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Upper carboniferous lithostratigraphic units (Belgium)

André DELMER[1], Michiel DUSAR[2] & Bernard DELCAMBRE[3]

(1 figure)

1. Honorary Director of Geological Survey of Belgium, Avenue Colonel Daumerie, 16, B-1160 Brussels.
2. Geological Survey of Belgium, Jennerstraat 13, B-1000 Brussels; michiel.dusar@pophost.eunet.be
3. Carte géologique de Wallonie, Université catholique de Louvain, Place Louis Pasteur 3, B-1348 Louvain-la-Neuve; delcambre@geol.ucl.ac.be

ABSTRACT. Upper Carboniferous, Namurian to Westphalian coal measures in Belgium form part of the Variscan Foredeep in northwestern Europe, with maximum preserved thickness over 3500 m. Despite post-depositional separation of the Wallonian and Campine coal basins by the Brabant Massif and different tectonic styles, a common lithostratigraphic nomenclature can be applied. The stratigraphic subdivision is based on the distinction between a carbonate-dominated marine "Dinantian" and siliciclastic continental, coal-bearing "Silesian". Basal units testify of a marine transgression, locally continuous with Dinantian carbonate sedimentation, elsewhere drowning an emergent karst landscape. Progressive advance and uplift of the Variscan orogenic belt caused rapid subsidence in the foreland and transition from prodelta mudstones to upper alluvial plain conglomerates, with fewer marine incursions. The Belgian Coal Measures Group encompasses this complete tectonically-driven sedimentary succession.

KEYWORDS: Upper Carboniferous, Belgium, coal, lithostratigraphy.

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1. Introduction

The Carboniferous system derives its name from the coal-bearing sedimentary deposits ("coal measures") in western Europe. This is evidently the case in Belgium. The coal industry has long been the major industrial sector of Belgium and has greatly contributed to the shaping of the country. Coal has been mined since the twelfth century but attained highest levels between 1880 and 1960. Coal production peaked at 30 million tons annually; altogether 2,500 million tons of hard coal has been mined from Belgium. Decline of coal mining from the 1960's till complete termination in 1992 was hastened by high exploitation costs and not by depletion of coal reserves.

Coal deposits of Upper Carboniferous "Westphalian" age extend across the national boundaries of Belgium into the Netherlands, Germany and France. They originally formed part of the extensive Northwest European paralic coal basin, now structurally divided by uplift zones where coal has been removed by erosion, and by former foredeep basins and grabens, where coal is covered by a thick pile of more recent deposits.

Two major coal basins occur in Belgium, separated by the Anglo-Brabant Massif. The southern or Wallonian basin extends along the Sambre-Meuse axis from the French Nord – Pas-de-Calais coalfield in the west to the southern parts of the German Aachen and Ruhr coalfields in the east. It is subdivided into several districts: Liège, and the Borinage (or Mons), Centre, Charleroi and Basse-Sambre districts, which are all located in the most prolific Hainaut province. Smaller depleted coal deposits occur near Namur and Huy along the Meuse river, in the Dinant and Theux basins. Coal seams crop out in these southern basins, hence the early start of mining.

The concealed northern basin or Campine basin, which forms the continuation of the equally abandoned South Limburg coalfield of the Netherlands and the northern part of the Aachen and Ruhr coalfields in Germany, was discovered in 1901. Two major parts can be distinguished: the larger, western part or Antwerp Campine contains only Namurian and Lower Westphalian deposits, with limited coal reserves; the eastern part or Limbourg Campine contains a fully preserved coal-rich Westphalian section. The boundary between both parts is constituted by the NNW-SSE Beringen - Rauw fault systems. The Limbourg coal basin is further subdivided in an eastern and western coalfield by the N-S Donderslag fault system, which has markedly affected burial history and coal rank. The east Limburg coalfield adjoins the Dutch South Limburg coalfield.

The structuration of the paralic Coal Measures into different basins mainly occurred in two steps, associated with the variscan deformation at the end of the Carboniferous and with the cimmeric deformation during the Jurassic. Out of a common sedimentary origin developed two structurally different basins which greatly influenced the mining history.

With the exception of some tiny basins in the deepest synclines of the Dinant Synclinorium and in the overturned Theux tectonic window, the Wallonian coal basin is located in the Namur-Verviers Synclinoria (used in the geometrical sense, encompassing all autochtonous and allochtonous beds that may be present within this frame) at the front of the variscan mobile belt. It was strongly affected by variscan folding and thrusted against the rigid Lower Paleozoic Brabant Massif to its north. Folds are steep and asymmetrical; mechanised mining was only possible in the flat fold limbs (plateures). Deformed allochtonous overthrust sheets ("nappes") wherein a more complete section of the Coal Measures has been preserved, complete the Hainaut mining districts. Tectonic style and "northern" thickness and coalification patterns suggest gravity sliding of the superficial massifs from the north as a result of uplift of the Brabant massif and evaporitic dissolution and subsidence in the Lower Carboniferous to Devonian strata underlying the Hainaut coal basin (Delmer, 1997). The Midi Overthrust forms the southern limit to this basin: Lower Devonian rocks are thrusted with a low angle over the parautochtonous coal basin whose real southern extension is yet unknown. In this way compressive tectonics dominated the southern basin; later deformation was possibly associated with dissolution of underlying carbonatic-evaporitic beds.

Variscan deformation of the Campine basin, which overlies the Brabant Massif, was relatively minor. It was associated with block-faulting movements along the major strike-slip faults affecting the Brabant Massif. Cimmeric uplift of the Brabant Massif caused a downwarp of the Campine basin towards the northeast. In this direction the Campine basin passes into the tectonically active Roer Valley Graben (or Roermond Graben) which forms the junction between the Lower Rhine Graben and the Central Netherlands Basin. In this way extensional tectonics and a more complete post-Carboniferous sedimentary record characterise the Campine basin.

The stratigraphic subdivision of the Carboniferous in Belgium, as in the remainder of western Europe, continues to follow the classic distinction between carbonate-dominated marine "Dinantian" and siliciclastic continental "Silesian" containing the coal deposits (the latter subdivided in Namurian and Westphalian). Thickness of eroded sediments of uppermost Westphalian to Stephanian age may attain 1800 to 2500 m (Helsen & Langenaeker, 1999; Littke et al., 2000). The chronostratigraphic standard scale for the Carboniferous, with Upper Carboniferous stages defined in the marine deposits on the Russian Platform and the Urals, as proposed at the latest international geological congresses, is not finding any application in Belgium. Chronostratigraphic correlations mentioned here are indicative only. Radiometric ages of both chronozonations are not always concordant. For practical convenience, the following correlations for base of corresponding series/stages are accepted:

303 Ma	Kasimovian	Stephanian	305 Ma
311 Ma	Moscovian	Westphalian C	311 Ma
		Westphalian A	315 Ma
323 Ma	Bashkirian	Kinderscoutian	319 Ma
327 Ma	Serpukhovian	Pendleian	325 Ma

The Upper Carboniferous stratigraphy of Belgium was last revised by Paproth et al. (1983), after previous subdivisions by Renier (1912, 1928, 1930) and Delmer & Ancion (1954a, b). Nevertheless, some modifications have been made, based on the following principles:

– a lithostratigraphic framework applicable to all Upper Carboniferous deposits in Belgium;

– a subdivision better adapted to the mapping exercise for the new geological map of Wallonia, and revised for the Westphalian C as stratigraphic insight has been improved;

– clear distinction between lithostratigraphic units (formations and members) on the one hand, and marker horizons (used as the base of the units) on the other hand;

– relying on the original definition of the different terms ("assises" and "horizons") to avoid confusion.

Mapping practices, however, do not widely use the formal stratigraphic subdivision. They traditionally represent coal seam bundles ("faisceaux") and follow marker horizons, such as marine bands. Detailed cross-sections or subcrop maps in coal basins show the succession of coal seams.

2. Descriptions

A general overview of the Upper Carboniferous lithostratigraphic units is provided in figure 1.

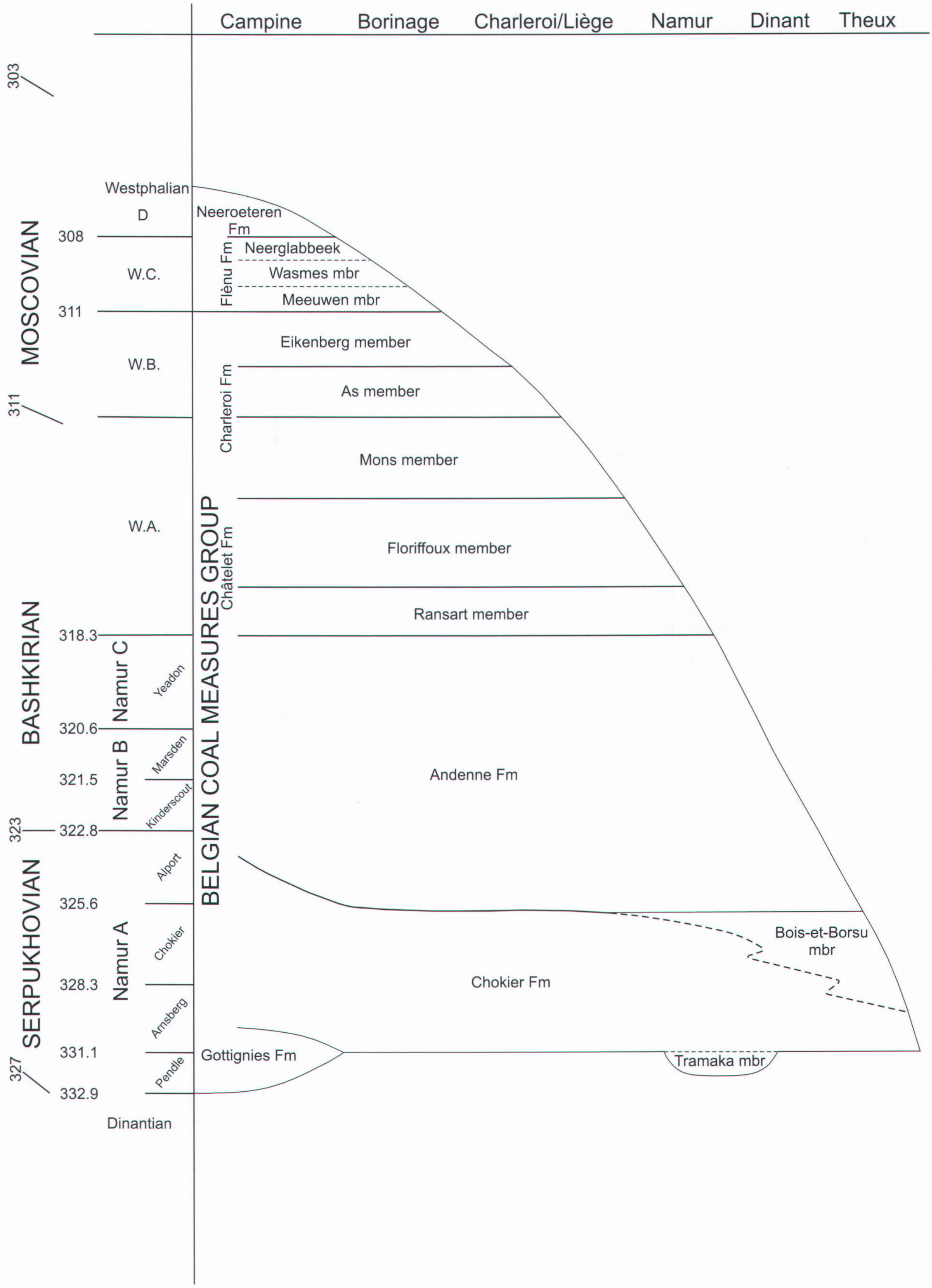

Figure 1. Geochronology, chronostratigraphy and lithostratigraphy of Belgian Upper Carboniferous deposits.

2.1. The Dinantian – Silesian transition

2.1.1. Gottignies Formation - GOT

Authors: Conil (1959); Paproth, Conil et al. (1983).

Description: Finely bedded silicites (completely silicified limestone beds or "phtanites" and siliceous "radiolarian" shales), transitional between Dinantian limestones and Namurian siliciclastics ("Phtanites tachetés de Gottignies"). The contact with underlying massive limestones is conspicuous and marked by an angular unconformity.
Boundaries: lower boundary coinciding with top of Dinantian carbonate units; upper boundary to the Belgian Coal Measures Group seems more transitional and traced below first shale bed with goniatite horizon, assigned to the Chokier Formation.

Stratotype: Northeast of Gottignies (Conil, 1959); parastratotype: Mont des Groseillers section, canal Blaton-Basècles (Bouckaert et al., 1961).

Area: Western part of the Namur Synclinorium ("Auge hennuyère", Blaton - Saint Ghislain area); corresponding beds in the northern (Turnhout well) and eastern Campine basin, including the Visé-Puth High are incorporated in the Souvré Formation.

Thickness: Up to 75 m in the Blaton area.

Age: Viséan – Serpukhovian transition. Unspecified, between Warnantian (Brigantian) and Arnsbergian-dated beds. The association of marker fossils such as *Caneyella membranacea - Eumorphoceras sp.* in Blaton points to a Pendleian (E1) age (earliest Serpukhovian).

Remark: The Gottignies and Souvré Formations are generally included in the Dinantian lithostratigraphic sequence, in accordance with Paproth, Conil et al. (1983). However, lithological change and hiatus tend to be greater at the base of this unit, which may favour its inclusion in the Belgian Coal Measures Group.

2.1.2. Souvré Formation – SOU

Authors: Charles, 1924; Calembert, 1945; Pirlet, 1967; Barchy & Marion, 2000.

Description: Thinly bedded laminated dark grey to black silicites ("phtanites"), or silicified shales and limestones, strongly weathered and porous at outcrop. The contact with underlying massive limestones of the Visé Formation is marked by an angular unconformity. Upper boundary locally transformed as a paleosol of Cretaceous age; otherwise covered by Chokier Formation (Charles, 1924; Calembert, 1945).

Stratotype: Top beds of Richelle quarries F, L and M, south of Visé (Pirlet, 1967).

Area: Visé-Puth High, probably extending in the northern (Turnhout well) and eastern Campine basin; corresponding beds in the western part of the Namur Synclinorium ("Auge hennuyère", Blaton - Saint Ghislain area) are assigned to the Gottignies Formation.

Thickness: About 15 m in Visé – Campine basin.

Age: Viséan – Serpukhovian transition. Unspecified, between Warnantian (Brigantian) and Arnsbergian-dated beds.

Remark: Lateral equivalent to the Gottignies Formation. Defined as a mappable unit on the mapsheet Dalhem-Herve (Barchy & Marion, 2000).

2.2. Belgian Coal Measures Group - HOU

Authors: Renier, 1912, 1928; Paproth et al., 1983; Laloux et al., 1996; Delcambre & Pingot, 2000.

Description: The Coal Measures Group includes all Carboniferous coal-bearing siliciclastic sediments. Paralic facies conditions were installed during the deposition of the Belgian Coal Measures Group because of basinal sag north of the variscan deformation front, balanced by increasing supply of siliciclastic erosion products in a closing intracontinental depression. From base to top, a regression can be observed by gradual transition from marine prodelta, to lower/upper delta plain, to lower/upper alluvial plain (Langenaeker & Dusar, 1992; Dreesen et al., 1995).
Autocyclic sedimentation of coal-bearing alluvial-delta plain deposits is controlled by the internal dynamics of the depositional system (relation compaction/subsidence – fluvial system/sediment supply). Basic, fifth order autocycles normally range from the roof of a coal seam to the top of the next seam. Different major paleoenvironments related to relative sea level rise and fall are distinguished: 1) non-marine swamps rich in plant remains, containing the coal seams; 2) non-marine floodplains, with fluvial channels and lakes; 3) brackish water floodplains under influence of distant marine ingressions; 4) euryhaline floodplains and lakes at the acme of marine ingressions. Fully marine beds are rare, all sediments are supplied by the paleofluvial system. Paleofluvial sandstone deposits may intervene at all positions. Third order glacio-eustatic allocycles are characterised by the marine bands at their base (Paproth et al., 1996; Dusar, 1997).
Marker horizons such as marine bands and volcanic ash layers provide the framework for a subdivision of the Coal Measures Group, based on the cyclotheme concept (Renier, 1930; Van Leckwijck & Fiege, 1963; Paproth et al., 1996). These bands allow firm, practically isochronous correlations between different basins, also with surrounding countries. (Van Leckwijck, 1948; Delcambre, 1987, 1996). Coal seams, particular faunal assemblages and sandstone beds provide the means for a more detailed subdivision on local to basin scale.
Boundaries: The base of the Belgian Coal Measures Group coincides with the top of either the Lower Carboniferous (Dinantian) carbonate deposits or the Gottignies Formation. In the former case, a hiatus accompanied by a sharp lithological change generally marks this boundary; in the latter case, the transition is more gradual. The top of the Belgian Coal Measures Group is everywhere erosive and unconformably overlain by Permian or younger deposits.

Stratotype: Cf. the lithostratigraphic units of lower rank.

Area: All Carboniferous basins (Campine basin, Namur, Dinant and Vesdre synclinoria and associated areas below overthrusts) in Belgium and extending beyond the national boundaries into Carboniferous basins of neighbouring countries.

Thickness: More than 4000 m in the northeastern Campine coal field, in area close to depocentre under late Permian cover (Bless et al., 1977).

Age: Serpukhovian – Bashkirian – Moscovian; Arnsbergian or Namurian A to Westphalian D according to traditional subdivision; at places of more continuous sedimentation the basal unit may be of Pendleian age.

Remarks: Locally translated as "Terrain houiller" or "Steenkoolterrein", which were miners'terms, encompassing all deposits containing the coal seams (Renier, 1912, 1928). Defined as formation restricted to the Westphalian part of the Upper Carboniferous in Paproth et al. (1983). Defined as group covering all Upper Carboniferous in Laloux et al. (1996) and Delcambre & Pingot (2000).

Equivalent unit in the Netherlands: Limburg Group (van Adrichem Boogaert & Kouwe, 1993).

The first appearance of coal seams in the Belgian Coal Measures is diachronous. In the eastern part of the Dinant synclinorium and in the Theux Massif, this occurs in the Bois-et-Borsu Member (Arnsbergian), whereas in the Campine basin paralic facies conditions did not appear before Alportian times and the first coal seams occur in the Châtelet Formation (Westphalian A). Thick, widely exploited coal seams are restricted to the Charleroi and Flénu Formations, however.

Especially within the Andenne to Flénu Formations (Upper Namurian to Westphalian C) the same lithologies and sequential successions are encountered. Distinction between formation and members is mainly based on the presence of marker horizons and frequencies of particular lithologies, e.g. coal. Members without distinctive lithologies are not separately described hereunder.

2.2.1. Chokier Formation

Authors: d'Omalius d'Halloy, 1853; Dumont, 1832; Purves, 1881; Van Leckwijck, 1957, 1964; Paproth et al., 1983.

Description: The Chokier Formation is composed of calcareous shales, pyrite-rich aluniferous shales ("ampélites") and silicites ("cherts" or "phtanites"), with a rich marine fauna, devoid of coal seams or rootlet beds with the exception of the Bois-et-Borsu Member ("Shales with Posidoniellas and goniatites", Purves, 1881). Weathered, fissile black or violaceous shales dominate in the outcrop areas.

Lower unit of the Belgian Coal Measures Group ("Houiller sans houille", Dumont, 1832). The base corresponds to the top of the Dinantian carbonates and is normally corresponding to a sharp boundary at the place of a stratigraphic gap of varying importance, often developed as a karst surface. Radioactive shales rich in organic matter ("hot shales") which are often incorporated in the Chokier Formation may be used as a practical indicator for delimiting the formation both upwards and downwards.

The Chokier Formation is always overlain by the Andenne Formation, whenever the stratigraphic record is sufficiently complete. In the western Namur Synclinorium and the eastern Campine basin, with thicker and probably more complete sequences, the basal transition is more gradual.

Stratotype: Former "ampelite" outcrops on the slopes below the castle of Chokier.

Area: As for the Belgian Coal Measures Group.

Thickness: Generally 20 to 40 m, decreasing towards the Brabant Massif (Bouckaert, 1967). Increasing to 80-150 m in the Charleroi mining district and Dinant – Theux basins (under the form of the Bois-et-Borsu Member) and possibly also in the eastern Campine basin (corresponding to Geverik Member of the Epen Formation in The Netherlands, van Adrichem Boogaert & Kouwe, 1993). The Chokier Formation becomes much thicker, reaching a thickness of 200 m, in the western part of the Namur Synclinorium ("Auge hennuyère", Blaton - Saint Ghislain area). In the St Ghislain borehole, Lower-Upper Carboniferous transitional beds (Gottignies Formation), together with undoubted Chokier beds, reach a thickness of 432 m.

Age: Serpukhovian; Arnsbergian and Chokierian, rarely Alportian, based on goniatite zonation, or Namurian A according to traditional subdivision. Transition beds such as the Tramaka Member, could be of Pendleian (E1) age.

Tramaka Member

Authors: Austin et al., 1974; Paproth, Conil et al., 1983.

Description: Grey-coloured coarse crinoidal limestone lenses, preserved in karstic dissolution structures, laterally passing into silty limestones and black finely bedded limestones ("Encrinite de Tramaka", Austin et al., 1974).

Boundaries: unconformably overlying karstified Lower Carboniferous limestones (Seilles Formation); unconformably overlaid by dark shales of the Chokier Formation.

Stratotype: Abandoned quarry of Tramaka, Seilles commune.

Area: Northern flank of Namur Synclinorium, between Namur and Huy (Andenne uplift zone).

Thickness: 3.70 m in type locality.

Age: Early Serpukhovian; conodonts and foraminifers suggest a Namurian age (Arnsbergian or older), possibly equivalent of lower part of Chokier Formation or of Gottignies Formation.

Remark: The Tramaka Member was defined as a formation in Paproth, Conil et al., 1983.

Bois-et-Borsu Member

Authors: Newly defined, after the Bois-et-Borsu commune, mining village in the 19th century.

Description: The Bois-et-Borsu Member contains marine "ampélites" typical for the Chokier Formation, interbedded with 3 coal seams and sandstone rootlet beds. Despite irregular thickness distribution and complex tectonics, coal seams with thickness of 30-70 cm have been mined.

The Bois-et-Borsu Member overlies Lower Carboniferous (Warnantian) deposits. The upper boundary is erosive. It is lateral equivalent to the Chokier Formation.

Stratotype: Bois road section and abandoned mining galleries (cf Vandercammen, 1948).

Area: Deep synclines in the eastern part of the Dinant Synclinorium (Clavier, Bois-et-Borsu and Bende coalfields) and the overturned beds in the Theux tectonic window.

Thickness: Possibly up to 250 m; due to poor exposure and presence of thrust faults, real thickness is not known.

Age: Early Serpukhovian, Arnsbergian and Chokierian, or Namurian A according to traditional subdivision, as for the Chokier Formation.

2.2.2. Andenne Formation

Authors: Dumont, 1832; Purves, 1881; Stainier 1901; Van Leckwijck, 1957, 1964; Paproth et al., 1983.

Description: The Andenne Formation consists of non-marine mostly silty shales, sandstones, thin coal seams (30 to 75 cm) or rootlet beds, with some intercalations of thin marine, goniatite-bearing shales and limestone beds (paralic facies). The cyclic nature is the most characteristic feature of the paralic sediments (Fiege & Van Leckwijck, 1964). Many grits (up to 30 m thickness) and ganisters (bleached quartzitic rootlet beds) have been distinguished at different stratigraphic levels within this formation. Local unit names such as Poudingue houiller, Grès d'Andenne, Gives, Java, Villerot, Salzinnes have been in use (Renier, 1912, 1928).

The Andenne Formation is conformably overlying the much thinner Chokier Formation, but may exceptionally rest directly on older Dinantian strata, as is the case on the Heibaart dome (Campine basin) (Bouckaert, 1967). The Andenne Formation is always overlain by the Châtelet Formation whenever the stratigraphic record is complete.

Stratotype: Java gallery, former Andenne coalfield (cf Paproth et al., 1983).

Area: As for the Belgian Coal Measures Group. Thin coal seams (30 to 75 cm) have been exploited in the Namur and Verviers (Herve) synclinoria.

Thickness: 300 to 800 m, with thinnest sediments in the Namur synclinorium (Andenne transversal ridge) or Dinant synclinorium and increased thicknesses in the Campine basin. Thickness attaining 1800 m is postulated in the northern Campine basin, north of the Hoogstraten listric fault, according to Vandenberghe (1984).

Age: Latest Serpukhovian to early Bashkirian (Chokierian or Alportian to Yeadonian, based on goniatite zonation) or Namurian B-C according to traditional subdivision.

Remark: Originally defined by Dumont (1832) as "Houiller avec houille", including all overlying coal-bearing formations of Westphalian age. More restrictively used by Purves (1881) as "Schistes et psammites avec houille maigre". Used in the actual sense by Stainier (1901) as "Assise d'Andenne".

2.2.3. Châtelet Formation

Authors: Renier, 1912, 1928; Stainier, 1932; Delmer, 1963; Delcambre & Pingot, 2000.

Description: The Châtelet Formation consists of non-marine partly silty shales, sandstones, thin coal seams (30 to 75 cm) or rootlet beds (paralic facies). It is still poor in coal but mineable seams occur in all coal basins. Two widespread goniatite-bearing marine horizons, at the base of thick cyclothemes and overlying beach barrier sandstone units, characterise this unit.

The following members have been distinguished (names and definition according to latest revision in Paproth et al., 1983), from bottom to top:

– Ransart Member (base: Ransart = Fraxhisse = Sarnsbank marine band; boundary Namurian - Westphalian), formerly known as "Sous-zone d'Oupeye";

– Floriffoux Member (base: Floriffoux = Bouxharmont = Finefrau Nebenbank marine band), formerly known as "Sous-zone de Beyne".

The Châtelet Formation is conformably overlying the Andenne Formation; its base coincides with the Ransart (=Sarnsbank) Marine Band. It is conformably succeeded by the Charleroi Formation.

Stratotype: Charleroi coal basin (Stainier, 1932).

Area: As for the Belgian Coal Measures Group.

Thickness: 200 m (Hainaut), 300 m (Liège), 500 m (Campine).

Age: Early Upper Bashkirian, Lower Westphalian A according to traditional subdivision.

Remark: The "Assise de Châtelet" as defined by Renier is equivalent to the "Assise de Beringen" as defined by Delmer.

2.2.4. Charleroi Formation

Authors: Renier, 1912, 1928; Delcambre & Pingot, 2000.

Description: The Charleroi Formation (originally defined as "Assise de Charleroi") is characterised by a rhythmic succession of coal-mudstone-sandstone sequences. Coal seams are frequent and much thicker (up to 3 m). It was the main coal-producing unit in

Belgium. Weakly marine incursions allow a further subdivision.

The following members have been distinguished (names and definition according to Renier, 1928; Delmer, 1963; Paproth et al., 1983), from bottom to top:

– Mons Member (base: Wasserfall = Stenaye = Gros Pierre marine band), formerly known as "Assise de Genk". Parastratotype: Winterslag colliery, Campine coal field;

– As Member (base: Quaregnon = Katharina marine band; boundary Westphalian A - Westphalian B), named Quaregnon Member in Paproth et al. (1983). Stratotype: Waterschei colliery, Campine coal field;

– Eikenberg Member (base: Eisden = Domina marine band), named Eisden Member in Paproth et al. (1983). Stratotype: borehole KB14 Meeuwen-Eikenberg.

The Quaregnon marine band is not known in the thrusted massifs of the Hainaut basin; the Eisden marine band has not been recognised at all in the southern Belgian coal basins, thus limiting the possibilities for generalised subdivision of the Charleroi Formation.

The Charleroi Formation is conformably overlying the Châtelet Formation along the Gros Pierre = Wasserfall horizon. It is conformably succeeded by the Flénu Formation along the Maurage marine band.

Stratotype: Charleroi coal basin. Reference section trench of the canal Charleroi-Brussels in Gosselies (Delcambre & Pingot, 2000).

Area: The mining districts of the Campine basin and Namur-Vesdre synclinoria (= Wallonian basin) in Belgium and extending beyond the national boundaries into Carboniferous basins of neighbouring countries.

Thickness: Preserved thicknesses of 500 m (central part of Wallonian basin) up to 1300 m (Borinage) and 1100 m (northeastern Campine basin).

Age: Late Upper Bashkirian; upper Westphalian A to Westphalian B according to traditional subdivision.

2.2.5. Flénu Formation

Authors: Renier, 1912, 1928.

Description: Originally defined as "Assise du Flénu" is largely similar to the Charleroi Formation, also characterised by a rhythmic succession of coal-mudstone-sandstone sequences. Coal seams are frequent and may be rather thick (up to 5 m), though mining was mostly limited to the Borinage and the eastern Campine. Weakly marine incursions but especially tonsteins (volcanic ashlayers in coals) allow a further subdivision.

The following members have been distinguished (names and definition according to Renier, 1928; Delmer, 1963; Paproth et al., 1983), from bottom to top:

– Meeuwen Member, according to Delmer (1963); base: Maurage = Petit Buisson = Aegir marine band, boundary Westphalian B - Westphalian C; named Maurage Member by Renier (1928) and Paproth et al. (1983). Stratotype: borehole KB121 Meeuwen-Bullen;

– Wasmes Member, according to Renier (1928); base Tonstein Hermance (Nord) = Hanas (Borinage) = Hagen 1 (Campine, Ruhr);

– Neerglabbeek Member, according to Dusar (1989); Dusar et al. (in press); named Hornu zone by Renier (1928); base weakly marine "Geisina" band, overlying the coal seam with Tonstein Nibelung. Stratotype: borehole KB146 Neerglabbeek.

The Flénu Formation is conformably overlying the Charleroi Formation along the Maurage = Aegir marine band. This marine band of glacio-eustatic origin is recognised everywhere and forms the best marker horizon within the Westphalian, above the marine bands of the Châtelet Formation. The boundary with the overlying Neeroeteren Formation is marked by the onset of coarse grained stacked sandstones.

Stratotype: Mons (Borinage) coal basin.

Area: The eastern Campine basin and nappes in the Borinage coalfield (western part of the Wallonian basin) in Belgium and extending beyond the national boundaries into Carboniferous basins of neighbouring countries.

Thickness: 1100 m preserved thickness in the Borinage; max 950 m in the Campine.

Age: Lower Moscovian; Westphalian C and basal Westphalian D according to traditional subdivision.

2.2.6. Neeroeteren Formation

Authors: Renier, 1944; Van Leckwijck, 1957; Delmer, 1958; Paproth et al., 1983.

Description: The formation starts with the onset of massive, partly coarse-grained to conglomeratic, kaolinitic white sandstones, characterised by high porosities and permeability. Interbedded with variegated mudstones, which tend to become predominant upwards, and rare coal seams. Deposited in braided alluvial channels of large extension and associated floodplain.

The Neeroeteren Formation is succeeding to the Flénu Formation. Locally, contacts may seem regular, taking into account the geometry of the sandstone bodies. On regional scale, however, a slight unconformity may be present.

The top of the formation coincides with the top of the Belgian Coal Measures Group and is always eroded.

Stratotype: Borehole KB113 (Neeroeteren-Neerheide).

Area: The unmined northeastern Campine basin (Neeroeteren-Rotem area). An extension in the neighbouring part of the Roer Valley Graben is probable (no borehole reconnaissance yet).

Thickness: Maximum thickness traversed in exploration boreholes is 300 m. Based on seismic evidence, preserved thickness attains 500 m (Dusar, 1989).

Age: Upper Moscovian; practically coinciding with the Westphalian D, according to traditional subdivision. The Westphalian C-D boundary, recognised by means of microflora, lies about 30 m below the base of the Neeroeteren Formation (Paproth et al., 1983).

Remark: First described by Renier (1944) as "Grès de Neeroeteren" and defined at formation level by Van Leckwijck (1957) and Delmer (1958) but restricted as a member of the Belgian Coal Measures Formation in Paproth et al. (1983).

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