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CHOKIERIAN

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(5 figures)

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ABSTRACT. The Chokier alum shales, exposed in the Meuse valley between Namur and Liège (Belgium), were defined by d'Omalius d'Halloy in 1853 as the lower unproductive unit of the Carboniferous coal measures. From this original concept, both a lithostratigraphic and a chronostratigraphic unit were defined. The Formation of Chokier returned to d'Omalius d'Halloy's original 'houiller sans houille' concept (Paproth *et al.*, 1983). The intermediate 'assise de Chokier' (Stainier, 1901) reflected a hybrid litho-bio construction by using synchronous marine incursions or goniatite bands for subdivision and basin-wide correlation. The 'assise de Chokier' became equivalent to the Namurian A, encompassing the *Eumorphoceras* and *Homoceras* goniatite zones, defined as the lower subdivision of the Namurian Stage at the first Carboniferous Congress in Heerlen, 1927. The Chokierian chronostratigraphic stage - with type section located in the UK - was defined by Hodson (1957), splitting the Sabdenian (or *Homoceras*) stage of Bisat (1928). The Chokierian formed a step in a coherent system of goniatite stages, whose applicability on regional, northwest European scale has not been questioned. The Chokierian received the status of an international faunal stage – necessarily as a substage to the Namurian - at the Sheffield Carboniferous Congress in 1967.
Chokierian and Alportian are transitional stages in the faunal turnover that characterises the difference between the lower and upper Carboniferous. Following the definition of a Mid-Carboniferous Boundary GSSP in 1985 and acceptance of the Mississippian – Pennsylvanian as the basic subdivision of the Carboniferous, the Chokierian is used as a Regional Stage on current ICS Geological Time Scales. The Chokierian was initially correlated with the Misissippian Subsystem and Serpukhovian stage. Re-assessment of the duration of the Namurian substages and goniatite – conodont correlation suggest to shift the Chokierian to the Pennsylvanian Subsystem and Bashkirian Stage. Exact position of the Mid-Carboniferous Boundary is probably very near the base of the Chokierian. According to recommendation by SCCS, the preferred use of the Chokierian is as a European Substage of the Namurian.

KEYWORDS: chronostratigraphy, lithostratigraphy, Mid-Carboniferous Boundary, Namurian, Alportian, Chokier Formation, Belgium.

Reference to this paper: Dusar, M., 2006. Chokierian. *In* Dejonghe, L., ed., Current status of chronostratigraphic units named from Belgium and adjacent areas, *Geologica Belgica*, Brussels, 9/1-2: 177-187.

1. Name and status

Chokierian (English), Chokieriaan (Dutch), Chokierium (German), Chokierien (French).
Originally defined as Faunal Stage of the Carboniferous; shown as Regional Stage on current ICS[1] documents; preferred use as Regional Faunal Substage of the Namurian, according to recommendation by SCCS[2].

2. Age

Although the stratigraphic position of the Chokierian as a faunal stage of the upper Carboniferous, evolving into a regional faunal substage within a succession of faunal substages of the Namurian has never raised doubts, its correlation with the chronostratigraphic time scale has not been constrained by radiogeochronometric data of a calibrated time scale (Fig. 1). Radiometric dating is obtained by interpolation and is not yet accurate enough to correlate the Namurian substages, whose duration is in the order of 1 Ma or less, with the global scale. Ages for the Chokierian from both time scales discussed here principally serve as a focus on problems of defining rates of sedimentation and subsidence or synchronicity of faunal changes.
According to the Geological Time Scale 'GTS 2004': 325 to 324.5 Ma. Preceeded by the Arnsbergian Faunal Stage (326-325 Ma) and followed by the Alportian Faunal

[1] International Commission on Stratigraphy <www.stratigraphy.org> 2004).
[2] I.U.G.S. Subcommission on Carboniferous Stratigraphy (see Namurian European Stage, this volume).

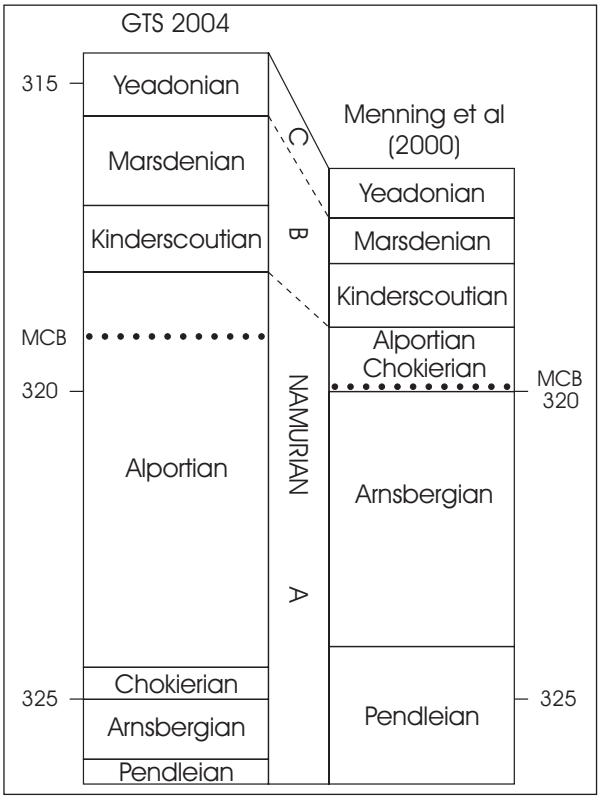

Figure 1. Chronostratigraphic chart of Namurian regional substages with presumed position of the Mid-Carboniferous Boundary (MCB), arranged by estimated radiometric age, comparing ICS 2004 scale (after Rohde, 2005, according to ICS 2004) with Menning *et al*. (2000). Age ranges of Menning *et al*. (2000) also take into consideration sedimentation rates, making them more plausible.

Stage (324.5-318.1 Ma). A substage of the Namurian European Stage (326.4 +/- 1.6 to 315 Ma) and of the Serpukhovian ICS Stage (326.4-318.1 Ma) and thus of the Mississippian Epoch (359.2-318.1 Ma) - (Geological Time Scale 'GTS 2004' in Gradstein *et al.*, 2004, and in ICS-GeoWhen Database (Rohde, 2005).

According to the integrated calibrated time scale of central and western Europe, recommended by Menning *et al.* (2000) or by Menning & German Stratigraphic Commission (2002), the Chokierian (H_1) – Alportian (H_2) time span ranges from 320 to 319 Ma, corresponding to the base of the Bashkirian ICS Stage instead of the Serpukhovian. Introduction of a GSSP[3] at the Mississippian-Pennsylvanian boundary equally tends to include the Chokierian in the Pennsylvanian.

3. Author

D'Omalius d'Halloy distinguished in 1853 as 'ampélites de Chokier' (Chokier alum shales[4]) the lower, unproductive unit of the coal measures, also known as 'Houiller sans houille' (Dumont, 1832, 1852). Purves (1881) provided the basis for a litho-biostratigraphic characterisation of these 'Shales with Posidoniellas and goniatites' (Schistes à Posidonomyes et Goniatites) and proposed the name 'assise de Loverval' (Purves, 1883). In the 1892 Legend of the geological map of Belgium, as also used on mapsheet 133 Jehay Bodegnée – Saint Georges (Stainier, 1899), the symbol H_{1a} was applied for the same unit, without other stratigraphic denomination. Applying priority rules, Stainier (1901) renamed this unit 'Assise de Chokier'[5], with Loverval as a junior synonym.
At the first Carboniferous Congress in Heerlen, 1927, the Assise de Chokier was incorporated in the Namurian A (Renier, 1928, 1930; Jongmans, 1928). Biostratigraphically, the assise de Chokier, as defined in the type area, encompassed the *Eumorphoceras* and *Homoceras* goniatite zones[6], corresponding to the later defined Arnsbergian (E_2), Chokierian (H_1)[7] and Alportian (H_2) faunal stages (Bouckaert & Delmer, 1959). Since then, the assise received formation status and was decoupled from chronostratigraphy, thus returning to the original descriptions by d'Omalius d'Halloy and Dumont (Paproth *et al.*, 1983; Delmer *et al.*, 2002).

[3] Global Standard Section and Point

[4] Ampelite or alum shale is the obsolete name for pyrite-rich, carbonaceous, hence black-coloured shales, which on weathering turn into purple-brown, fissile and porous shales. Marine fossils such as goniatites and pelecypods are frequently impressed on the bedding planes. Oxidation of the pyrite produces sulphuric acid which reacts with the clay to form aluminium sulphates [KAl3(SO4)2(OH)6]. Alum extraction went by calcination, which formed the major industrial use for the Namurian coals from the local Saint-Georges – Awirs coal field (Fourmarier, 1910). The brick-red clays that can be observed on bare hilltops overlooking the Meuse river valley over a 15 km-long stretch between Ampsin and Flémalle are the spoil heaps of the alum production (Van Scherpenzeel Thim, 1875) - (Fig. 5). Alum was used as a herbicide to kill insects on vines. Such activity was particularly relevant in Chokier where half of the population used to be engaged in wine growing. Actually one vineyard 'Dame Palate' is left at the foot of Trokay hill, below Chokier castle, on Famennian shales and siltstones <http://www.vignes.be/chokier.htm>.

[5] In early publications referring to the site of Chokier or to the 'ampelites' deposit, spelling occasionally was Chockier or Choquier. English-language literature occasionally uses the simplified form Chokerian instead of Chokierian, possibly initiated by Bouckaert & Higgins (1970). Current website documents by ICS use both terms Chokierian and Chokerian.

[6] When a generic or specific name is used as part of a formal lithostratigraphical or palaeogeographical term the name should not be changed to accord with subsequent taxonomic revision (British Geological Survey Notes for Authors, 4th Ed., Jackson, 2000).

[7] The different use of the symbol H_1 either in the Belgian (litho)stratigraphical legend, established in 1892 for the new geological map of Belgium on scale 1:40.000 and standing for 'Houiller', or for the Lower Homoceras goniatite zone, established on the British

The origin of the Chokierian Stage as a time-stratigraphic unit must be found in Great Britain and Ireland, where successions are more complete than in Belgium. The Chokierian Stage was defined by Hodson (1957), who decided to subdivide the Sabdenian (or *Homoceras*) Stage of Bisat (1928) and Hudson (1945) into the Chokierian and Alportian Stages, with reference section along the River Darwen in Samlesbury Bottoms near Blackburn, Lancashire[8]. The Namurian Working Group at the 6th Carboniferous Congress (Sheffield, 1967) accepted the Chokierian stage as an international stage, despite the geographic anomaly between the stage name and the type-locality (Ramsbottom, 1969; George & Wagner, 1969).

4. Historical type area

D'Omalius d'Halloy (1853) did not properly define a stratotype for the 'ampélites de Chokier'. The location most fitting the original description was the trench remaining after exploitation of the alum shales at the contact zone (H_{1a}) between the small Saint-Georges - Awirs coal mining basin (H_{1b} - H_2) and the Visean limestones assigned to the Livian (V_{2b}-V_{3a}), near the 'Ferme de Chokier', in the commune of Flémalle (Fig. 2-3). This location forms part of a narrow stretch on the high left bank of the Meuse river between the cities of Huy and Liège, protected by a range of massive Dinantian limestones. In the Chokier – Engihoul area, H_{1a} (Chokierian) ampelites rest directly on middle Visean (Livian) limestones, resulting in an important hiatus encompassing the upper Visean (Warnantian) and the Serpukhovian. Locally, more abrasive silty shales, reduced to a few metres thickness and assigned to the late Arnsbergian (Eumorphoceras $E2_c$ zone), might intervene at the base of the Namurian (Bouckaert & Lambrecht, 1967).

Ampelite outcrop zones were easily recognisable by their topographic expression at the foot of the Visean limestone cliffs. Ampelites, which were mined in the area of Chokier during the 18th-19th centuries left an environmental mark by the presence of hot, ferruginous and sulphuric springs and temperature anomalies (early snowmelt and blowing holes) – (Doudou, 1902). Ampelite strata also provided a sharp upper contact for the Pb-Zn sulphide and oxide ore bodies precipitated along transverse N-S fractures crossing the limestones, encountered in paleokarst or developed at contacts between massive limestones and either bedded limestones or shales (de Rauw, 1907)-(cf. Fig. 2).

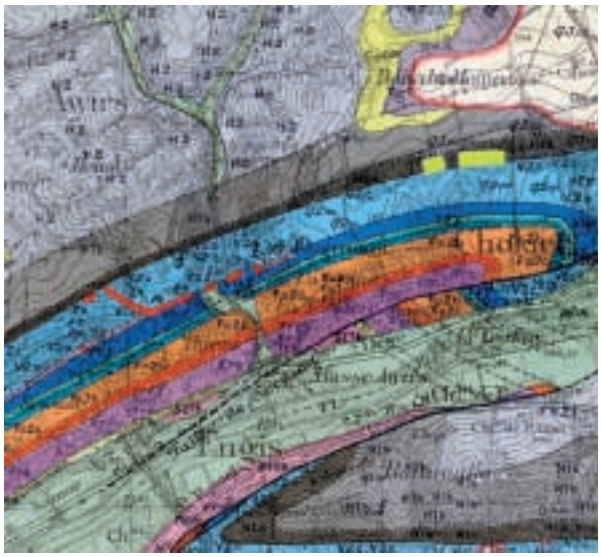

Figure 2. Location of presumed type section near Ferme de Chokier (fluorescent yellow) in outcrop band of Chokier Formation (H_{1a}, dark grey); in red: ore body worked by La Mallieue mine (Engis). Extract of 1:40.000 geological map 133 Jehay-Bodegnée – Saint-Georges (Stainier, 1899). Exposed area ca. 10 km².

5. Description

Purves (1881) provided a description of the beds now assigned to the Chokier Formation, between the overlying Andenne Formation and the underlying Visean limestones. For Purves, the Chokier Formation consisted of shales with some irregular sandstone intercalations and 2-3 thin coal seams[9] in the middle of the unit (Veine du Calvaire and Fort d'Orange in the Namur – Basse-Sambre coal field, Petite Hierchisse, Petite Veine and Grande Hierchisse in the Clavier – Bois-et-Borsu coal fields in the Dinant synclinorium, Coureuses de gazon in the Blaton area north of the Borinage coal field). The Andenne sandstones mark the passage to the Andenne Formation. Renier (1928) redefined the upper boundary to stay closer to the original 'Houiller sans houille' concept of André Dumont, so that only the coal seams in the Dinant synclinorium remain included in the Chokier Formation. These were later assigned to the Bois-et-Borsu member (Paproth *et al.*, 1983).

[8] Earth Heritage Site, Geological Conservation Review N. 317.

[9] Coal seams with thickness in the order of 30-40 cm were exploitable when dips exceeded 30°. The greatest thicknesses in the order of 90 cm were observed in localised zones of merged (Scharung) coal seams (e.g., in the Bois-et-Borsu coal field).

Figure 3. Situation of the ampelite outcrop band at the site described by d'Omalius d'Halloy (1853), indicated on fig. 2. The former trenches left by ampelite mining have evolved naturally to reedponds (redbrown) and wood-lined marshes and ponds in the depression crossing the middle of the photograph. View May 2005 from Flémalle-Haute (northeast) in direction of Château d'Aigremont (southwest).

Two peculiar rock types, finely bedded cherts ('phtanites'[10]) and organic-rich, pyrite-rich fossiliferous shales ('ampelites') characterise the Chokier Formation. The ampelites from the Chokier area were describeded by Van Scherpenzeel Thim (1875), Purves (1881) and Fourmarier (1910): they are rich in fossils (listed by the original authors as *Posidoniella laevis*, *P. minor*, *Lingula mytilloides*, orthoceras, *Nautilus stygialus* and goniatites) but also in carbonaceous, ferruginous carbonate nodules ('bullions') with uncompressed goniatites and other fossils, containing the paraffin wax hatchettite (Lohest, 1883; http://www.mindat.org/min-1826.html) and by frequent cone-in-cone concretionary structures (Dewalque, 1878). One must bear in mind that carbonate nodules are seldom observed in the Chokier Formation, but goniatite bullions from Chokier containing *Homoceras beyrichianum* were popular collectors' items in the 19th century. This ultimately contributed to the international acceptance of this stage name. So was the caseodontoid fish *Campodus (Megalichthys) agassizianus* (L.-G. De Koninck, 1844) conserved at the Cambridge Museum of Comparative Zoology (USA), the British Museum (London) and Ecole des Mines (Paris) – (Lohest, 1884) - (Williams, G. S., 1999. A Listing of Fossil Sharks and Rays of the World. Version 32: http://www.afn.org/~afn02877/eusel.html).
In the concealed western Campine basin, north of the Brabant Massif (Turnhout – Loenhout area), the Chokier Formation corresponds to a Arnsbergian to Alportian sequence, determined by *E. bisulcatus* (E_2c), *I subglobosum - H. diadema - H. beyrichianum* (H_1) and *H.* aff. *eostriolatum - Ht. prereticulatus* (H_2) goniatite bands. This sequence of reduced thickness (3 to 25 m) is formed by ampelites intercalated with phtanites at the base, also known as "hot shales", characterised by high radiation levels as recognised on geophysical well logs (Paproth *et al.*, 1983; Dusar & Langenaeker, 1993; Vandenberghe *et al.*, 2001). These petrophysical properties are probably common for all occurrences of the Chokier Formation, including those south of the Brabant Massif.

6. Historical background

Whereas the lower boundary of the Assise de Chokier, marked by the contact with the Viséan limestones is unequivocal in the type area, the upper boundary has drifted according to different stratigraphic concepts. This is due to the recurrence of rock types considered relevant for the definition of the assise, at different stratigraphic levels. Despite its name, the 'Houiller sans houille' of Dumont (1852) contains some coal seams and rootlet beds, but excluded the Fort d'Orange coal seam group in Namur. Ampelite-type rocks may equally occur as thin intercalations in the overlying Andenne Formation. Purves (1881) included the Andenne sandstone (grit) horizon as the top of his assise but other sandstone beds occur at widely varying stratigraphic positions, even very low within sections dominated by ampelites. Renier (1912) suggested the base of the first exploitable coal seam in the Liège coal field as the contact between the Chokier and Andenne assises.
In any case, Renier (1912, 1927, 1930) did not advocate use of lithological changes for tracing basinwide boundaries. Strict paleontological arguments (last occurrence of *Homoceras*) were then proposed for defining the upper limit of the assise (Renier, 1930), but this was impractical as *H. striolatum* continues well into the overlying Kinderscoutian stage. Finally, the synoptic table with subdivision of the Namurian A, B and C, presented by Renier at the first Carboniferous Congress (1928), and based on correlation of marine faunal bands, was retained as the most

[10] Phtanite is a fine grained, dark-coloured, carbonaceous biosiliceous quartzite, resembling the nodular chert present in underlying limestone beds, but thinly bedded. By alteration of the organic matter, phtanites can turn light grey to white. The phtanites at the base of the Chokier Formation are so rich in sponge spicules that they could be named spongolites, although the lowermost bed may contain concentrations of quartz pebbles. The beds are cemented and largely recrystallised into chalcedony. The beds often display a shaly cleavage but secondary silicification is responsible for the homogeneous chert-like appearance (Anten & Bellière, 1920). Phtanites form the first deposits of the Namurian transgression that slowly drowned the karst landscape created on Visean limestones by the end-Visean sea level fall. Biosiliceous deposits could accumulate in a sheltered, shallow-marine environment fed by land-derived nutrients and silica. Although the term has become obsolete in geological literature, it is still widely used (with less lithofacies constraints) in archaeology.

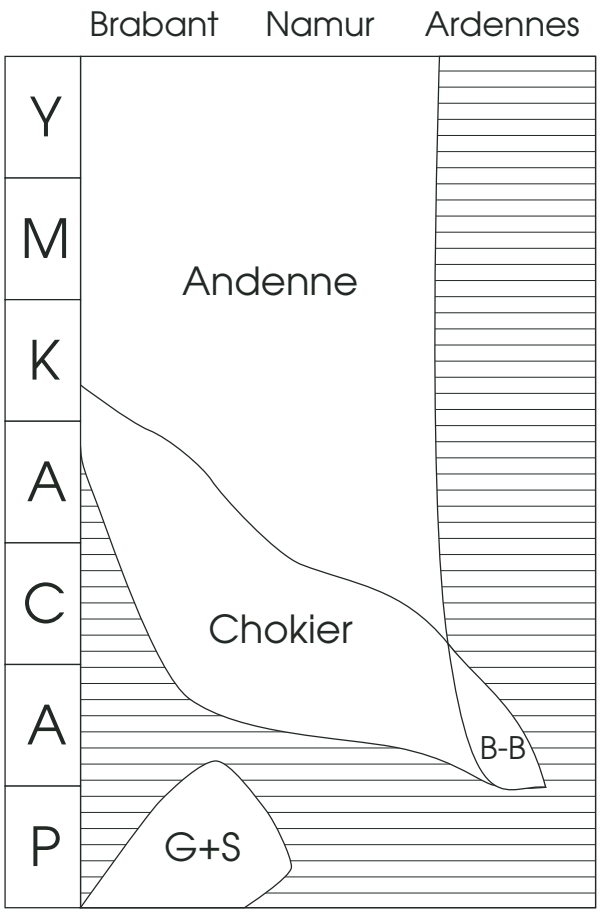

Figure 4. Approximate age position of Andenne and Chokier formations compared to Namurian faunal substage stratigraphy (G: Gottignies Formation, SW of Brabant Massif; S: Souvré Formation, E of Brabant Massif; B-B: Bois-et-Borsu coal-bearing member of Chokier formation in eastern Dinant synclinorium).

practical means of delimiting the Chokier Formation, by using bed-to-bed correlations.

Following British examples, Demanet (1941) introduced a subdivision of the Namurian into biozones. For the assise de Chokier, the upper zone of Spy (Nm_{1c}) corresponded to the *Homoceras* (H) zone. The scheme for the underlying zones of Malonne (Nm_{1b} set as equivalent to the E_2 goniatite zone) and Bioul (Nm_{1a} originally set as equivalent to the E_1 goniatite zone) did not function well, as the identification of the E_1 goniatite zone had proved to be erroneous and was later reset to the E_{2a} (Van Leckwijck, 1964; Bouckaert & Higgins, 1963). The real E_1 zone (and part of the E_2 zone as well) represents a stratigraphic gap in the central sections of the Namur and Dinant Synclinorium. Mixing lithological content and biozonation has moreover resulted in statements about the incompleteness of the Assise de Chokier and a plea to abandon the assise concept (Van Leckwijck, 1957, 1964). The 'missing' lower part of the Assise de Chokier is of varying importance (Bouckaert, 1967); in high subsidence areas where sedimentation could be more continuous, transitional deposits dominated by phtanites are now assigned to the Gottignies and Souvré Formations[11] (Delmer *et al.*, 2002).

As a consequence, the Chokierian faunal substage comprises only part of the time span during which the Chokier Formation had been deposited, which itself has been gradually more restricted to such an extent that the lower part of the Andenne Formation may locally already start within the Chokierian Substage (Fig. 4).

7. Sedimentology and palaeogeography

The Chokierian sediments described here were deposited in the NW European paralic basin, extending from Ireland to Germany (Ziegler, 1990). Namurian sedimentation started in tectonically-controlled fragmented basins until the Chokierian-Alportian time, and then spread over the entire paralic basin as part of the more regularly subsiding Variscan foreland from the Kinderscoutian onwards (Collinson, 1988). As part of the Namurian A (Pendleian to Alportian) sequence, they are mostly marine, with deltaic grits along the edge of the basin in northern England and Ireland, paralic coal-bearing floodplain southeast of the Brabant Massif (from Namur to Aachen), and deep-marine Culm facies southwest of the London-Brabant Massif (Hodson, 1959).

Basinal mudstones or pro-delta organic shales form the bulk sediment in this NW European basin during the Chokierian. They constitute source rocks, if they are not overmature, which is the case in the Belgian basins. Namurian A prodelta shales of the Gainsborough Trough in the Eastern Pennines have sourced oil and gas fields in overlying Namurian and Westphalian sandstone reservoirs (Ward *et al.*, 2003).

The northward progradation of the paralic environment affecting Belgian deposits south of the Brabant Massif was related to the advancing Variscan deformation front. During the Arnsbergian substage, marine deposits with ampelites prevailed, except in the central and eastern Dinant Synclinorium, the Theux tectonic window, the eastern Vesdre synclinorium and the Inde Syncline, where coal seams are intercalated. Marine deposits with ampelites and bullions containing *Isohomoceras subglobosum* and *Homoceras beyrichianum* are characteristic for the Chokierian substage all over the area of deposition,

[11] A tentative explanation for the occurrence of localised depocentres is the dissolution of Middle Devonian to Lower Carboniferous evaporites in the Haine basin (resulting in the Gottignies Formation) and the Visé-Puth basin (Souvré Formation and Geverik Member)- (Bless *et al.*, 1986; Delmer, 1997).

reaching a thickness of approximately 10 m. Nevertheless, the Chokierian substage was a period of relative sea-level lowstand and shrinking of the depositional basin, combined with normal marine-salinity necessary for survival of the marine fauna. Fossil extinctions characteristic for the Mid-Carboniferous Boundary cannot be linked specifically to these lowstands (Hodson, 1959; Holdsworth & Collinson, 1988).

The ampelites are succeeded by prograding paralic deposits with coal seams and rootlet beds (Fort d'Orange and Six Mai coal seam groups in the Namur and Andenne coal basins) with thickness over 25 m, locally also with massive sandstones (Villerot Sandstone). The boundary with the Alportian passes near the base of this unit: goniatite bands with appearance of *Hudsonoceras proteum* alternate with the coal seams. Marine conditions prevailed to the west in the Namur Synclinorium and to the north in the Campine basin. A very widespread marine incursion, known as the Spy crinoidal limestone horizon (H_{2c}), and containing abundant *Homoceratoides prereticulatus*, terminates this sequence and marks the top of the Alportian substage. Depending on the classification principles utilised and the regional depositional environment, all or none of these Alportian deposits can be assigned to the Andenne Formation.

8. Palaeontology

Fossil occurrences are restricted to short-lived favourable facies conditions, reflecting sedimentary-tectonic, often synchronous events. They are not useful for high-resolution interregional correlation based on evolutionary lineages. Recognition of the Chokierian faunal substage is based on the goniatite biozonation established on the British Isles. Hodson (1957) placed the base of the Chokierian 'Stage' at the base of the first faunal band containing *Homoceras* (H_1 Superzone) and the base of the Alportian at the *Homoceras smithi – Hudsonoceras proteum* faunal band (H_2 Superzone). The boundary between Chokierian and Alportian depends on observation and identification of goniatites, and so will always coincide with a marine band. In the Belgian lithostratigraphic type area (Chokier region, between Namur and Liège), this boundary is preceeded by the Chokier – Andenne formation boundary, thus occurring in the Fort d'Orange coal seam bundle, which contains only poor goniatite faunas. The Chokierian – Alportian transition is placed at Bed 52 of the Java Gallery reference section, Andenne coal field, in between the Grande Veine de Marsinne and the Petite Veine de Marsinne (Ancion *et al.*, 1947; Hodson, 1957; Paproth *et al.*, 1983).

A rich and diverse marine macrofauna has been observed in the ampelites and bullions of the Chokierian (brachiopods, pelecypods, goniatites, fish: list in Demanet, 1941; corals were not recorded). The base of the Chokierian faunal substage is marked in Belgium by the H_{1a} *Homoceras subglobosum* goniatite band, whose known occurrences are rather limited. Succeeding H_{1b} *H. subglobosum* with *H. beyrichianum* goniatite bands have been recorded all over the Namur and Campine basins (Paproth *et al.*, 1983).

The overlying sequence with coal seams is much poorer in fauna but richer in macroflora, containing the *Pecopteris aspera* flora with endemic species. This assemblage is not well suited for detailed biostratigraphy or correlation (Van Leckwijck, 1964). Biozonation based on macrofloral assemblages is possible from the Kinderscoutian onward, when the sedimentary basin started to present a more extensive and uniform paralic character. A palynological zonation could not be established because of the high coalification in these strata.

Foraminifers were not recorded from the Chokierian in Belgium. The most important horizon containing different fossil groups useful for biozonation is the Calcaire de Spy, H_2c zone of Alportian age (Conil *et al.*, 1990). Endemic foraminifers with *Asteroarchaediscus* and *Biseriella* were recovered. These are assigned to foraminifer zone Cf8, which also covers the Chokierian (Paproth *et al.*, 1983).

Chokierian conodonts were first recovered from ampelitic shales by Demanet (1941) and from bullions by Higgins & Bouckaert (1968). Published records can be compared to the Pennine basin (UK), although observations are less abundant, resulting in fewer levels and fewer species (Higgins, 1975). Conodont biozonation of the Namurian in Belgium (Higgins & Bouckaert, 1968; Bouckaert & Higgins, 1970; discussed in Paproth *et al.*, 1983) correlated Arnsbergian with Chesterian (Mississippian) and Kinderscoutian with the earliest Pennsylvanian of eastern North America. Impoverished Chokierian and Alportian conodont faunas reflect the Mid-Carboniferous faunal turnover. The Mid-Carboniferous GSSP guide *Declinognathodus noduliferus* was not recorded.

Support for a position of the Mid-Carboniferous Boundary toward the base of the Chokierian is provided by conodonts from Stonehead Beck section in the Pennine Basin (UK, northwestern part of the paralic basin), a proposed auxiliary stratotype for the Mid-Carboniferous Boundary (Riley *et al.*, 1987, 1994). The first occurrence of *Declinognathodus noduliferus* is observed from the $H_{1a}{}^2$ goniatite horizon, about 2 m (11.5 m along outcrop) above the base of the Chokierian and overlying 2.1 m of rather barren deposits from the last occurrence of the precursor fauna consisting of *Gnathodus bilineatus bollandensis* and *G. postbilineatus,* in the top of the Arnsbergian ($E_{2c}{}^4$) - (Varker, 1994).

9. Chronostratigraphy

Within the regional stratigraphic framework established for western Europe, the Chokierian was assigned to the Namurian A (lower part of the Silesian and the then Upper Carboniferous). The introduction of a new twofold

subdivision of the Carboniferous, based on the American-defined Mississippian and Pennsylvanian proposed by the SCCS at the International Carboniferous Congress in Moscow (1975), was ratified by the IUGS following the XIVth International Congress on the Carboniferous and the Permian, held in Calgary (1999). According to the correlations in use at that time (1975), the Chokierian, as part of the Namurian A, became a substage of the Mississippian Sub-epoch and the Serpukhovian ICS Stage. This correlation can still be derived from the ICS stratigraphic scale in use. However, the definition of a Mid-Carboniferous GSSP at Arrow Canyon in Nevada, USA (Lane *et al.*, 1985 and 1999; Richards *et al.*, 2002) has created a relative change for the Chokierian. The GSSP boundary near the first appearance of the conodont *Declinognathodus noduliferus* slightly follows the transition between the *Eumorphoceras* to *Homoceras* ammonoid zones (Titus *et al.*, 1997), hence the boundary between the Arnsbergian and Chokierian faunal substages. As a result, the greater part of the Chokierian and Alportian faunal substages should move from Serpukhovian (Upper Mississippian) to Bashkirian (Lower Pennsylvanian) ICS Stage.

A consequence of this new age assignment is that the lower, Arnsbergian, part of the Chokier Formation, mapped in Belgium, remains Mississippian (Serpukhovian) and the upper, Chokierian possibly also Alportian, parts are already Pennsylvanian (Bashkirian).

In essence, the confusion arising from shifting the Chokierian from Upper Mississippian to Lower Pennsylvanian is caused by the comparison to different radiometric scales, resulting in different ages for the Mid-Carboniferous Boundary with respect to the faunal substages (Fig. 1). The age range 325 to 324.5 Ma as on the 'GTS 2004' (Geological Time Scale) for the Chokierian leaves it in the Serpukhovian; using the 320-319.50 Ma age from the calibrated Ar-Ar sanidine scale (Menning, 2000) moves the Chokierian toward the Bashkirian. The latter scale is considered more reliable than the ICS scale, because of adaptation to normal sedimentation rates. The extremely long time span of the Alportian on the ICS scale (4.5 Ma) is not supported by sedimentary-tectonic evidence, contrary to the greater time lengths for the Pendleian-Arnsbergian on the Menning scale (6.4 Ma).

An important argument in favour of the Serpukhovian Stage (although its boundaries are ill-defined) over the Namurian faunal stages, and reducing these to substage status, is the unequal, sometimes very short time span of these substages, too short in comparison with the average duration of chronostratigraphic stages, which is in the order of 5 Ma. According to Menning *et al.* (2000), the assumed time-span for the Chokierian and Alportian combined takes not more than 1 Ma. This may explain the limited thickness of these units (usually in the order of 10-20 m), compared to the Arnsbergian (up to 250 m for ca 4.5 Ma).

Widespread utilisation of the Serpukhovian, or Bashkirian, instead of the western European faunal substages is hindered by absence of reliable guides, either fossil (conodonts) or radiometric. Hence, continued use of the faunal substages in the regional western European scale is allowed, as long as their relationship with the ICS stratigraphic scale is acknowledged. These regional time scales are not under supervision by the SCCS but fall under responsibility of national or regional stratigraphic commissions (Heckel, 2004).

10. Geochronology

No radiometric dates are available for the Namurian in Belgium. Only interpolations can be made for defining the boundaries of the Chokierian Substage. The preferred time scale makes use of 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

Chokierian deposits occur in the NW European paralic basin, a foreland basin in intracontinental setting north of the Variscan deformation front, extending to the Tornquist Trend in the NE and to the Iapetus Suture in the NW (Ziegler, 1990).

Deposits included in the Chokier Formation occur in all structural units containing Upper Paleozoic strata in Belgium. Deposits assigned to the Chokierian Substage occur only in the Namur-Vesdre and Campine basins, because of erosion in the Dinant synclinorium and Theux tectonic window.

Deepest burial and diagenesis were attained by the end-Westphalian (≈ Moscovian), at the onset of Variscan structural inversion. Variscan deformation resulted in folding south and block faulting north of the Brabant Massif. Strong compression with overturned strata resulted from the Midi Thrust and from gravity tectonics associated with the emplacement of the superficial nappes in the coal basin of southern Belgium (Delmer, 2004).

12. Reference sections in Belgium

The presumed stratotype of the 'Ampelites' of Chokier (d'Omalius d'Halloy, 1853) corresponds to the old underground workings for the mining of alum shale near the Ferme de Chokier, in the old commune of Chokier, now incorporated in the commune of Flémalle (province of Liège), Geological Survey of Belgium file number 133E 368 (mapsheet Saint-Georges 41/8, Lambert coordinates X 225250 Y 143400, 5°26'50°35'45"). Around 1900 these workings were already completely abandoned but still

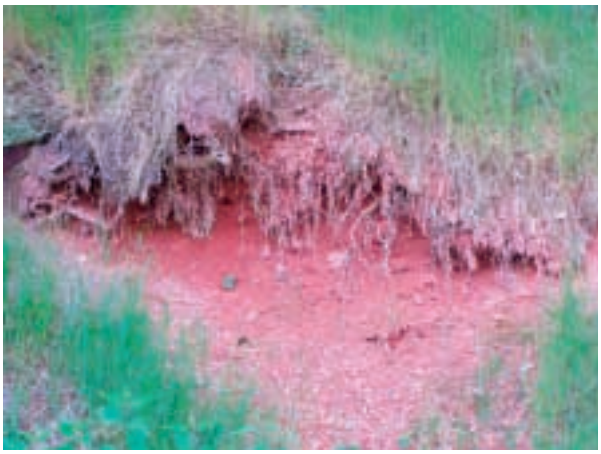

Figure 5. Spoil heaps after calcination of ampelite, lining the trench with former ampelite workings. View May 2005 near road Flémalle – Aigremont.

recognisable by the presence of trenches and mine tailings (Fig. 2). Alum shale workings were located all along the outcrop of massive Visean limestones and provided the only access to the ampelites, whose occurrences were marked by a topographical depression (Fourmarier, 1910). Today, the trenches have become wetlands, surrounded by woods, occurring as a narrow depression between Visean limestones and the coal measures assigned to the Andenne Formation; the tailings with characteristic bright red colour are equally wooded (Fig. 3,5).
Currently, the best exposure is at the entrance of the Carmeuse quarry near Engihoul accross the River Meuse (Gerrienne *et al.*, 1999). The section is well exposed but presents a large hiatus at the Visean – Serpukhovian transition.

13. Main contributions

(after Renier, 1912, 1927, 1930; Van Leckwijck, 1957, 1964)
Dumont (1832): système inférieur dans le basin houiller de Liège, becoming the 'Houiller sans houille' (H_1)- (Dumont, 1852).
d'Omalius d'Halloy (1853): introducing the name Chokier in defining this lithostratigraphic unit as 'Ampélites de Chokier'.
Purves (1881): revising the 'houiller sans houille' as biolithostratigraphic units with clearly defined boundaries and content.
Purves (1883): introducing the name 'assise de Loverval' for the 'houiller sans houille'.
Légende de la carte géologique de la Belgique (1892), in use on the 1:40,000 geological maps of Belgium: H_{1a} as the lowermost subdivision of the coal measures ('Houiller inférieur'), corresponding to the Chokier ampelites or to the Loverval assise.
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 ever continued since.
Renier (1928): presenting a synoptic table for the correlation between the coal basins in Belgium and adjacent territories; Assise de Chokier corresponding to the Namurian A.
Renier (1927, 1928, 1930) and Jongmans (1928): international use of the Namurian as a chronostratigraphic stage.
Bisat (1928) and Hudson (1945): introduction of the *Homoceras* (Sabdenian) faunal stage.
Demanet (1941): introduction of paleontological marker (goniatites) for delimiting the Namurian and subdivision of the Assise de Chokier into biozones, 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): lithostratigraphic use of the Assise de Chokier as proposed by Stainier (1901), with 'typostratigraphic' marine band boundaries proposed by Renier (1927).
Hodson (1957): introduction of the Chokierian and Alportian faunal stages as subdivision of the Sabdenian.
Ramsbottom (1969), George & Wagner (1969): Chokierian stage as an international stage
Paproth *et al.* 1983), Delmer *et al.* (2002): lithostratigraphic use of the Chokier Formation sensu Dumont.
Riley *et al.* (1987, 1994): Mid-Carboniferous Boundary recognised near the base of the Chokierian.
Lane *et al.* (1999), Richards *et al.* (2002): ratification of the Mississippian and Pennsylvanian as Carboniferous subsystems, relegating the Namurian to a Western European regional stage.
Menning *et al.* (2000): time constraints for incorporation of the Chokierian in the base Pennsylvanian.
Heckel (2004): Western European subdivision of the Namurian, including Chokierian, ranked as regional substages.

14. Acknowledgement

Phil Heckel, SCCS chairman, is thanked for his thorough review and great care for proper definition and usage of the chronostratigraphic scale.

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Manuscript received on 27.05.2005 and accepted for publication on 27.09.2005.