NAMURIAN

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(7 figures, 1 table)

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ABSTRACT. Carboniferous rocks had a great impact on the landscape and industrialisation of western Europe, hence a distinction between 'Carboniferous limestone' and 'Coal Measures' since the dawn of geological science. André Dumont (1852) and Omalius d'Halloy (1853) already distinguished a 'Houiller sans houille' (Coal Measures without coal), subsequently named 'Namurian' by Purves in 1883. Whereas the lower boundary was quite clear – the quick transition from carbonates to siliciclastics – the boundary of the Namurian with the overlying coal-rich Coal Measures was subject to different interpretations and miscorrelations. International status of the Namurian as a chronostratigraphical stage was acquired in 1927 at the first International Carboniferous Congress, as part of a general classification scheme for the West European Carboniferous. Boundaries were based on ammonoid biozonation, selected to coincide with major events affecting the regional lithological framework.

The twofold subdivision of the Carboniferous, Dinantian - Silesian or Mississippian – Pennsylvanian Subsystems, has been a matter of debate since the second Carboniferous Congress in 1935. Dinantian and Silesian were ratified for the Lower and Upper Carboniferous in 1971 although the western European Upper Carboniferous was not considered very suitable for intercontinental correlation, due to its position in the Variscan closure zone of the Pangaea supercontinent. The definition in 1985 of a Mid-Carboniferous Boundary and GSSP at Arrow Canyon, Nevada paved the way to adoption of Mississippian and Pennsylvanian Subsystems for the Lower and Upper Carboniferous in 1999. As a consequence, the status of the Namurian stage has been reduced to a regional European Stage. This decision has also practical consequences as the Namurian straddles this Mid-Carboniferous Boundary. Actually, the time span for the Namurian is 326.4 – 315 Ma and the accepted GTS age for the Mid-Carboniferous boundary is 318.1 Ma. The lower part of the Namurian is equivalent to the Mississippian Serpukhovian stage, the upper part of the Namurian is equivalent to part of the Pennsylvanian Bashkirian stage. Application of the global time scale in western Europe is hindered, however, by poor correlation potential of the fossil record and by insufficient radiometric dating. Continued use of the Namurian stage is allowed, on condition that global equivalents are indicated, and that ambiguous terms such as Lower and Upper Carboniferous are avoided, except when related to historic concepts.

KEYWORDS: chronostratigraphy, Carboniferous, Silesian, Mississippian, Pennsylvanian, Belgium.

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1. Name

Namurian (English), Namuriaan (Dutch), Namur(ium) (German), Namurien (French).

2. Age

326.4 +/- 1.6 to 315 Ma (Geological Time Scale 'GTS 2004' in Gradstein *et al.*, 2004a,b).

Lower stage of the Silesian European Epoch. Preceded by the Visean ICS Stage (345.3 – 326.4 Ma) and followed by the Westphalian European Stage (315 – 306.5 Ma). Dating of the lower boundary underwent important shifts, from 333 Ma in Harland *et al.* (1982 = GTS 82), whereas the upper boundary has remained stable but not well constrained at 314-315 Ma (Fig. 1).

The Namurian overlaps with the Mississippian Subsystem (359.2 – 318.1 Ma) and the Pennsylvanian Subsystem (318.1 – 299 Ma) of the Carboniferous Period (ICS - International Commission on Stratigraphy, Overview of Global Boundary Stratotype Sections and Points (GSSP's), Status June 2004, compiled by J. Ogg <www.stratigraphy.org> 2005).

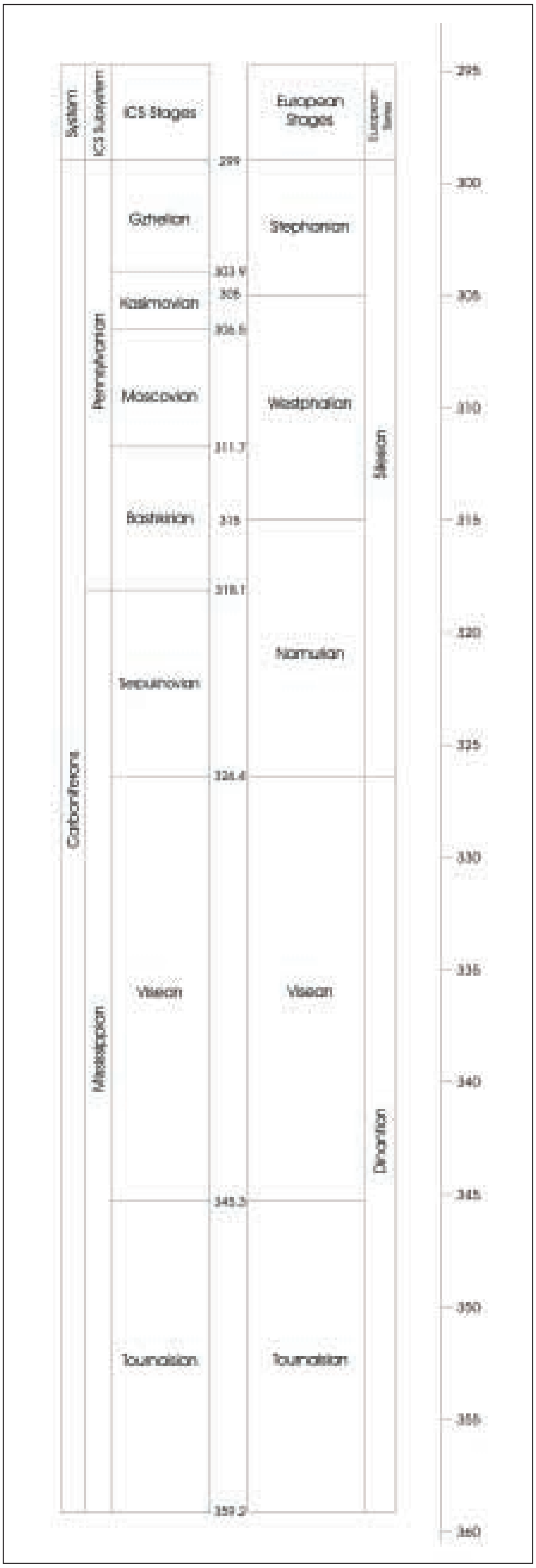

Figure 1. Chronostratigraphic chart showing correspondence between ICS stages and European stages.

3. Author

J.C. Purves distinguished in 1881 a 'lower coal measures stage' still rich in marine fossils and thus reminiscent of the underlying Carboniferous limestone, as an intermediate unit between the Lower Carboniferous limestones (= 'Kohlenkalk') and the Upper Carboniferous coal measures. For the purpose of showing the validity of the stage concept, Purves (1881) provided a lithological, paleontological and sedimentological description of the stratigraphical range from top ('Grès d'Andenne') to base of his Namurian, based on sections mainly located in the Andenne area, ca 10 km east of the city of Namur following the Meuse river but still in Namur province, and he demonstrated their constancy and international correlation potential within a Northwest European context. In 1883, he coined the name Namurian ("Namurien") for these deposits. The Namurian Stage was ratified at the first Carboniferous Congress in Heerlen, 1927, but the stratigraphical range was extended upward to include all strata that generally do not form part of the productive coal measures in western Europe (cf. infra, historical background).

Figure 2a. Coal measures map of Basse-Sambre coal field with concession boundaries, location of Citadelle outcrops (encircled) and cross-section (line I-I) on fig. 3. Hatched line delimitates mined-out zones (adapted from Bouckaert, 1967).

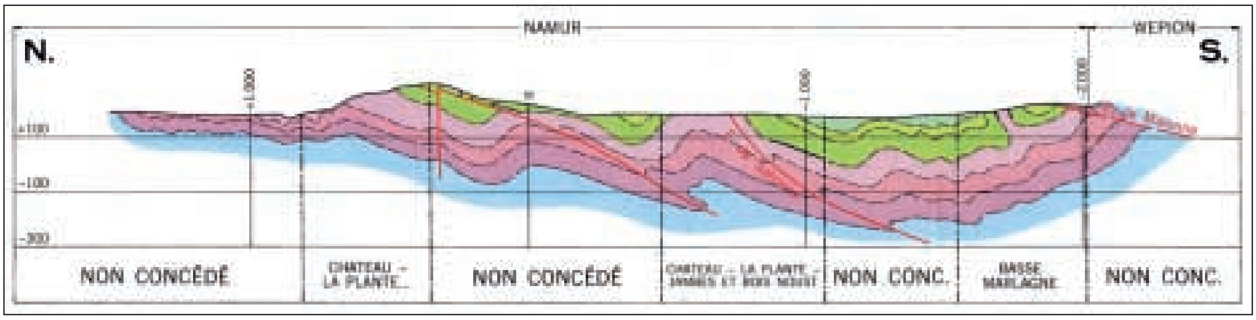

Figure 3. North-South cross-section following 64600m coordinate of mining map through centre of Namur and Citadelle, which is located on northern part of Chateau - La Plante, Jambes et Bois-Noust coal mining concession (adapted from Bouckaert, 1967). Structural position of Citadelle outcrops indicated by arrow. Colour legend: see fig. 2.

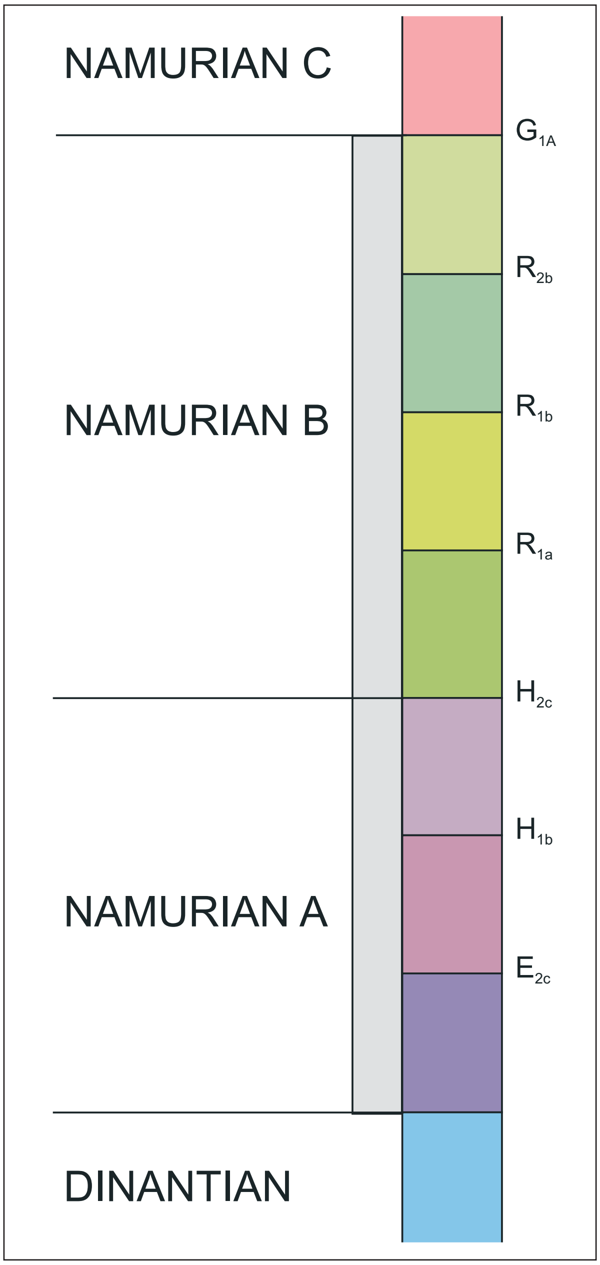

Figure 2b. Legend for figs. 2a, 3, 4.

4. Historical type area

Purves (1881, 1883) did not define a stratotype for the Namurian but rather used it for a great number of small outcrops and mining sections, often of temporary nature, in the Namur and Dinant basins.

By coincidence, the most secure outcrops actually displaying characteristic lithology and structure of the Namurian stage in the type area happen to be the road sections on the way up to the Citadelle in Namur, completed by underground sections of the Chateau – La Plante, Jambes et Bois-Noust coal mining concession (Fig. 2-3). The most detailed lithological and tectonic description of these sections is provided by Kaisin (1924-1933). By studying the goniatite faunas Bouckaert (1961) was able to show that the Citadelle sections do not contain the complete Namurian, but range from Alportian to Kinderscoutian faunal substages, straddling the boundary between the Chokier and Andenne formations. However, sections between the confluence of the Meuse and Sambre rivers, surrounding the Citadelle site, range from Arnsbergian to Yeadonian faunal substages, covering almost the complete Namurian as known in Belgium (Kaisin, 1924; Bouckaert, 1961, 1967a)-(Fig. 4).

5. Description

Purves (1881) provided a description of the top and base units of his Namurian. The 'Grès d'Andenne' (= Andenne grit), constituting its top, consists of massive dark grey quartzarenitic to arkosic sandstones, weathering to an ash-grey colour, often conglomeratic with rounded quartz and angular silicite ('phtanite') pebbles. The Grès d'Andenne was observed all along the outcrop zone of the coal measures in southern Belgium, but was known under many local names such as Grès de Salzinne in the Basse-Sambre coal field (see also Renier, 1928). The underlying strata are composed of dark grey, carbonaceous silty shales, quartzitic sandstones and litharenitic micaceous sandstones. Poorly developed thin coal seams with rootlets occur in

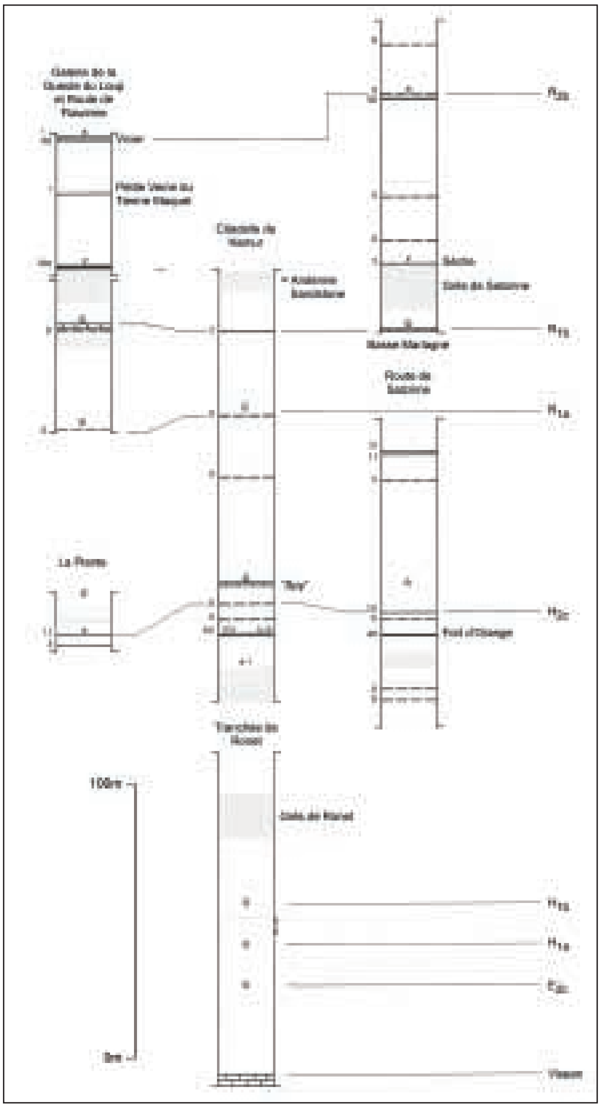

Figure 4. Studied vertical sections in Meuse-Sambre confluence from Basse-Sambre mining map, showing coal seams with thickness in centimeters (left of column), volatile matter and ash content (in column), sandstone and limestone beds, goniatite horizons (G), flora horizons (v) and fauna horizons (*)-(adapted from Bouckaert, 1967).

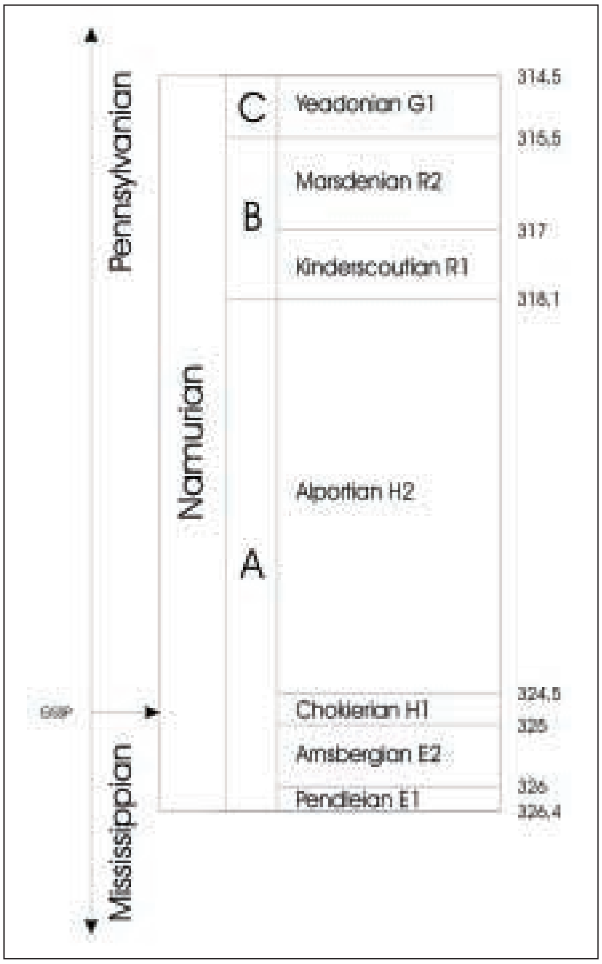

Figure 5. Chronostratigraphic chart with reference to the Namurian Regional Stage and its faunal substages (dates after Rohde, 2005, according to ICS 2004). Radiometric dates currently available are not accurate enough for correlation between different stratigraphic scales. Note the discrepancy between the ages assigned to the faunal substages of the Namurian, which are based on interpolations, and the position of the Mississippian-Pennsylvanian or Mid-Carboniferous Boundary (MCB) defined at Arrow Canyon GSSP. The age assigned to the Mississippian – Pennsylvanian boundary on the ICS 2004 time scale (age 318,1 +/- 1,3 Ma) is also the age assigned to the Alportian – Kinderscoutian boundary, whereas the age assigned to the Arnsbergian – Chokierian boundary is 325 Ma. However, the MCB is biostratigraphically defined. When comparing the biostratigraphic data defining the MCB at the GSSP and its corollary sections with the British reference section for the Chokierian, it is quite clear that the MCB slightly postdates the Arnsbergian – Chokierian boundary. Therefore the ages assigned to the Namurian substages are questionable (see report on the Chokierian, this volume, for full discussion on Chokierian chronostratigraphy).

the upper part. The "Fort d'Orange"[1] coal seam of 40 to 60 cm thickness and anthracitic composition (10.5 % volatile matter content for 5.16% ash content) was the main seam worked by the collieries, and was also exploited from the Citadelle road outcrops during the Second World War (Bouckaert, 1967a). Thinly bedded silicified shales ('phtanites') succeeded by fissile organic-rich, pyrite-bearing fossiliferous shales ('ampelites') dominate the basal unit (see Chokierian Regional Stage, this volume).

The Namurian stage as described by Purves encompassed the Namurian A (Arnsbergian, Chokierian and Alportian faunal substages, the Pendleian being represented by a hiatus in the Namur area) and the Kinderscoutian faunal substage of the Namurian B. In the Citadelle area, the total thickness of the exposed Namurian reaches 300 m

[1] The name of the coal seam and also the fort (citadelle) are both derived from William of Orange, king of the united Netherlands

Heerlen Congress	Belgian assises	Demanet's biozones	Goniatite zones
C			
B	Andenne ($H_{1b,c}$)	Gilly Nm_{2c}	*R. superbilingue, G. cancellatum*
		Baulet Nm_{2b}	*R. bilingue*
		Sippenaeken Nm_{2a}	*R. reticulatum*
A	Chokier (H_{1a})	Spy Nm_{1c}	*H. beyrichianum*
		Malonne Nm_{1b}	*E. bisulcatum*
		Bioul Nm_{1a}	*E. pseudobilingue*

Table 1. Regional (bio)stratigraphical subdivision of Namurian in Belgium, after Van Leckwijck (1957) and Demanet (1941): *G. Gastrioceras* [*Cancelloceras*], *R. Reticuloceras* [*Bilinguites*], *H. Homoceras* [*Isohomoceras*], *E. Eumorphoceras.* For stratigraphical subdivision and correlation purposes, the original denomination of the goniatite zones are maintained unchanged (British Geological Survey Notes for Authors, 4th Edition, Jackson, 2000).

(Fig. 4). The Namurian A practically corresponds to the Chokier Formation with its base at the contact between the silicified shales and the massive Visean limestones. It is topped by the Spy crinoidal limestone bed containing the H_{2c} marine horizon with *Homoceratoides prereticulatus* and *Homoceras henkei* (Paproth *et al.*, 1983; Delmer *et al.*, 2002). The Chokier formation attains a thickness of 180 m. The overlying Andenne Formation corresponds to the Namurian B and attains a thickness of 120 m up to the level of the Salzinne (= Andenne) sandstones (Bouckaert, 1967a). In 1883, Purves provided names for this twofold subdivision: assise de Loverval for the lower unit and assise d'Andenne for the upper unit. These names were never used (Loverval, replaced by Chokier) or were used with different meanings (Andenne).

The overlying part of the Namurian B and the Namurian C (Marsdenian to Yeadonian faunal substages), corresponding to the upper half of the Andenne Formation originally was not included in Purves' concept of the Namurian stage. It reaches an additional thickness of 125 m in the Basse-Sambre coalfield (Bouckaert, 1967a).

The subdivision of the Namurian stage in the assises of Chokier and Andenne was based on lithological criteria that reflected important events in basin development. As such, they were not proposed as international substages, for which paleontological arguments were necessary. Moreover, Renier (1927) demonstrated the uncertain nature and stratigraphic position of the conglomeratic sandstones (grits) associated with the Grès d'Andenne, and hence their unsuitability as a basis for interregional stratigraphic subdivision. The faunal substages into which the Namurian was subdivided are based on the British goniatite succession by Bisat and Hudson (cf. Hodson, 1957; Ramsbottom, 1971, 1980; Fig. 5). Demanet (1941) proposed a further subdivision of the Belgian assises according to goniatite biozones (Table 1), which is considered redundant in view of the internationally accepted subdivision of the Namurian (Fig. 5).

The lithostratigraphical subdivision of the Belgian coal measures currently in use is provided by Delmer *et al.* (2002). The stratigraphical relationship between the Chokier formation and the Chokierian faunal substage is discussed in the section devoted to the Chokierian Regional Stage in this volume.

6. Historical background

The 'classification', or stratigraphic subdivision, of Carboniferous deposits in Europe was the main objective of the first Carboniferous Congress (cf. Ramsbottom, 1991; Dusar, 2003). This sought "agreement on the foundation for stratigraphic subdivision and common terminology" (Renier in Jongmans, 1928, p. XXII). Despite the lack of proper terminology (chrono-bio-lithostratigraphy) and the unavailability of global concepts (eustatic sea-level changes, plate tectonics), the decisions made at this congress testified to remarkable insight to the value of stratigraphic subdivisions and their paleogeographic causes, and rejected interregional correlation of units based on purely lithological and diagenetic characteristics or on sudden appearance of new genera without support of a phylogenetic lineage. A single classification of the West European Carboniferous, with major boundaries for Namurian, Westphalian, Stephanian, was based on the biozonation of marine ammonoids. During following Carboniferous congresses, micropaleontology furnished the major guide fossils, foraminifers and fusulinids since the 1960's and conodonts since the 1970's. Paleobotany was more important in defining biogeographical provinces. This provided the "truest synchronic correlations that paleontology could achieve" (Renier in Jongmans, 1928, p. XXXV). This subdivision is still utilised in western Europe today; needless to say, it is very useful, "serving the need for miners and stratigraphers alike" (Jongmans & Gothan, 1937).

The formal twofold subdivision of the Carboniferous System, and the establishment of the Upper Carboniferous Namurian, Westphalian and Stephanian stages, achieved at the first Carboniferous Congress in Heerlen 1927, remained the basis for subdivision during the following years. The IUGS Subcommission on Carboniferous Stratigraphy (SCCS) confirmed the Carboniferous as a unified system and the European subdivision was retained in the sense and meaning given in western Europe (Van Leckwijck, 1960). The Dinantian and the Silesian Subsystems were ratified for the Lower and Upper Carboniferous Series (Epochs) respectively at Krefeld in 1971,

with the Namurian Stage as the lower subdivision of the Silesian Subsystem (George & Wagner, 1972).
This upper Carboniferous subdivision was based on the stratigraphic framework of the coal measures in western Europe. The subdivision was thus linked to coal seams, conglomerates and marine beds as lithological marker beds. The paleontological content of these beds, or of the lithological units that were separated by these markers, was mostly imprecise and unfit for interregional correlations. This duality was fully recognised: "*La limite entre les étages Namurien et Westphalien avait, après un échange de vues assez long, été, en 1927, tracée au niveau de la veine Sarnsbank du bassin rhénan-westphalien. Dans le Compte-rendu, il a été inséré en conclusion que la limite était l'horizon à Gastricoceras subcrenatum, avec l'indication de la mention Sarnsbank. Il y a, à mon avis, dans cette double définition matière à confusion.*» [Renier in Jongmans & Gothan, 1937, p. 11-12]. This means that to start with, a convenient lithological boundary was chosen, and that subsequently, paleontological arguments had to be assembled, supporting this boundary choice. These arguments, though officially required, were often rather weak and of secondary importance, at least in the discussions: "*La coupure entre Namurien et Westphalien devrait correspondre plutôt à quelque fait de stratigraphie assez général pour être reconnue dans la plupart des bassins. Mais si on est obligé à recourir à la paléontologie pour établir une limite aussi importante, c'est plutôt l'expansion et la prédominance du genre Gastrioceras à partir du niveau à Gastrioceras cumbriense - qui fournirait cette limite.*» [Delépine in Jongmans & Gothan, 1937, p. 13]. Part of this discussion arises from the fact that goniatites identified in the German and Belgian coal basins were of different species, *G. subcrenatum* and *G.* aff. *cumbriense*, respectively. In Belgium, *G. subcrenatum* has not been recorded but is replaced by *G. aff. cumbriense*. Rather than using the first appearance of *Gastrioceras* (which already occurs in the underlying Schieferbank horizon), a fixed horizon, namely Sarnsbank, was used for defining the Namurian – Westphalian boundary.
The twofold subdivision of the Carboniferous (Dinantian - Silesian) that is so characteristic of the landscapes and the mining history of western and central Europe was not recognised in North America or in Gondwana. For the upper Carboniferous (*sensu* western Europe) it was realised that western European successions did not provide good arguments for global correlation. Nevertheless, the western European stratigraphical scheme retained its status as the reference, because intercontinental comparisons had been made at the initiative of western European geologists, mainly Jongmans, Pruvost and Gothan. These founding fathers of European upper Carboniferous stratigraphy already had the insight that the basis for correlation, at least for the upper Carboniferous and the Permian, had to be found outside western Europe (Jongmans & Gothan, 1937; van Waterschoot van der Gracht, 1938): " *The gradual transition and interfingering, within the American Midcontinent, of paralic plant bearing beds, into marine sediments, over the entire column of the Carboniferous section, creates an unparallelled opportunity for paleontological and stratigraphical research, which is only partially possible in Europe*" [van Waterschoot van der Gracht, 1937, p. 302]. Moreover, the presence of an important hiatus between Mississippian (Chesterian) and Pennsylvanian (Morrowan) in the eastern USA, corresponding to the Chokierian – Alportian, did not induce a rapid change in classification scheme.
The Carboniferous-Permian world was dominated by the assembly of the supercontinent Pangaea (see Blakey, 2004). This means that the lower Carboniferous or Mississippian mostly consists of marine sediments deposited in a rather equable climate under sea-level highstands, and contains cosmopolitan faunas that allow good global correlations, whereas the upper Carboniferous or Pennsylvanian consists of sediments deposited in closing sedimentary basins, stretching almost from North Pole to South Pole under a more differentiated climate, and contains mostly endemic or provincial faunas with less correlation potential. Accordingly, most effort devoted to solving the stratigraphic correlation problems in the Pennsylvanian resulted in establishing new formal stratigraphic subdivisions in regions remaining under marine influence (Wagner & Winkler-Prins, 1991, p. 214).
As a result, the fate of the Namurian depended on the attempt to subdivide the Carboniferous into two subsystems, corresponding to the Mississippian and Pennsylvanian, or even to elevate these to system status. At the American initiative, a proposal for this new subdivision has been on the agenda of the International Congresses for the Carboniferous since 1951 and on International Geological Congresses since 1952 (Williams, 1952). The terms Mississippian and Pennsylvanian had the advantage of clarity concerning their boundaries compared with the terms lower and upper Carboniferous[2]. "*The names in use (e.g. Dinantian) should be retained in the regions to which they had been applied hitherto, as they were adapted to major, regional changes in facies and lithology. However, every endeavour should be made to reach an agreement that would enable a uniform nomenclature to be adopted for North America and Europe*" [Jongmans, chairman & van der Heide, secretary, in van der Heide, 1952, p. XIV].
This means that, following the IUGS Subcommission on Carboniferous Stratigraphy (SCCS)'s definition of a Mid-Carboniferous Boundary and GSSP (Global Stratotype Section and Point) at Arrow Canyon in Nevada, USA, at the evolutionary appearance of the conodont *Declinognathodus noduliferus*, which slightly postdates the transition

[2] The terms *lower* and *upper* Carboniferous are ambiguous because they are defined and used differently in different places, so they should be used in lower case, with a possible exception when referring to historical use (pers. comm. Philip Heckel).

between the *Eumorphoceras* to *Homoceras* ammonoid zones (Lane *et al.*, 1985 and 1999; Titus *et al.*, 1997; Richards *et al.*, 2002), the concept of lower and upper Carboniferous has been revised such that the lower part of the Namurian Stage is now included within the upper part of the lower Carboniferous Subsystem. Therefore, the Namurian (326.4 – 315 Ma) contains the Late Mississippian Epoch or Serpukhovian ICS Stage (326.4 – 318.1 Ma) and partially overlaps with the Early Pennsylvanian Epoch or Bashkirian ICS Stage (318.1 – 311.7 Ma). Only recently (2000), Mississippian and Pennsylvanian were ratified as subsystem names for the lower and upper Carboniferous by the SCCS and accepted by the IUGS following the XIV International Congress on the Carboniferous and the Permian, held in Calgary, 1999. As a consequence, the status of the Silesian Series and the Namurian Stage has been reduced to regional western European denominations. They can still be used in the regions where they have been established, but global equivalents should be mentioned in the scientific literature dealing with chronostratigraphic nomenclature.

7. Sedimentology and palaeogeography

Dinantian (lower Carboniferous) limestones are succeeded by siliciclastic sediments deposited first in a marine environment, and later in turbiditic, deltaic, lagoonal, fluvial or floodplain environments with a decreasing number of marine incursions. All these rather monotonous 'paralic' siliciclastics are grouped in the coal measures, chronostratigraphically corresponding to the Silesian. Within this rather monotonous sequence of molasse sediments, up to 4000 m thick in Belgium, the marine horizons and their characteristic fauna, controlled by eustatic sea level changes, form the basis for stratigraphic subdivision, resulting inevitably in a combined litho- and biostratigraphic zonation (Paproth *et al.*, 1983).

Whereas the transition to the overlying Westphalian is continuous, the base of the Namurian is marked by a hiatus of increasing importance toward the culmination axis of the Anglo-Brabant massif (Bouckaert, 1967b). In the most strongly subsiding parts of the paralic basin, the 'Auge hennuyère' of the Namur synclinorium and the Visé-Puth basin east of the Anglo-Brabant massif, sedimentation between the Visean and Namurian might have been more continuous with the deposition of poorly dated, finely bedded silicites assigned to the Gottignies and Souvré Formations (cf. Delmer *at al.,* 2002).

Delmer & Ancion (1954) suggested that the Namurian deposits could be distinguished from the succeeding Westphalian deposits of the paralic basin by the frequent recurrence of marine-influenced (deltaic-turbiditic) environments between soil horizons (or coal seams). A formal characterisation as such is questionable because unambiguous marine facies is restricted to thin faunal bands. However, it is obvious that marine 'influence' (marine bands and near-shoreline deposits, lacustrine-to-brackish water conditions) is more strongly expressed in Namurian strata, at least in Belgium and neighbouring areas (Collinson, 1988; Langenaeker & Dusar, 1992).

The paralic sediments are organised in 3rd to 5th order cycles (Süss *et al.*, 2000). Basic 5th order parasequence cycles in the Namurian were described by Fiege & Van Leckwijk (1964), starting with (marine) clays, coarsening upward from sand-clay alternations to proximal sands, then fining-upwards to floodplain and coal bed. The upper fining-upwards part of the basic cycle is often lacking in the Namurian; also the sand content is variable and rather low in many cycles. Their thickness approximates 10 m. Seven to eight 5th order cycles combine to form 4th order sequence cycles with average thickness of 60 m in the Namurian of Belgium (corresponding to the mesothems of Ramsbottom, 1978). The lower cycle is marked by the strongest marine influence and will contain the best marine faunas including the goniatite horizons, and so corresponds to periods of eustatic sea-level rise. 4th order cycles represent the same shale-sand-coal distribution and coarsening upward – fining upward trends as is observed within the basic 5th order cycle. 4th order parasequences may be overprinted by 3rd order glacio-eustatic cycles, which build the fundamental stratigraphic framework of the coal measures group. Fiege & Van Leckwijk's model of cyclicity is only applicable to the sequences containing alternating coal seams or rootlet beds with higher salinity (marine) beds, as it is difficult to find proof of similar trends between 5th to 3rd order cycles (Holdsworth & Collinson, 1988): in the Namurian A without coal, application of Fiege & Van Leckwijk's model is not possible. Important thickness differences in Arnsbergian to Alportian (Namurian A) sequences testify of differentiated bathymetry and subsidence, resulting from tectonically-controlled uplift and progressive drowning of karst landcapes on the Visean carbonates. More uniform basinal sag controlled subsidence and sedimentation from Kinderscoutian (Namurian B) sequences onward (Collinson, 1988).

8. Palaeontology

The Visean-Namurian boundary was based at the *Glyphioceras spirale* horizon, occurring at the top of the Visean *Glyphioceras* zone (Jongmans, 1928). In Belgian practice, where the transition is represented by a hiatus or by sediments without distinctive fossils, the change from carbonate to siliciclastic sedimentation was used as the boundary. This hiatus corresponds to the Pendleian and lowermost Arnsbergian faunal substages (E_1-E_{2a}) but may extend toward the Alportian in the direction of the culmination of the Brabant Massif (Bouckaert & Higgins, 1963, 1967b).

The Namurian-Westphalian boundary was set at the *Gastrioceras subcrenatum* horizon, which in the German Ruhr basin overlies the Sarnsbank coal seam. By seam-to-seam correlation between the different western European coal basins, this boundary could be traced at the corresponding coal seam – marine horizon couplet of regionally synchronous age (Jongmans, 1928), known as Gros Pierre in the Basse-Sambre coal field (Renier, 1928, Bouckaert, 1967a).

9. Chronostratigraphy

A major problem consists of relating the Namurian to the Serpukhovian - Bashkirian Stages. The Serpuhkovian type section, containing the base of the stage is located in the Zaborie quarry in the Moscow basin. All over this basin, the lower boundary of the type Serpukhovian is an unconformity which approximates the equally unconformable Visean – Namurian boundary in the Namur and Dinant basins in Belgium (Kabanov, 2003; Skompski *et al.*, 1995). The process for defining a GSSP would thus not be much different for the Visean-Namurian or the Visean-Serpukhovian boundary. No biotic lineage has yet been chosen to define the boundary but the stratigraphic level of the Visean-Serpukhovian GSSP should correspond with the base of the type Serpukhovian as closely as possible to maintain stability of stratigraphic meaning and interpretation. The GTS 2004 boundary between the Visean and Serpukhovian ICS stages is provisionally defined near the lowest occurrence of the conodont *Lochriea cruciformis,* as the *Lochriea* group of species could be suitable for the definition of a GSSP near the current Visean-Serpukhovian boundary (Skompski *et al.*, 1995; Richards and Task Group, 2004).

The Serpukhovian-Bashkirian boundary is defined by a GSSP. The IUGS Subcommission on Carboniferous Stratigraphy (SCCS)'s definition of a Mid-Carboniferous Boundary and of the GSSP (Global Stratotype Section and Point) coincides with the evolutionary appearance of the conodont *Declinognathodus noduliferus* in Arrow Canyon in Nevada, USA (Lane *et al.*, 1985 and 1999; Richards *et al.*, 2002). This approximately postdates the transition between the *Eumorphoceras* to *Homoceras* ammonoid zones, marking the boundary between the Arnsbergian and Chokierian faunal stages, a boundary that could also be used in the Namurian of Belgium.

Some ambiguity remains in the late Carboniferous timescales (see also Cleal & Thomas, 1996). Whereas the Mid-Carboniferous Boundary is set at 318.1 +/- 1.3 Ma, the correspondence to the Namurian substages is less clear. On the ICS' Geological Time Scale 2004, the Arnsbergian – Chokierian boundary is placed at 325 Ma (Fig. 5). In the same time scale, the 318 Ma level occurs near the top of the Alportian, close to the Alportian – Kinderscoutian boundary (formerly the Namurian A/B boundary), more in conformity with the original proposal for a Mid-Carboniferous Boundary made at the International Congress on the Carboniferous held in Moscow, 1975: correlation of top Serpukhovian to top Alportian, making the Serpukhovian equivalent to the Namurian A (Harland *et al.,* 1982, 1989).

These divergent ages are mainly due to poor age constraints for the intra-Namurian subdivision, in the absence of high-resolution paleontological correlations. The real problem might not be so much a wrong date picked for the Mid-Carboniferous Boundary, but rather wrong ages for the Namurian faunal substages in ICS' GeoWhen database. The review by Menning *et al.* (2000) of the Carboniferous time scale in Europe suggests an age closer to 318-320 Ma for the Arnsbergian-Chokierian faunal substage boundary than the 325 Ma in the GTS 2004 database.

Nevertheless, the faunal substages based on ammonoid zonation, defined as subdivisions for the Namurian Stage in western Europe, retain their validity, either within the Serpukhovian or Bashkirian Stages. The SCCS approved of their continued use as regional substages, a decision that does not need further ratification (Heckel, 2004).

10. Geochronology

No radiometric datings are available for the Namurian in Belgium. The time scale used is based on radiogeochronometric anchor points (RAPs) based on ages of volcanic tuffs and coal tonsteins, integrated and calibrated, and combined with time-relevant geological indicators for establishing the duration of the intervening intervals, obtained from Carboniferous basins in western Europe (Menning *et al.,* 2000).

11. Structural setting

Namurian sediments in Belgium form part of the Variscan orogenic cycle. They were deposited in the northwestern European Variscan foreland basin, which transformed from a carbonate platform during the Sudetic phase close to the Visean-Namurian transition and filled with cyclic molasse deposits. The main, Asturian stage, during the late Carboniferous, left the major part of the Namurian deposits in Belgium along the margins of the Brabant parautochthon (known as the Namur Synclinorium to the south and Campine Basin to the north of the Brabant massif) and a smaller part in the deepest synclines of the folded Dinant synclinorium of the Ardennes allochthon (Sintubin, 2004).

Frequent soft-sediment deformation structures testify to the tectonic instability of the sedimentary environment during the initial sagging stage of the foreland basin, and these were overprinted by hard-rock tectonic deformation during the stage of maximal subsidence and basin shortening. In this way, Kenis *et al.* (2003) distinguished three deformation phases at the Namur – Citadelle site.

Figure 6. Partial view of Citadelle site with Donjon on promontory, seen from Northeast across Meuse river. © Geobelphot, Dejonghe & Jumeau, 2004. Photo L. Dejonghe.

12. Reference section in Belgium

In absence of a properly defined stratotype, the Citadelle site may serve as an auxiliary reference section for the Namurian in Belgium (Kaisin, 1924; Bouckaert, 1961, 1967a)-(Fig. 2-4, Fig. 6), even though quality of exposure has been greatly reduced over time (Kaisin, 1933a). This section is covered by GeoDoc file 155W688 of the Geological Survey of Belgium (map sheet Malonne 47/3, Lambert X 185000 Y 127775, 4°52'00" 50°27'45"). Especially the Route merveilleuse and Chemin de Ronde sections are composed of discontinuous outcrops displaying all sedimentary-tectonic characteristics of the Namurian paralic, coal-shale-sandstone bearing deposits with various exposed folds and faults, soft-sediment deformation structures and weathering features (Kaisin, 1933a, Kenis *et al.*, 2003; Vandenberghe & Bouckaert, 1984)-(Fig. 7). More sections in the Namur area were measured in relation with coal mining or large infrastructural works. Tectonic observations were described in great detail by Kaisin (1932, 1933a,b) and completed by ammonoid biozonation by Bouckaert (1961, 1967a): Ronet railway cut, Basse-Marlagne, Gueule-du-Loup, Milieu-du-Monde and La Plante collieries, Salzinnes road cut.

13. Main contributions

(after Renier, 1912, 1927, 1930; Van Leckwijck, 1957)
Dumont (1852) and d'Omalius d'Halloy (1853): distinction between a lower 'Houiller sans houille' (H_1) and an upper 'Houiller avec houille' (H_2). However, the 'Houiller sans houille' (Flözleeres or unproductive coal measures), a precursor to the Namurian, only encompassed the silicified strata ('phtanites'), quartzites and alum shales ('hot shales' or 'ampelites'), transitional to the Visean stage, actually encompassed in the Chokier formation.

Figure 7. North-verging anticline between bent tunnel mouths near Tour César, along Route Merveilleuse on Namur Citadelle (see also Kaisin, 1933a and Bouckaert, 1961 (outcrop 8); Vandenberghe & Bouckaert, 1984). © Geobelphot, Dejonghe & Jumeau, 2004. Photo L. Dejonghe.

Cornet & Briart (1876): correlation of the conglomeratic sandstones surmounting the phtanites and ampelites to the Millstone Grit, after Murchison (1859) correlated the 'houiller sans houille' to the Millstone Grit in the UK, based on paleontological arguments.
Mourlon (1880): raised the limit between 'houiller sans houille' and 'houiller avec houille' to the level of the Andenne conglomeratic sandstones (then named the 'Poudingue de Monceau-sur-Sambre').
Purves (1881): rationale for defining the 'houiller sans houille' as a separate stage with clearly defined boundaries (Grès d'Andenne as upper boundary) and content.
Purves (1883): introduction of the name 'Namurian'.
Légende de la carte géologique de la Belgique (1892), in use on the 1:40,000 geological maps of Belgium: Houiller inférieur (H_1) instead of Namurian, probably because the name for the succeeding Westphalian stage was created not before 1893 by de Lapparent. The lower stage of the coal measures was further subdivided in H_{1a} (corresponding to Purves' Loverval assise), H_{1b} (corresponding to

Purves' Andenne assise) and H_{1c} (corresponding to the Andenne sandstone, originally seen by Purves as the base of the next stage) - (Unit names not to be confused with the H_{1a} etc of goniatite sub-zones).
Stainier (1901): re-introduction of the name Namurian for the H_1 of the geological map and twofold subdivision in the assises of Chokier (H_{1a}) and Andenne (H_{1b} and H_{1c}). Subsequent use of these assises in their lithostratigraphic meaning as formations has continued ever since.
Renier (1927, 1928, 1930) and Jongmans (1928): international use of the Namurian as a chronostratigraphic stage, moving its upper limit and boundary with the Westphalian to the level still in use (see chapters 6-7).
Demanet (1941): introduction of paleontological marker (goniatites) for delimiting the Namurian, in conformity with the requirements put forward by the International Carboniferous Congresses. However, Bouckaert & Higgins (1963) partly invalidated the biozonation proposed by Demanet for the Pendleian-Arnsbergian.
Delmer & Ancion (1954), Fiege & Van Leckwijck (1964), Van Leckwijck (1964), Paproth *et al.* 1983), Delmer *et al.* (2002): continued use of the lithostratigraphic subdivision as proposed by Stainier (1901) with the boundaries proposed by Renier (1927).
Lane *et al.* (1999) and Richards *et al.* (2002) : ratification of the Mississippian and Pennsylvanian as Carboniferous subsystems, degrading the Namurian as a Western European regional stage.
Heckel (2004): Western European subdivision of the Namurian ranked as regional substages.

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