

The influence of host-rock composition on the colour alteration of Namurian conodonts from Belgium

S. Helsen

Historische Geologie, Instituut voor Aardwetenschappen, K.U. Leuven, Redingenstraat 16, B-3000 Leuven, Belgium

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Abstract

The thermal alteration of Namurian conodonts of Belgium from existing stratigraphic collections has been examined and reviewed, their colour alteration indices (CAIs) being mapped. Comparisons with CAIs from Dinantian strata and with vitrinite reflectance data not only suggest little hydrocarbon potential for the Namurian in Belgium, but also indicate that the colour alteration of most Namurian conodonts has been influenced by their organic-rich host-sediments. Possible causes for this additional alteration, such as irradiation by natural radioactive decay of authigenic uranium, are discussed.

Introduction

Colour changes of conodont elements are the result of the irreversible thermal alteration of organic compounds within their apatitic biomineralised structure. Based on pyrolysis experiments and comparisons with naturally heated conodonts, Epstein et al. (1977) and Rejebian et al. (1987) coded these colour changes in a conodont Colour Alteration Index (CAI) scale from 1 to 8. During carbonisation processes, the colour of thermally immature conodont elements changes progressively from pale yellow (CAI 1.0) through brown to black (CAI 5.0). The subsequent colour changes towards grey (CAI 6.0), white and crystal clear (CAI 8.0) are the result of oxidation and volatilisation of traces of organic matter and carbon, release of constitutional water, and recrystallisation. Because conodont colour alteration is generally related to depth of burial, the CAI technique has become a tool in the evaluation of organic maturity and in studies on the regional thermal history of sedimentary basins (see Nowlan & Barnes 1987a, and Helsen & Königshof 1994 for an overview).

The Upper Carboniferous in Belgium comprises Namurian and Westphalian molasse-type detrital sediments, deposited in cyclic paralic conditions with few

short-lived marine incursions. Shales, siltstones and sandstones alternate with modest coal seams in the Namurian, and with important measures in the Westphalian. Once covering most of the study area, the present-day main deposits are in the areas north and south of the Caledonian Brabant Massif, and to the east, where both areas meet. In the northerly Campine Basin, Upper Carboniferous strata are not exposed, but at least for the Westphalian well-known from numerous collieries and coal exploration wells in the eastern Campine mining district. South and southeast of the Brabant Massif, Namurian and Westphalian rocks constitute large portions of the Namur Syncline and the Verviers Synclinorium (NE of Liège) where coal seams have been mined for centuries. In the southerly Dinant Synclinorium, only the lower sequences of the Namurian are preserved in a few synclines. Namurian deposits are known to be up to 600 m thick (Van Leckwijck 1964). Maximum composite thicknesses for the Westphalian are in the range of 2500–3000 m (Paproth et al. 1983, Langenaeker & Duser, 1992 a, b). On the strength of thermal alteration data, an accumulation of more than 4000 m of Upper Carboniferous sediments is assumed in the central parts of the Campine, Namur and Dinant basins (Helsen 1995a).

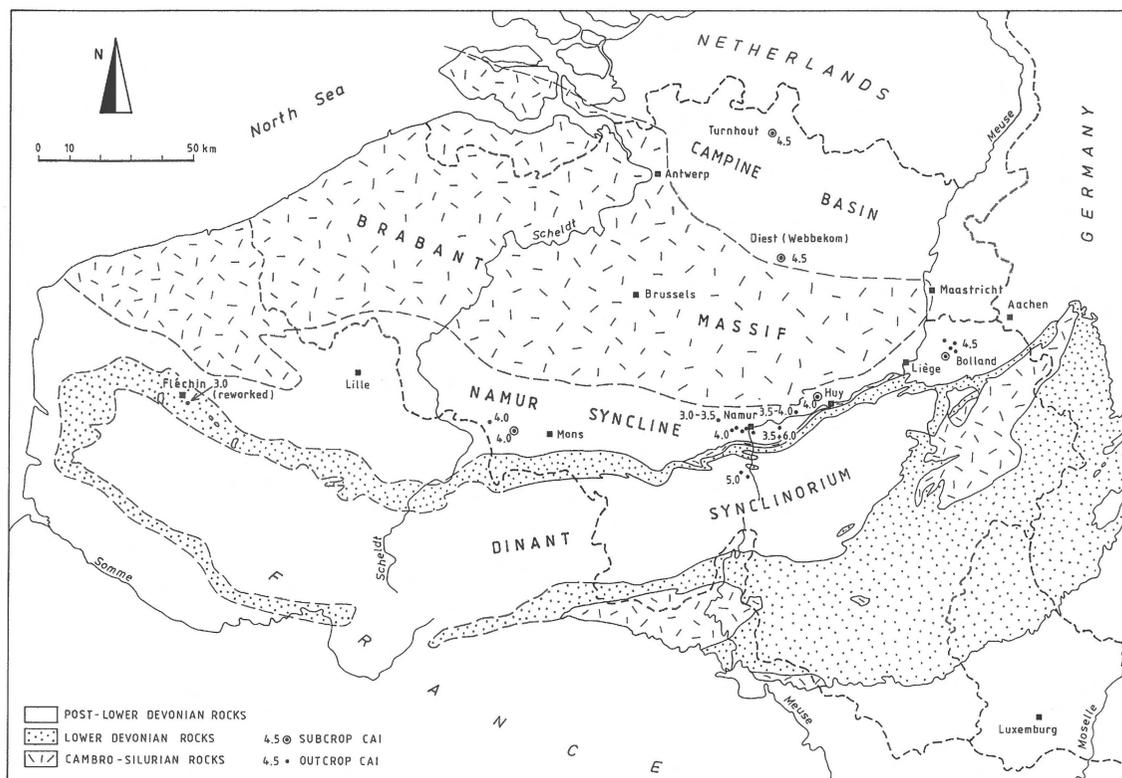


Figure 1. Map showing conodont colour alteration indices (CAIs) for the Upper Carboniferous strata in Belgium, listed in Table 1.

Conodonts from the Namurian in Belgium have been studied by Higgins & Bouckaert (1968), Austin et al. (1974) and Groessens (1983), among others, to enable detailed correlations with palaeogeographically associated areas, such as the Pennines of northern England. Together with other faunal groups, including goniatites, conodonts indicate an important, but geographically variable sedimentary gap at the base of the Belgian Namurian (Bouckaert 1961b, Bouckaert & Higgins 1963). As a result, the Pendleian stage has not been recognised in the area. For some of the carbonate-rich 'transition beds', originally assigned to the latest Viséan (so-called V3c supérieur), conodont faunas suggest early Namurian (Arnsbergian) ages, e.g. at Thon-Samson and Seilles near Namur (Groessens 1983). However, at other localities, similar beds are dated Warnantian (latest Viséan), e.g. at Bioul and Warnant (Higgins & Bouckaert 1968).

Objectives and design of the study

Although the colour alteration of conodonts has been mapped for the Devonian and Lower Carboniferous strata in Belgium (Helsen 1992, Helsen & Königshof 1994) and applied in basin analysis (Helsen 1995b), conodont colour alteration data for Upper Carboniferous strata in Belgium have not been published yet. This is mainly because such data are relatively scarce, as compared with Devonian and Dinantian data. The aim of this study is to discuss the Namurian CAIs, partly reported in the literature, considering other available thermal maturation data. Due to the scarcity of marine facies, hardly any Westphalian conodont data exist.

For this purpose, CAI measurements were newly made in outcrop and subsurface samples from the collections of Higgins & Bouckaert (1968) and Groessens (1983), and from the unpublished conodont material of E. Groessens, incorporating unpublished data of Burnett (1985). Additional field samples were barren of conodonts (Helsen 1995b). Sampled wells are located in the Namur Syncline at Bolland, and in the Campine

Table 1. Studied Upper Carboniferous (mostly Namurian) conodont sample locations, references to location descriptions, CAI, lithology and age. With the exception of Seilles-Tramaka (Groessens 1983) and Thon-Samson (Groessens unpubl.), all samples are from Higgins & Bouckaert (1968). CAIs marked* were determined by Burnett (1985), those without * by the author. The CAI of 6.0 of the Thon-Samson sample is considered as an effect of dolomitisation.

Sample location (reference)	CAI	Lithology	Age
Aubel-Val Dieu, NE of Liège (Bouckaert 1960)	4.5*	dark grey shale	Kinderscoutian
Bioul, Dinant Synclinorium (Bouckaert & Higgins 1963)	5.0*	black shale, bullion ls.	Warnantian/Arnsbergian
Blaton canal, W of Mons (Bouckaert et al. 1961)	4.0*/3.5–4.0	phtanite, calcareous shale	Chokierian
Bolland well, NE of Liège (Graulich 1975)	4.5*	bullion ls., grey-black sh.	Chok./Kinderscoutian
Charneux-Houyeux, NE of Liège (Bouckaert 1960)	4.5*	dark grey bullion ls.	Marsdenian
Charneux-Wadeleux, NE of Liège (Bouckaert 1960)	4.5*	dark grey shale	Kinderscoutian
Diest-Webbekom well, Campine Basin (Delmer 1955)	4.5*	dark grey shale	Marsdenian
Flawinne, W of Namur (Bouckaert & Delmer 1959)	4.0*	brown shale	Kinderscoutian
Flawinne-Ronet, W of Namur (Bouckaert 1961a)	4.0*	bullion limestone	Chokierian
Hautrage colliery, W of Mons (Stainier 1938)	4.0*	dark grey shaly limestone	Kinderscoutian
Jambes, S of Namur (Bouckaert 1959)	4.0*	bluish mudstone	Arnsbergian/Chokierian
Moha colliery, NW of Huy (Bouckaert & Molitor 1962)	4.0*/4.0	dark grey bullion ls.	Westphalian A
Mortroux, E of Liège (Lambrecht 1958)	4.5*	dark grey shale	Marsdenian
Namur-Citadelle (Bouckaert 1961a)	4.0*/4.0	shaly limestone	Alportian
Seilles-Tramaka, NE of Namur (Groessens 1983)	3.5–4.0	crinoidal limestone	Arnsbergian
Spy, NW of Namur (Higgins & Bouckaert 1968)	3.0–3.5	crinoidal limestone	Alportian
Thon-Samson, E of Namur (Schiltz 1987)	3.5 + 6.0	dolomitic limestone	Arnsbergian
Turnhout well, Campine Basin (Delmer 1962)	4.5*	bullion limestone	Marsdenian
Warnant, Dinant Synclinorium (Bouckaert & Higgins 1963)	5.0*	shaly limestone	Warnantian (latest Viséan)

Basin of Turnhout and Diest-Webbekom (Figure 1, Table 1). Outcrop sampling localities are concentrated in the Namur Syncline, viz. northeast of Liège, in the Namur-Huy area and west of Mons. Only a few conodont faunas have been described from the uppermost Viséan-lower Namurian rocks of the Dinant Synclinorium. Detailed information on most of the sampling sites is given in Higgins & Bouckaert (1968) and Groessens (1983). Nearly all samples are from organic-rich host-rocks, such as dark-grey shales, shaly limestones and bullions (calcareous concretions) (Table 1).

Conodont colour alteration indices and comparison with other thermal maturation indicators

Most of the Namurian CAI determinations discussed in this paper and listed in Table 1 are from the unpublished PhD thesis of Burnett (1985). Although CAIs are determined by comparison with CAI standard reference sets, accurate CAI determination is often hindered by heavy deposition of organic matter upon the surface of the conodont elements. Some of the con-

odont elements recovered from dolomitic limestones show the effects of superficial oxidation of their organic compounds, resulting in a grey patina (Table 1).

Generally, the CAIs range between 4.0 and 5.0 (Figure 1), exceeding data from Viséan limestones in the same area by a 0.5 CAI unit (Helsen & Königshof 1994). CAIs from Namurian rocks immediately west of Mons (Hautrage, Blaton) are 4.0, indicating higher palaeotemperatures than the Dinantian CAIs of 3.0 to 4.0, and the vitrinite reflectance data for lowermost Westphalian rocks, which vary between 1.5 and 1.8 % R_{max} (Pillement 1982). In the type area, Namurian CAI values of 4.0 at Flawinne, Namur and Jambes accompany Dinantian CAIs of 3.5 and reflectance data in the Dinantian of up to 2.8 % R_{max} (Teichmüller & Teichmüller 1979). At Moha, northwest of Huy, lower Westphalian conodonts have CAIs of 4.0. Northeast of Liège, outcrop samples from Mortroux, Charneux and Aubel, and subsurface samples from Bolland reveal Namurian CAIs of 4.5. Immediately west of this area, in the Meuse Valley, Viséan CAIs of 4.0 to 4.5 are recorded, while lowermost Westphalian rocks south of Bolland show a southward increase in vitrinite reflectance from 2.1 to 2.5 % R_{max} (Pillement 1982). In the Dinant Synclinorium, at Bioul and Warnant, low-

er Namurian and uppermost Viséan CAIs of 5.0 indicate, again, a higher rank than the Dinantian CAIs of 4.5 and vitrinite reflectance data of $3.6\%R_{max}$ at nearby Salet and Anhée (Teichmüller & Teichmüller 1979). In the Turnhout well, in the central Campine Basin, Namurian CAIs of 4.5 occur together with reflectance data of 2.14 to $2.87\%R_{max}$ (Muechez et al. 1987) and with CAIs of 4.0 to 4.5 in the Viséan strata in the same well.

Some Namurian CAIs are anomalously high, and do not agree with local vitrinite reflectance data, nor with CAIs from Viséan limestones, i.e. in the Diest area where CAI 4.5 at Webbekom is found with 1.05 to $1.20\%R_{max}$ (Muechez et al. 1987) and CAI 3.0 to 3.5 in the upper Viséan at nearby Halen. Moderate CAIs of 3.0 to 4.0 are found in relatively pure crinoidal limestones only, i.e. in the lower Namurian at Spy, Seilles and Thon-Samson near Namur (Table 1). These CAIs are within the same range as the data from nearby Dinantian strata.

Influence of the host-rock composition on CAI

The above data indicate that Namurian conodont colour alteration indices in Belgium are not only related to burial temperature and burial time, but also influenced by the surrounding sediment. Several authors already discussed the influence of the host-rock on CAI, particularly the effect of organic matter. In northern Canada, Mayr et al. (1978) noticed CAI 2.0 in limestones and, in the same area, CAI 3.0 in black shales. Likewise, Austin & Burnett (1994), Belka (1990) and Legall et al. (1981) recorded slightly higher CAIs in shales, as compared to limestones. These differences in CAI are generally less than 0.5 CAI unit and are best observed at low rank (CAI 1.0–2.0). In a contact-metamorphic series adjacent to a granitic intrusion in the Harz Mountains, Germany, Köningshof (1991) noticed an effect of bitumen on CAI in the Frasnian Upper Kellwasser Limestone (Schindler 1990). Whereas the CAI in the pure limestones in the section ranges between 6.5 and 7.0, conodont elements are predominantly black in the Upper Kellwasser Limestone: 78% of the fauna was indexed 5.0 and 22% was indexed 6.0. It thus appears that organic-rich host-rocks, such as bituminous shales or limestones, darken the enclosed conodont elements. In areas with background CAIs smaller than 5.0, this implies a tendency towards higher CAIs; in areas with background CAIs of 5.5 to 8.0,

conodonts from organic-rich host-rocks appear less altered.

Nowlan & Barnes (1987b) suggested that perhaps in reducing conditions hydrocarbons or pyrite are introduced into the laminated conodont elements, producing seemingly higher CAIs in organic-rich sediments. However, in the Namurian of Belgium the darkening of conodont elements may also be related to the irradiation by natural radioactive decay of uranium into radium and radon. Several studies, including Dahl et al. (1988a, b), Leventhal et al. (1986) and Sassen (1984) have discussed the effect of irradiation on organic matter. Apparently, this process lowers H/C ratios by hydrogen loss, resulting in seemingly higher organic maturation. The possible effect of irradiation on palynomorphs from uranium-bearing phosphates was studied by Moczydłowska & Vidal (1992).

In Belgium, radioactivity anomalies, due to high concentrations of authigenic uranium, are especially known from the lower Namurian (Charlet et al. 1977). Probably due to reducing, anoxic depositional conditions in the basin (Steele 1988, Maynard et al. 1991), uranium was fixed in organic-rich muds. These basinal sediments are now preserved as ampelites, i.e. dark-grey to black marine pyritic shales. The enrichment in uranium may be the result of the very low sedimentation rate characteristic for such deposits. The uranium content may also be associated with the occurrence of zircon and other detrital minerals in adjoining fluvial sandstone and conglomerate bodies (Scheere & Van Leckwijck 1962, Klerckx 1966). Furthermore, some of the uranium anomalies in the Belgian Namurian seem to be related to the presence of silicified horizons (e.g. Scheere 1964). In the Carboniferous limestones and shales east of the Brabant Massif, north of Liège, radioactivity anomalies are systematically related to the occurrence of calcium phosphate (Herbosch et al. 1979). 'Hot' shale facies from the paralic Namurian are also known in other parts of the Variscan foreland basin, e.g. in northern England (Steele 1988, Maynard et al. 1991). On geophysical logs, the uranium-rich shales are very distinctive because of the high gamma-ray and low sonic readings (Langenaeker & Dusar 1992b).

Thermal maturity and hydrocarbon potential

As a result of the influence of the host-rock, the assessment of palae temperatures and overburden on the basis of CAIs in the Namurian of Belgium may not be very

reliable. Furthermore, comparison with thermal maturation patterns for older strata is limited. According to vitrinite reflectance data and Viséan CAIs of 3.0 and more in the same areas (Pillement 1982, Helsen & Königshof 1994), palaeotemperatures for the sampled organic-rich Namurian rocks likely exceed 120 °C, indicating only little hydrocarbon potential, i.e. barren or generation of dry gas only (Epstein et al. 1977, Grow et al. 1994, among others). This can be documented by the few, economically unimportant traces of gas in the Campine Basin, produced by Namurian source rocks (Belgian Geological Survey, unpublished data).

Reworked conodont faunas

Near Fléchin in northern France (Delattre et al. 1973: 88), probably Upper Carboniferous conglomerates yield reworked Famennian through Viséan conodont faunas with CAI 3.5 (A. Smolderen, unpubl. report Instituut Aanmoediging Wetenschappelijk Onderzoek in Nijverheid en Landbouw, Brussels 1987). According to the CAI maps of Helsen & Königshof (1994), similar thermal maturation data are recorded from Upper Devonian and Lower Carboniferous limestones towards the east (Namur Syncline), implying a source area nearby.

Conclusions

1. Ranging between 3.5 and 5.0, Namurian conodont colour alteration indices (CAIs) are generally higher than CAIs from Viséan strata.
2. Along with the thermal maturation of organic compounds, the colour alteration of Namurian conodont elements in Belgium may also be influenced by the composition of the host-rock.
3. Capture of hydrocarbons or pyrite in the conodont elements, or, more likely, irradiation effects due to natural radioactive decay of uranium, are possible explanations for this influence.
4. CAIs indicate only little hydrocarbon gas potential for the Namurian source beds in Belgium.

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