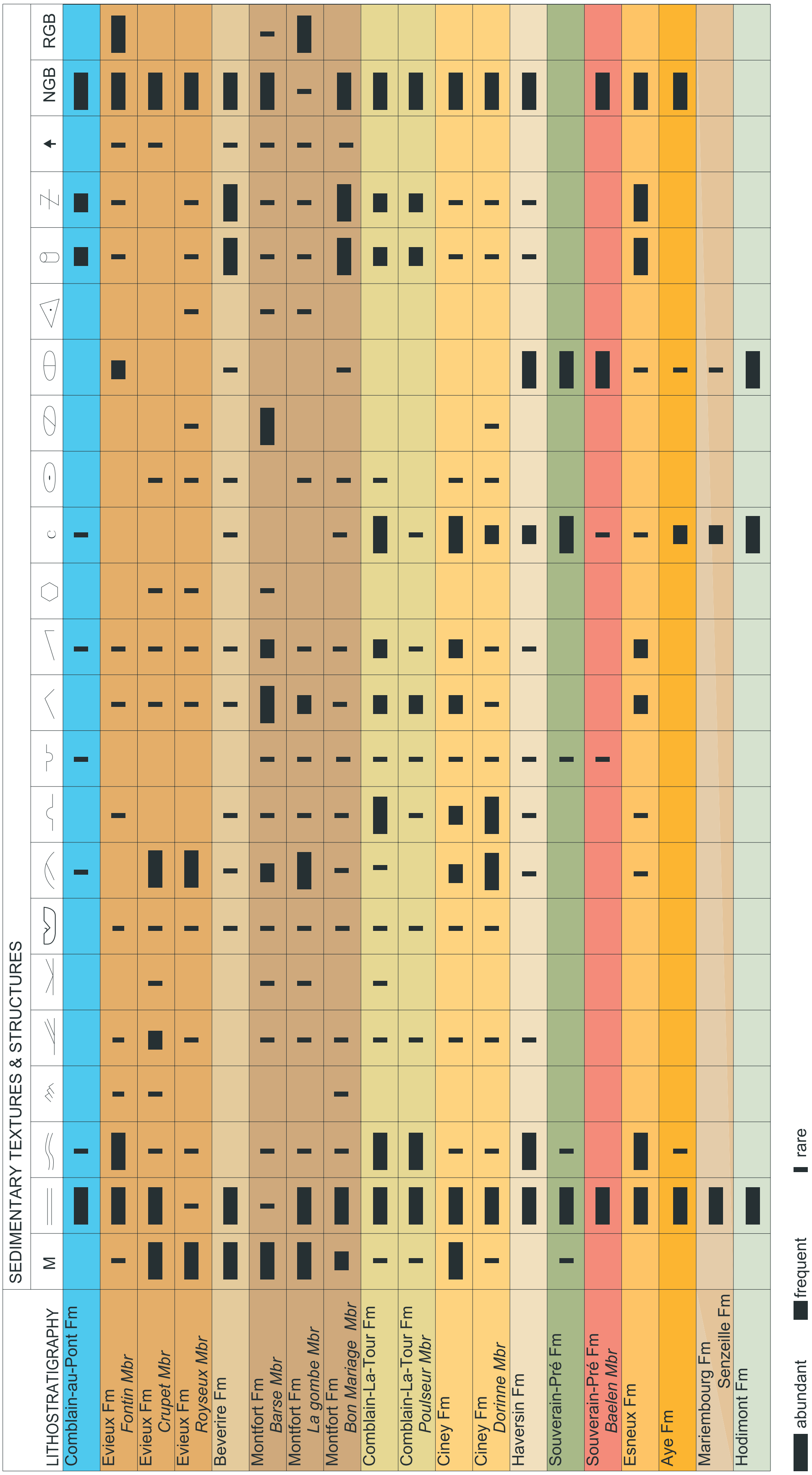
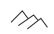
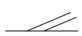
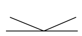
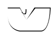
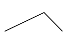
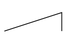
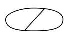
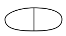
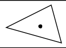

SEDIMENTARY TEXTURES & STRUCTURES
LITHOSTRATIGRAPHY
M
NGB
RGB
Comblain-au-Pont Fm
Evieux Fm Fontin Mbr
Evieux Fm Crupet Mbr
Evieux Fm Royseux Mbr
Beverire Fm
Montfort Fm Barse Mbr
Montfort Fm La gombe Mbr
Montfort Fm Bon Mariage Mbr
Comblain-La-Tour Fm
Comblain-La-Tour Fm Poulseur Mbr
Ciney Fm
Ciney Fm Dorinne Mbr
Haversin Fm
Souverain-Pré Fm
Souverain-Pré Fm Baelen Mbr
Esneux Fm
Aye Fm
Mariembourg Fm Senzeille Fm
Hodimont Fm
abundant
frequent
rare

Table 3. Characteristic sedimentary structures of the Condroz Sandstone Group with their relative frequencies (mostly restricted to the Dinant Synclinorium). No clear differentiation can be made for each of the formations. However, some characteristic "finger prints" allow for the identification of some particular depositional environments. See legend of used symbols below.

M	Massive texture (lack of internal bedding due to the lack of mica concentrations or changes in grain size)
	Planar horizontal bedding
	Undulating bedding
	Ripple drift
	Tabular cross-stratification
	Through cross-stratification
	Fluvial channel or creek
	Dune, longitudinal or transversal sand bar, megaripple
	Hummocky cross stratification
	Load cast, slump, ball-and-pillow
	Oscillation ripple-mark (wave activity)
	Asymmetric ripple-mark (current generated)
	Desiccation crack
c	Coquina bed
	Nodular anhydrite (dissolved)
	Dolomite intraclasts
	Nodular limestone or limestone intraclasts
	Geode (dissolved nodular anhydrite)
	Various types of burrowing
	Bioturbated sediment
	Plant drift (debris)
NGB	Normal graded bedding (fining-upward)
RGB	Reverse graded bedding (coarsening-upward)

tently reached storm wave base, as indicated by the occurrence of coarse-grained lenticular crinoidal-foraminiferal grainstones. Finally, several stratigraphically distinct stromatoporoid boundstones ("biostromes") occur interbedded with micaceous shales and siltstones in the latest Famennian (Strunian: Conil, 1968; Conil & Lys, 1980). These boundstones are known from the Comblain-Au-Pont Fm (Dinant Synclinorium), the Dolhain Fm (Vesdre Nappe), the "Strunian" (Aachen area) and from the top of the time-equivalent Etroeungt Fm (Avesnois area). The latter limestones herald the extensive shallow carbonate shelf conditions of the succeeding Lower Carboniferous. For a detailed microfacies analysis of the Etroeungt Fm in the Avesnois area, the reader is referred to Mamet & Préat (2003). On the other hand, parautochthonous-allochtonous limestones are more common: they represent the hallmark of the sandy Condroz Group, although they also occur in the shaly Lower Famennian formations. In contrast with the Famenne Group, the limestone beds in the Condroz Group are more contaminated by siliciclastics. Generally they consist of bioclastic packstones and grainstones with variable mixtures of shallow-marine to restricted-marine skeletal grains and coated grains. Some of the allochthonous carbonates have been interpreted as calcareous tempestites, "seismites" and erosional lags according to sedimentological evidences (Dreesen & Thorez, 1994). An exceptional accumulation (locally exceeding 100 m) of irregular, subrounded, many centimetre-sized clasts of sandy algal-foraminiferal-crinoidal wackestones/ packstones and grainstones, embedded in a siliciclastic matrix, is known as the Souverain-Pré Fm (Dreesen, 1978). This mixed silicilastic-carbonate facies most probably represents a reworked shallow-marine carbonate ramp that temporarily developed behind sup-

posedly tectonically-controlled submarine crinoidal sand shoals. The carbonate ramp developed during a mid-Famennian eustatic sea-level rise (Thorez & Dreesen, 1997; Sandberg *et al.*, 2002).
Table 3 summarizes the nature, the relative abundance and the association of sedimentary structures characteristic for each formation in the Dinant Synclinorium, where most of the detailed field observations were made (Thorez, 1969, Thorez & Dreesen, 1986 and Thorez *et al.*, 1988). In addition to the above lithological characteristics, sedimentary structures were most helpful for interpreting the various depositional environments of the Condroz Group: these are listed in Table 4. Figure 7 depicts the lateral lithofacies shifts and inferred depositional environments of the Condroz Group within the "classical" Ourthe valley.
During Famennian times, the Condroz shelf corresponded to a relative shallow epicontinental sea, bordering the south side of the Old Red Continent (Fig. 8; Paproth *et al.*, 1986). The latter continent was intersected by the Caledonian mountain belt. The frequent occurrence of red beds (Evieux Fm), evaporites (Montfort and Evieux Fms), dolcretes and aridisols (Evieux Fm) is symptomatic of prevailing arid to semi-arid climatic conditions within the then tropical trade wind belt (located between paleo-latitude 10° and 20° S). In the then southern hemisphere, the easterly tropical trade winds drove a warm, equatorial sea current westward between the Equator and 20°S (Heckel & Witzke, 1979). This south-equatorial current flowed through the Paleotethys Sea toward Western Europe, before splitting at the east-end side of the Russian Platform generating a southwestwardly moving branch through the basins of Central Europe, known as the West-bound Current (WBC). The latter incoming strong and warm, south-equatorial WBC passed through the Polish Basin and was deflected towards the Ardenno-Rhenish Basin,

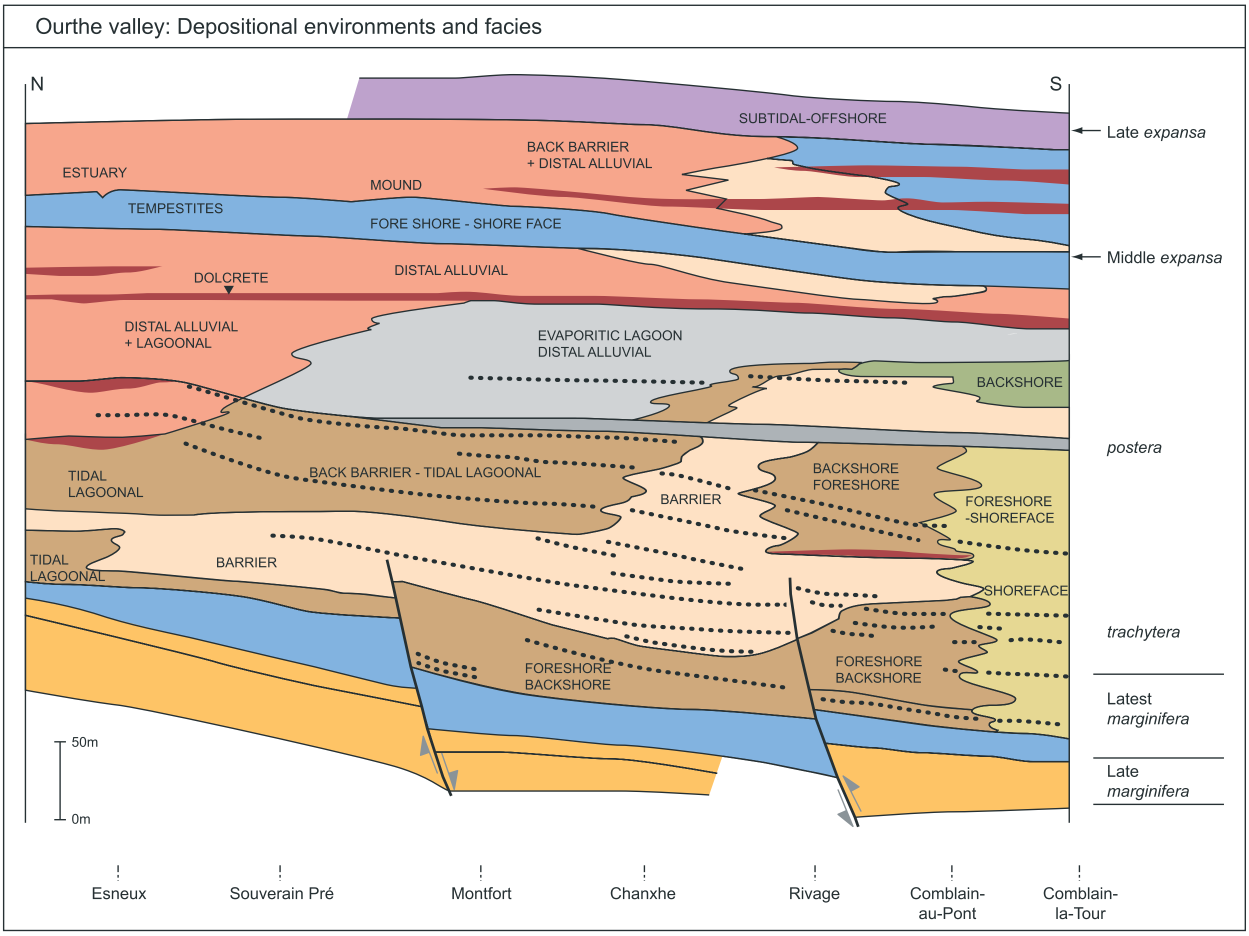


Figure 7. Distribution in time and space of the main depositional environments of the Condroz Sandstone in the "classical" Ourthe valley (quarries and outcrops), from the towns of Esneux to Comblain-la-Tour. Syn-sedimentary tectonics directly influence the distribution of depositional environments. Note the (re)activation of listric faults and related pillow levels, the temporary stacking of the barrier system (La Gombe Mbr), the development of distal alluvial facies, containing red beds intercalated with evaporitic dolomite. The Souverain-Pré Fm reaches a maximum thickness on the flank of a listric fault whereas it is wedging out towards Esneux (dolomitized here) and it is thinning towards Comblain-la-Tour (more pelitic matrix). Dotted lines correspond to ball-an-pillow levels. Thick red lines represent red beds.

LITHOSTRATIGRAPHY / DOMINANT DEPOSITIONAL ENVIRONMENTS	Flood plain	Fluvial channel	"Vertisol" reddened	Evaporitic pans	Aridisol (dolomite)	Supratidal-lagoonal	Intertidal	Restricted marine	Back barrier	Barrier + tidal inlets or estuary	Backshore Foreshore	Upper shoreface	Lower shoreface	Longshore bars subtidal	Proximal subtidal	Proximal turbidites with clasts	Distal subtidal
Comblain-au-Pont Fm																abundant	rare
Evieux Fm *Fontin Mbr*							abundant	abundant	frequent	rare	rare		rare				
Evieux Fm *Crupet Mbr*	abundant	frequent	rare														
Evieux Fm *Royseux Mbr*		rare		abundant	rare	rare	frequent		abundant								
Beverire Fm								rare	abundant	rare	abundant	rare					
Montfort Fm *Barse Mbr*						abundant			abundant	abundant	rare	rare	rare				
Montfort Fm *La Gombe Mbr*							rare		abundant	abundant	frequent	rare					
Montfort Fm *Bon Mariage Mbr*											abundant	abundant	frequent				
Comblain-La-Tour Fm												frequent	abundant	rare			
Comblain-La-Tour Fm *Poulseur Mbr*							abundant		abundant		abundant	rare	rare				
Ciney Fm													frequent	abundant	rare		
Ciney Fm *Dorinne Mbr*												rare	abundant	rare			
Haversin Fm														rare	abundant	abundant	
Souverain-Pré Fm												rare	rare		abundant		
Souverain-Pré Fm *Baelen Mbr*															abundant		abundant
Esneux Fm													abundant		abundant		
Aye Fm															abundant		abundant
Mariembourg Fm / Senzeille Fm																rare	abundant
Hodimont Fm															abundant	abundant	

abundant frequent rare

Table 4. Depositional environments and their stratigraphical distribution in the Lower and Upper Famennian (mainly Dinant Synclinorium). Transition of relative "deep" offshore open-marine settings in the Lower Famennian Senzeille and Mariembourg Fms to progressively more inshore "continentally influenced" depositional settings in the Upper Famennian. This shift represents a "regression" but it is rather the result of prograding pro-delta sands on a shallow epi-continental shelf. The depositional environments can be grouped into 3 main settings: a) distal alluvial to back-barrier setting, with evaporitic lagoons fed by tidal inlets, b) a barrier complex setting including foreshore and shoreface subsettings, and c) offshore settings.

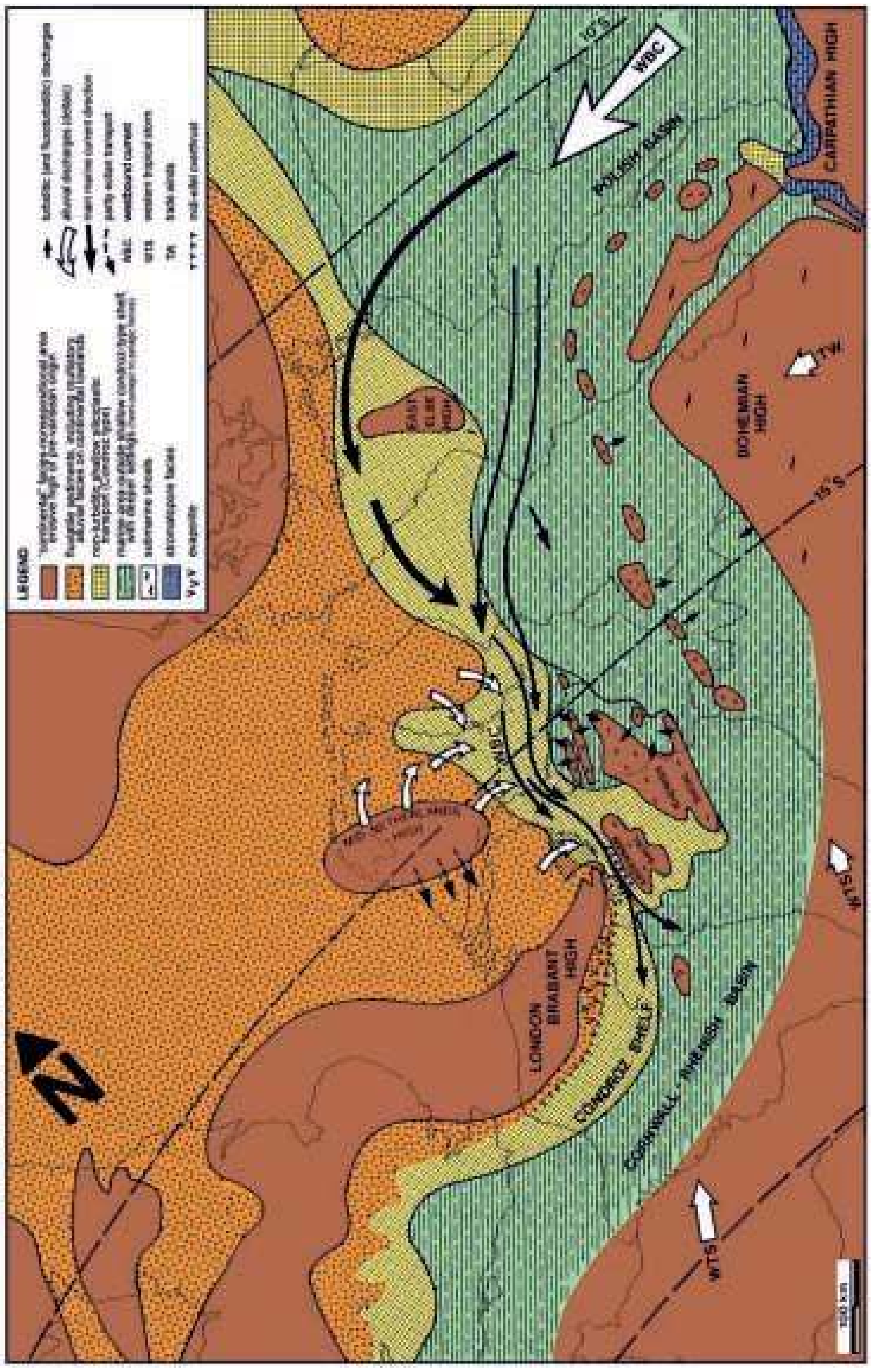


Figure 8. Paleogeographic reconstruction of the Ardenno-Rhenish depositional realm during the Famennian (after Paproth *et al.*, 1986) showing the redistribution of reworked pro-delta sands by a deflected Westbound Current (WBC). The white arrows point to alluvial discharges from different source areas. The mountainous areas of the Bohemian-Carpatian Highs in the South, supposedly acted as barrier to the then trade winds (TW), so that arid conditions prevailed on and in the immediate surroundings of the London-Brabant High. The latter supposed arid paleo-climatic conditions are corroborated by the development in the coastal areas of evaporites and dolcretes during the Late Famennian. The westerly tropical storms (WTS) most probably triggered the tempestites that frequently occur in the Condroz Sandstone Group.

still encroaching the northern shelf areas. This current was sufficiently strong to redistribute the alluvial discharges coming from small prograding deltas on the southern border of the Old Red Continent, where the Netherlands and North-German High and Lowlands were located. Thus, the Condroz Sandstone material represents reworked pro-delta sands resulting from the destruction of delta lobes located outside Belgium (Paproth *et al.*, 1986). The arid climatic conditions over the surroundings of the London-Brabant High most probably resulted from the fact that the moisture in the trade winds was lost during their passage over the mountain areas of the Bohemian and Carpathian Highs (see Fig. 8).

10. Biostratigraphy

A new lithostratigraphical scheme for the Famennian, mostly applied to the Condroz Group in the Dinant Synclinorium, has been compiled after two decades of detailed and intensive interdisciplinary investigations, involving both sedimentological (Thorez, 1969; Dreesen, 1976; Thorez *et al.*, 1977 & 1988; Dreesen & Thorez, 1980, 1994; Thorez & Dreesen, 2002) and micropaleontological-palynological tools (*i.e.* Bouckaert *et al.*, 1965 & 1968; Dreesen *et al.*, 1986b; Conil *et al.*, 1986; Dusar & Dreesen, 1984). The latter studies lead to the proposition of a detailed biostratigraphical framework, mainly based on conodont and miospore zones (Fig. 9), with accessory input from foraminifera (Bouckaert *et al.*, 1966), ostracodes (Becker *et al.*, 1974) and, for the lower(most) Famennian, brachiopods (*i.e.* Sartenaer, 1957a; Dusar, 1976) and acritarchs (Vanguestaine *et al*, 1983). The micropaleontological framework provided a powerful tool for intrabasinal biostratigraphical correlations and allowed the first detailed paleogeographical reconstruction of the Condroz Group (Thorez *et al.*, 1977). This was achieved within the area bordered by the Ourthe, Hout-si-Plou, Amblève, Hoyoux, Bocq, Meuse and Lesse rivers, largely thanks to the intensive extraction of sandstone as a building stone during the 1960's-70s'. These huge quarries then provided excellent outcrops offering good observation conditions and allowed a bed-by-bed sampling for further petrographical and micropaleontological-palynological investigation. The combined biostratigraphical and lithostratigraphical data support the formal subdivision of the Famennian Stage into four substages, most especially in the thoroughly investigated eastern part of the Dinant Synclinorium. It must be noted however, that some formations are either strongly reduced in thickness, missing, wedging out or are conspicuously diachronous, as shown in Figure 3. This is particularly true along the northern limb of the Namur Synclinorium, in the Hainaut area (lateral extension of the Namur Synclinorium) and especially in the Campine Basin (a good biostratigraphical control is lacking here, hence the correlations are tentative and based on lithostratigraphical criteria only; Laenen, 2003).

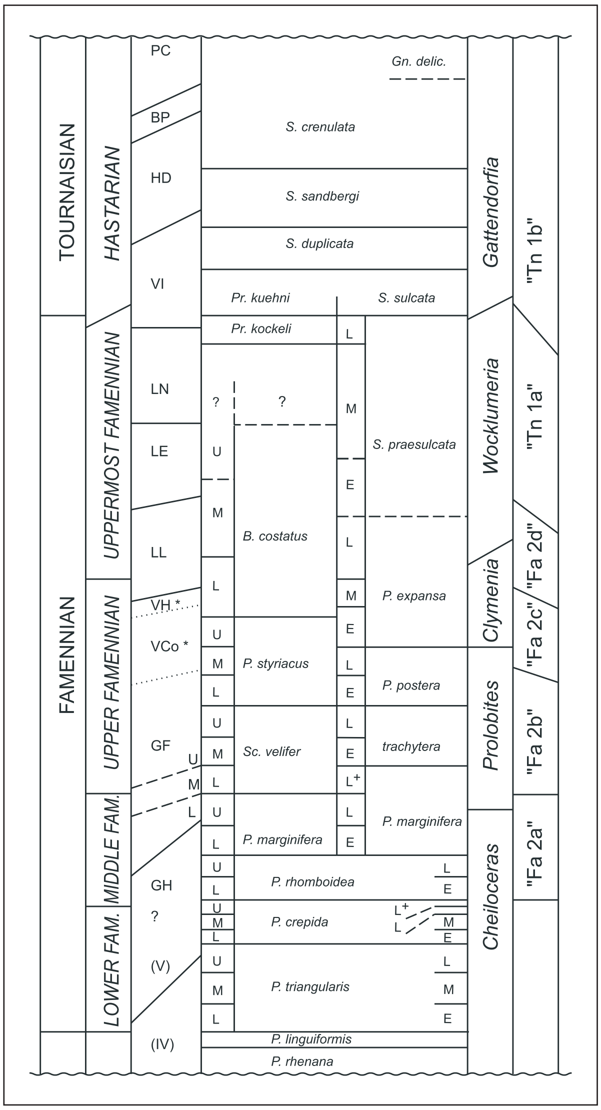


Figure 9. Biostratigraphical framework of the Famennian and Lower-Tournaisian Stage and correlations between formal miospore, conodont and ammonoid zones. In the right hand column the former Belgian (litho-)stratigraphical subdivisions are indicated. The latter have now become completely obsolete. Note presence of dotted lines at the base of the VH and VCO miospore biozones: the correlations of the latter miospore zonal boundaries with the conodont zones are correct for the Ardenne-Rhenish realm but they are somewhat different for the deposits on the western side of the Acadian Mountains (i.e. in Pennsylvania, USA).

11. Structural setting (synsedimentary tectonics)

Block tilting and block faulting (*cf.* listric faults grading into vertical faults, related to the Asturian phase, resulting from compression of the original sedimentary basin) have influenced to a large extent the architecture and paleogeographical evolution of the Condroz Group in the Dinant Synclinorium. At least ten tilted and faulted blocks have been identified by indirect evidences (Thorez *et al.*, 1988; Thorez & Dreesen, 2002). The latter blocks are bordered by NNW-SSE and SSW-NNE lineaments forming a conspicuous chessboard-like pattern (Thorez & Dreesen 1986, Thorez *et al.*, 1988; Paproth *et al.*, 1986). Ball-and-pillow levels in the Montfort, Comblain-la-Tour and Ciney Fms of the Ourthe, Hoyoux and Bock valleys, were supposedly triggered by seismic shocks, related to the above block tilting: the seismic shocks induced abrupt sea-level changes or they have increased locally the accommodation space. Moreover, the ball-and-pillow levels (12 distinct levels in the Ourthe valley) laterally crosscut the different coeval Members or Formations (Fig.7). The chessboard-like configuration of tilted blocks has also influenced the progradation of the Condroz sandstones in the eastern Dinant Synclinorium. Finally, listric faults and regional irregularities of the basin floor were responsible for the lithostratigraphical architecture of the Famennian in the Campine Basin.

12. Reference sections in Belgium and GSSP

The Global Standard Section and Point (GSSP) for both the Frasnian-Famennian boundary and the Famennian-Tournaisian (Devonian-Carboniferous) boundary are located in the Montagne Noire area of Southern France. The base of the Famennian Stage is defined to coincide with the lower boundary of the Lower *Palmatolepis triangularis* Zone. The GSSP for the Frasnian/Famennian (F/F) stage boundary is drawn in a section exposed near the Upper Coumiac Quarry in the southeastern Montagne Noire (Klapper *et al.*, 1993). The F/F boundary records one of the five largest mass extinction events in the fossil record. Dark shales at the boundary are interpreted to be the equivalent to the upper part of the Kellwasser anoxic event recognized throughout the Paleo-Thetys (Sandberg *et al.*, 1988, 2002). Glass spherules believed to be of impact origin are associated with the F/F boundary in 2 Belgian sections (Senzeille and Hony: Claeys & Casier, 1994; Claeys *et al.*, 1996). The top of the Famennian is defined to coincide with the entry of *Siphonodella sulcata*. The GSSP for the D/C boundary is drawn in an artifical trench ("E") near La Serre, southeastern Montagne Noire (Paproth *et al.*, 1991). Most Belgian reference sections for the formations of the Condroz Group are located in the Ourthe valley, between the towns of Esneux and Comblain-la-Tour (NE-part of Dinant Synclinorium). However, their accessibility is strongly hampered nowadays (abandoned sandstone quarries with badly exposed beds). Incomplete reference sections for the formations of the Famenne Group are located in the Famenne area (former railroad and road cuts near the towns of Senzeille and Mariembourg).

13. Main contributions

Beugnies, 1965; Bouckaert, J. *et al.*, 1968; Bouckaert *et al.*, 1969; Bultynck. & Dejonghe, 2001; Dreesen, 1987; Dreesen *et al.*, 1986a.; Dreesen *et al.*, 1986b; Paproth *et al.*, 1986; Sartenaer, 1957a; Thorez & Dreesen, 1986; Thorez *et al.*, 1977; Thorez *et al.*, 1988.

14. Concluding remarks

The lithostratigraphic framework of the Famennian Stage in Belgium and neighbouring areas conforms with the recommendations of Hedberg's International code (1976). The revised stratigraphical correlation framework of the Famennian presented here is the result of several decades of combined litho- and biostratigraphical research. This work started 125 years ago, with the pioneering work of M. Mourlon, on the lithological units ("assises") in the then well-exposed sections of the Belgian type localities. The PhD thesis of one of the senior authors in 1969 has been the starting point for renewed sedimentology and event-stratigraphical interest in the Belgian Famennian Stage. It was the onset of thorough interdisciplinary research by an extensive and international group of colleagues trying to unravel the complex depositional history of the Condroz Group. In order to reach their goal, all the effects of mutually interplaying paleogeographic, tectonic, paleohydrodynamic and paleoclimatologic conditions had to be taken into account. Even now, many interpretation problems still remain unsolved. However, it is a pity that the quality of exposure of the rocks has dramatically decreased over the years, hampering or even excluding future detailed bed-by-bed sampling in the field.

15. Acknowledgements

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