Annales de la Société Géologique de Belgique, T. 115 (fascicule 1) - 1992, pp. 135-143 Juin 1992

CONODONT COLOUR ALTERATION MAPS FOR PALEOZOIC STRATA IN BELGIUM, NORTHERN FRANCE AND WESTERNMOST GERMANY - PRELIMINARY RESULTS

by

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(1 table and 6 figures)

ABSTRACT.- Four maps, based on Conodont Colour Alteration Indices (C.A.I.s) have been established for Belgium : one for the Eifelian and the Givetian, one for the Frasnian, another for the Famennian and a last one for the Tournaisian and Visean. Conodonts have not been found in the Cambrian of the Ardennes and as they are scarce in the Ordovician-Lower Devonian of this area, it was impossible to integrate these C.A.I. data into an isograd map. The maps for the Middle Devonian-Lower Carboniferous interval show variations in C.A.I. which can be explained by sedimentary burial and by regional Varistic deformation patterns. In contrast to the Ardennes where in general conodonts are showing C.A.I. values of 3.0-5.0, indices in two adjacent areas, the Eifel Hills (Germany) and the Boulonnais area (France) are ranging between 1.5-2.0.

RESUME.- L'auteur établit quatre cartes montrant les variations d'index d'altération de couleur des conodontes (Conodont Colour Alteration Indices, C.A.I.s) pour la Belgique: une pour l'Eifelien et le Givetien, une pour le Frasnien, une autre pour le Famennien et la dernière pour le Tournaisien et le Viséen. Le Cambrien de l'Ardenne n'a pas fourni des conodontes et ils sont trop rares dans l'intervalle Ordovicien-Dévonien Inférieur pour permettre l'établissement de cartes avec les isogrades C.A.I. Dans l'intervalle Dévonien Moyen-Carbonifère Inférieur les variations de C.A.I. peuvent être expliquées par l'enfouissement sédimentaire et par le modèle régional des déformations varisques. En Ardenne l'index C.A.I. varie généralement entre 3.0 et 5.0; ces valeurs contrastent avec celles reconnues dans deux régions avoisinantes, l'Eifel (Allemagne) et le Boulonnais (France) où l'index C.A.I. varie entre 1.5 et 2.0.

INTRODUCTION

Alteration of aminoacids in conodonts (Pietzner *et al.*, 1968; Savage *et al.*, 1990; among others) is mainly determined by temperature and corresponding exposure time and can be reproduced experimentally by heating (Epstein *et al.*, 1977). The resulting colour changes are represented in a numeric C.A.I. scale which has a range from one to eight (Epstein *et al.*, 1977; Rejebian *et al.*, 1987). For almost thirty years conodonts from Belgium, northern France and westermost Germany (Eifel Hills) have been studied quite intensively for biostratigraphical and biofacies purposes. Yet, C.A.I. data are very scarce and so far they have never been compared or studied systematically. In this study we examined conodonts from collections of the Belgian Geological Survey, the Koninklijk Belgisch Instituut voor Natuurwetenschappen and the Instituut voor Aardwetenschappen of the K.U. Leuven (*see:* Appendix). However, in most areas additional samples were taken to complete the C.A.I. maps. All conodonts are Ordovician through Carboniferous in age and they originate from following structural units: the Campine Basin, the Verviers Synclinorium (including the Theux Window), the Namur Synclinorium,

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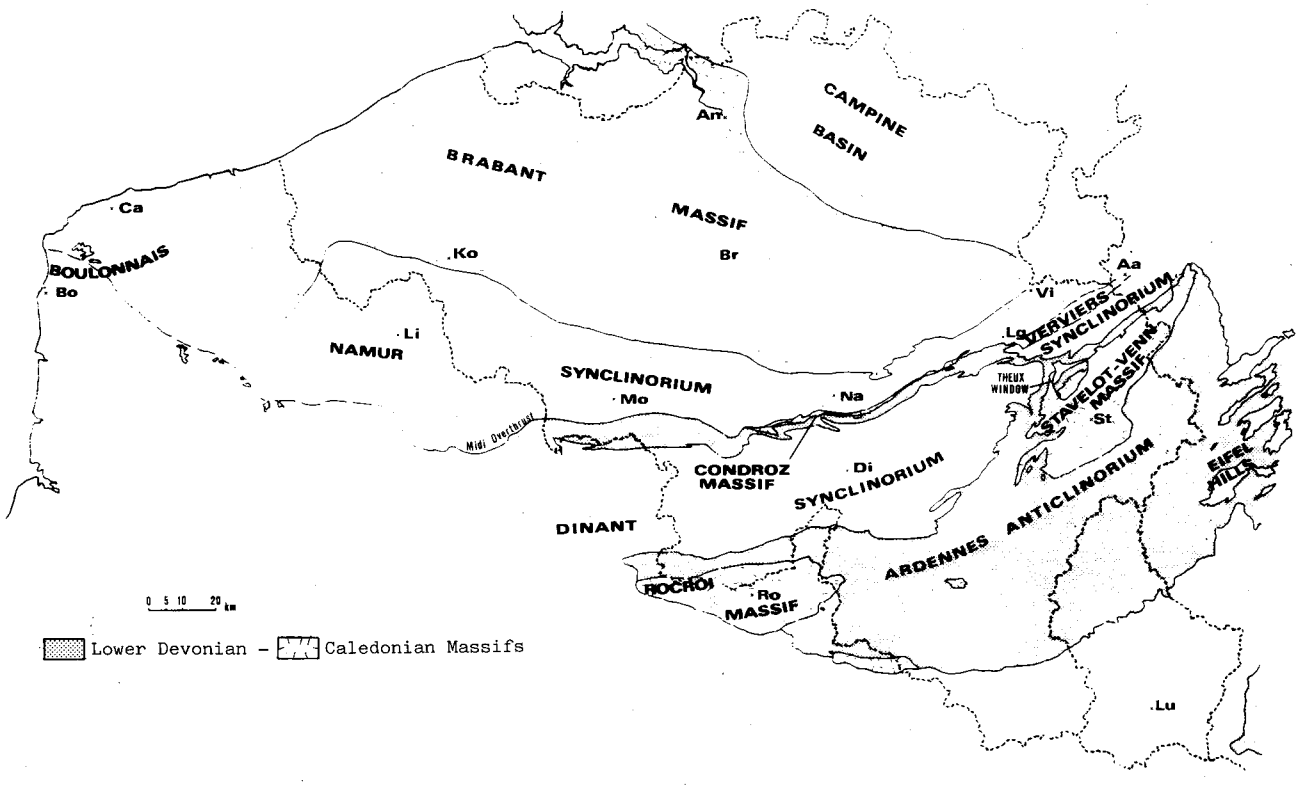

Fig. 1.- Structural units in Belgium and adjacent areas.

Aa: Aachen - An: Antwerp - Bo: Boulogne - Br: Brussels - Ca: Calais - Di: Dinant - Ko: Kortrijk - Lg: Liège - Li: Lille - Lu: Luxembourg - Mo: Mons - Na: Namur - Ro: Rocroi - St: Stavelot - Vi: Visé

the Condroz Massif, the Dinant Synclinorium and the Ardennes Anticlinorium. Furthermore, conodonts were studied from adjacent areas, namely the Eifel Hills, Germany and the Boulonnais area, France (Fig. 1).

Up to July 1991 C.A.I. data from more than 500 localities have been compiled. Most of them represent outcrops in Upper Devonian and Lower Carboniferous rocks (Table 1).

Table I.- Stratigraphical distribution of localities from which conodonts have been examined in the present study (up to July 1991)

Epoch	Stage	Number of localities
Carboniferous	Tournaisian-Visean	173
Devonian	Famennian	110
	Frasnian	136
	Eifelian-Givetian	87
	Emsian	11
Silurian	Pridolian-Lochkovian	4
Ordovician	Caradoc	2

For practical reasons we only examined conodonts from limestones. If possible we studied both small and large specimens to appoint an alteration index because the shape and size of conodonts are important to the determination of C.A.I.s.

C.A.I. VALUES FOR PALEOZOIC STRATA IN BELGIUM AND NORTHERNMOST FRANCE (AVESNOIS, ARDENNES)

C.A.I. VALUES FOR ORDOVICIAN STRATA (Fig. 2)

In the western part of the Condroz Massif, thin limestone beds occur in some Upper Ordovician (Caradoc) formations. Near le Roux we recovered conodonts with a C.A.I. value of 4.0. When we assume the end of the Carboniferous as the time of maximum burial, the C.A.I. 4.0-4.5 interval for those Caradoc rocks corresponds to a burial temperature of 185-240°C (after Epstein *et al.*, 1977). Until now no conodonts have been described from the Belgian Cambrian.

C.A.I. VALUES FOR LOWER DEVONIAN STRATA (Fig.2)

Because limestones are very scarce in the Belgian Lower Devonian as well, there are too few C.A.I. data available to draw any isograds.

In the Ardennes of northern France, conodonts from the Naux limestone of earliest Lochkovian or latest Pridolian age were already described by Bender (1967), Bultynck (1982) and Borremans and Bultynck (1986). Naux is located close to the

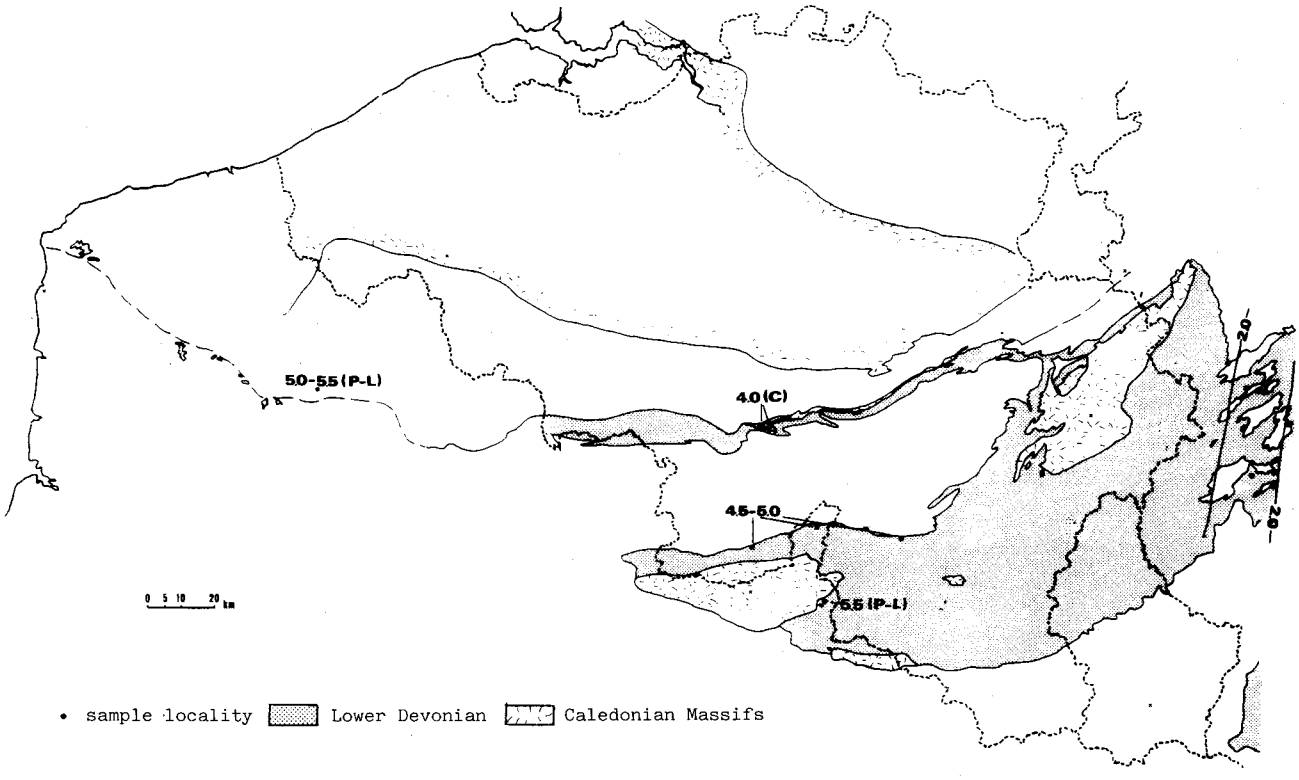

Fig. 2.- C.A.I. values for Ordovician - Lower Devonian strata.
C.A.I.s labeled (C) and (P-L) on the map represent Caradoc and Pridolian-Lochkovian values respectively. If no specification is given, indices refer to Emsian conodonts.

southern border of the Cambrian Rocroi Massif and lies within a regional metamorphic belt that stretches out towards the east. The conodonts show C.A.I.s as high as 5.5 (300-340°C). Most of the specimens have been cracked and deformed or show wildgrowth of minerals such as quartz and apatite upon their surface. At some conodont elements, bars for example, teeth have been recrystallized into prismatic apatite crystals. Naux is the only place in our study area where Devonian conodonts show these metamorphic features. Similar texturally altered specimens from regionally metamorphosed rocks have been studied in detail by Rejebian *et al.* (1987), among others.

The Emsian sequence close to the southern flank of the Dinant Synclinorium is locally characterized by some calcareous horizons. Immediately south of Couvin, conodonts with C.A.I. 5.0 were recovered from the base of the stage. Upper Emsian specimens from Couvin, Halma and nearby Chooz, France have C.A.I.s ranging between 4.5 and 5.0. All these Emsian C.A.I. values conform to burial temperatures of 245-310°C.

C.A.I. ISOGRADS FOR MIDDLE DEVONIAN STRATA (Fig. 3).

Eifelian-Givetian C.A.I.s in the Dinant Synclinorium range between 3.0-4.5, although there are samples that reach the higher maturation level of C.A.I. 5.0. In some areas however, the lack of sample localities necessitated important extrapolations and thus much of the C.A.I. isograds should be compared with those for younger strata.

Towards the centre of the Synclinorium there are no more Middle Devonian rocks outcropping, as younger covering Frasnian through Namurian formations occur. Sampling from Upper Devonian and Lower Carboniferous limestones in this area showed relatively high maturation levels (e.g. values up to C.A.I. 4.5 for Famennian rocks are quite common), which implies raised values for the Middle Devonian strata too. This way, we assume Eifelian-Givetian indices of 5.0 in the central part of the Dinant Synclinorium. Most of the Middle Devonian C.A.I.s however range between 4.0 and 4.5. Only at the northern and western sides of the Caledonian Rocroi and Stavelot-Venn Massifs respectively, values equal or less than 3.5 occur. The C.A.I.s 4.0-4.5 indicate a burial temperature of 190-245°C, while the C.A.I. 4.5-5.0 interval corresponds to 245-310°C. The lower 3.0-3.5 and 3.5-4.0 values point out temperatures of 120-150 and 150-190°C. Closer to the Caledonian London-Brabant Massif, in the Namur Synclinorium Eifelian and Givetian formations are dominantly terrigenous or even absent. Only at Aisemont, Floreffe and Alvaux-Mazy Upper Givetian conodonts have been recovered. They show C.A.I.s

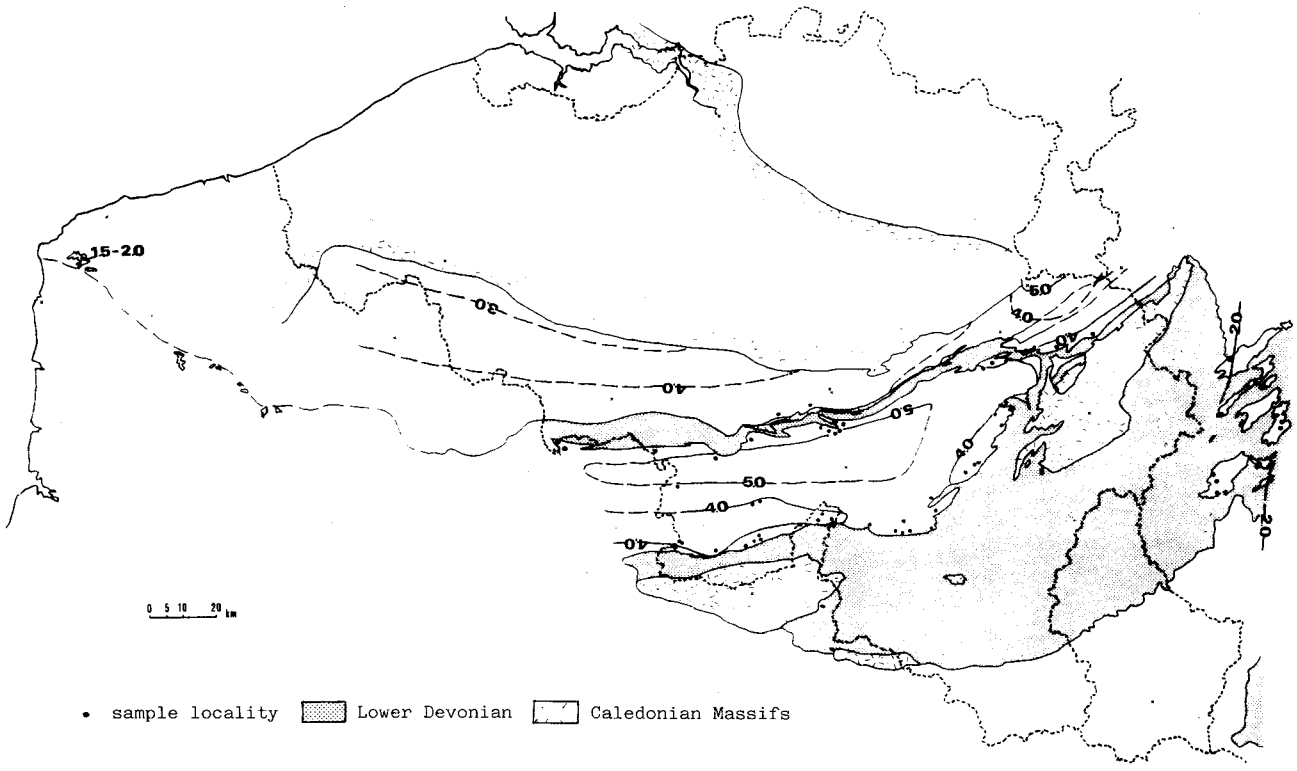

Fig. 3.- C.A.I. isograds for Middle Devonian strata.

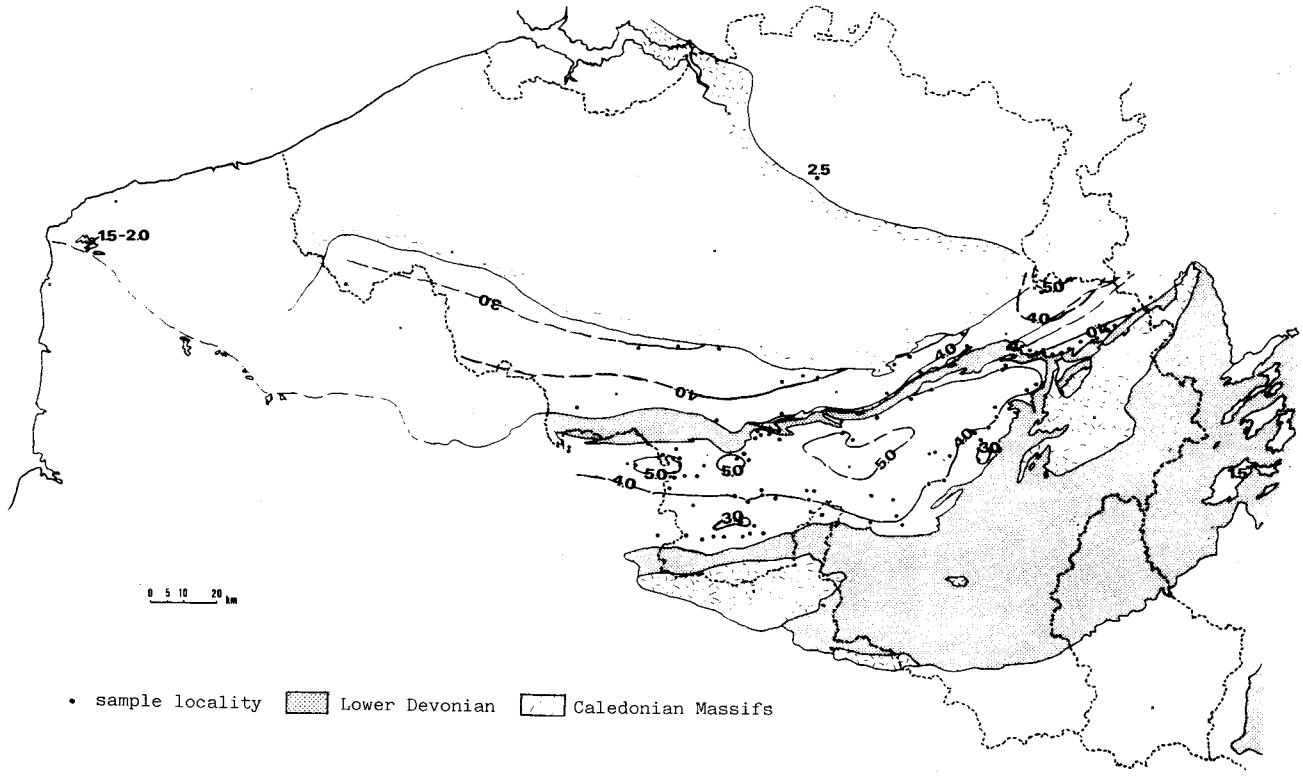

Fig. 4.- C.A.I. isograds for Frasnian strata.

ranging between 4.0 and 4.5 (190-245°C). According to Upper Devonian and Lower Carboniferous data, Middle Devonian C.A.I.s on the northern flank of the Namur Synclinorium are different from those on the inverted southern flank, especially towards the west. E.g. in the Mons area we notice C.A.I. 2.0-3.0 immediately south of the Brabant Massif, whereas 4.0s are common on the southern flank.

Anomalous high values may occur near Visé east of the Brabant Massif, as sampling from Lower Carboniferous limestones in this area showed C.A.I.s of 5.0. The Verviers Synclinorium is characterized by C.A.I. values of 3.5-4.0.

C.A.I. ISOGRADS FOR FRASNIAN STRATA (Fig. 4)

Similar to the Middle Devonian values in the Dinant Synclinorium, most of the Frasnian C.A.I. data range between 3.0 and 5.0. C.A.I. values tend to rise towards the centre of the Synclinorium, as far as Frasnian strata can be sampled in some scattered outcrops. In this central part we recognized values up to C.A.I. 5.0, which correspond to burial temperatures of 245-310°C. With exception of the southern flank, Frasnian C.A.I. 4.0-4.5 values are very common in the Synclinorium. These indices point out temperatures of 190-245°C. Sampling on the southern flank showed C.A.I.s between 3.0 and 4.0 (120-190°C). Only at Ny (in the eastern part) and Mariembourg (towards the west) conodonts with indices of 2.0-2.5 were recovered (55-90°C).

The northern flank of the Namur Synclinorium west of Namur is characterized by relatively low values (C.A.I. 2.5; 55-90°C), in contrast to the southern flank where 4.0s are common (190-245°C).

Higher values, C.A.I. 4.0-4.5, and (according to Lower Carboniferous data) indices up to 5.0, are centred in the Visé area. In the Verviers Synclinorium C.A.I.s of 3.5-4.0 are common.

Frasnian conodonts from the Booischot borehole, north of the Brabant Massif, reach indices of 2.5, which point out temperatures of 55-90°C, assumed maximum burial at the end of the Carboniferous.

C.A.I. ISOGRADS FOR FAMENNIAN STRATA (Fig. 5)

In general, Famennian strata in the central part and on the northern flank of the Dinant Synclinorium show conodont alteration indices between 4.0 and 4.5 (corresponding temperatures 190-245°C), in contrast to the southern flank where C.A.I.s are ranging between 2.0-4.0. This means Famennian C.A.I. isograds too, reflect the same higher maturation pattern towards the centre of the Synclinorium, as mentioned earlier for the Middle Devonian and Frasnian formations. Areas with values lower than C.A.I. 3.0 (120°C or less) lie north of the Rocroi Massif and west of the Stavelot-Venn Massif.

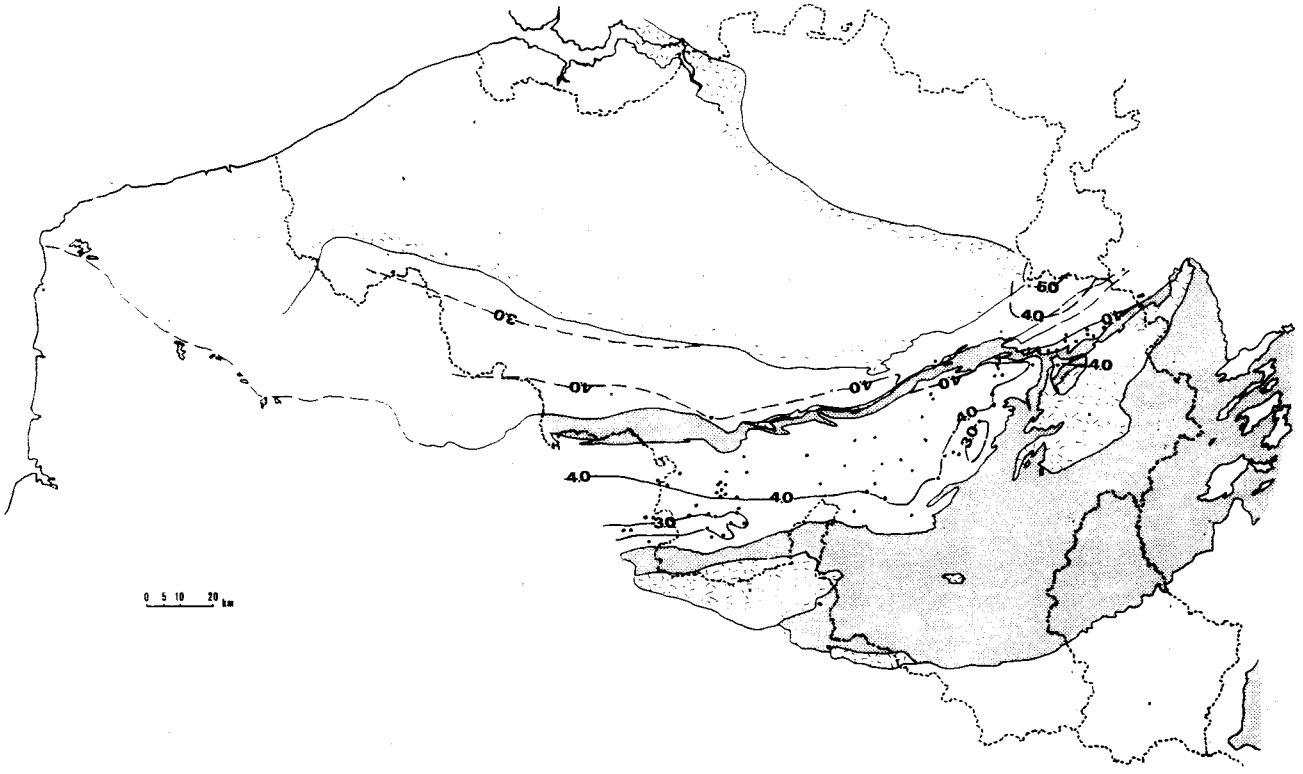

Fig. 5.- C.A.I. isograds for Famennian strata.

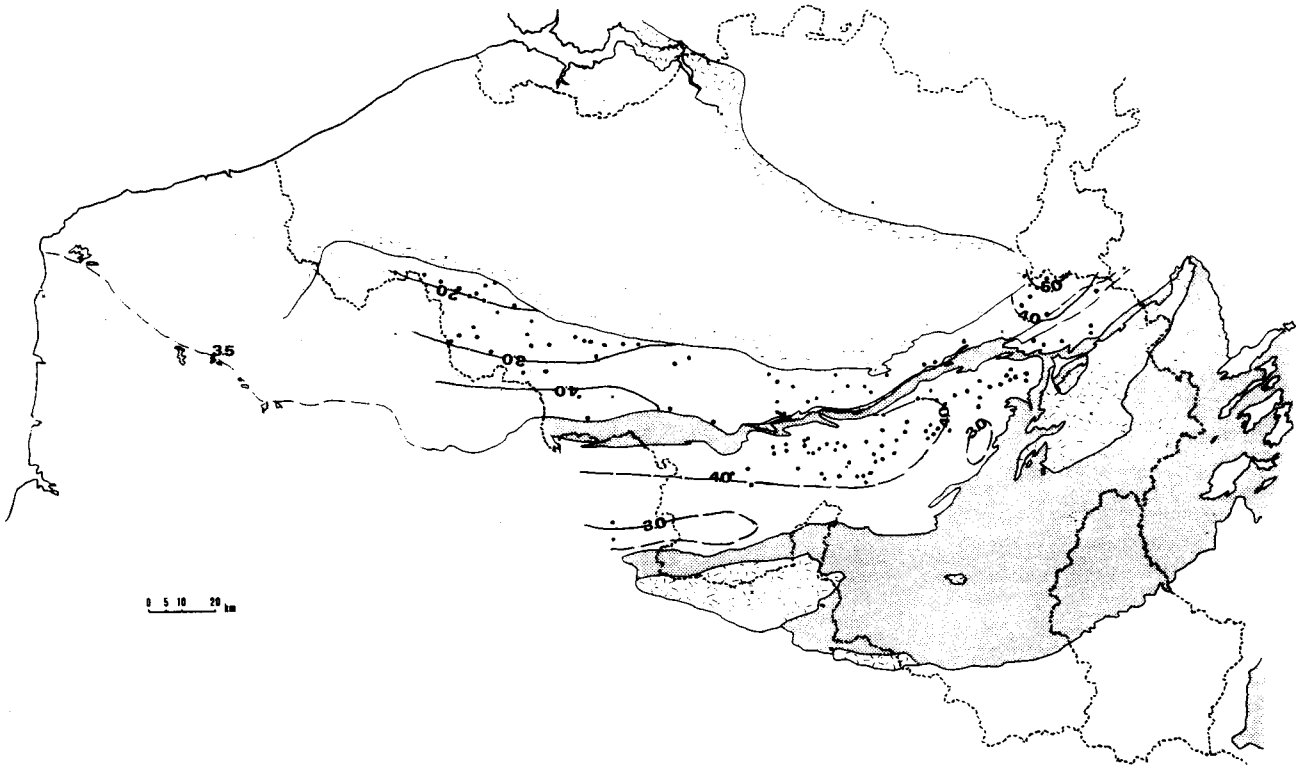

Fig. 6.- C.A.I. isograds for Lower Carboniferous strata.

In the Namur Synclinorium, there is a lack of Famennian limestone outcrops, which obviously results in a scarce C.A.I. record. According to Frasnian and Lower Carboniferous data, we assume relatively low values (C.A.I. 2.0-3.0) close to the Brabant Massif and higher indices on the southern flank (C.A.I. 3.5-4.0). We also expect a high C.A.I. anomaly in the Visé area with values up to C.A.I. 5.0. In the Verviers Synclinorium, including the nearby Theux Window, C.A.I.s vary between 3.0-4.0.

C.A.I. ISOGRADS FOR LOWER CARBONIFEROUS STRATA (Fig. 6)

C.A.I. mapping for Lower Carboniferous stages shows similar patterns as those discussed above for the Middle and Upper Devonian strata.

Values in the Dinant Synclinorium reach 4.0 and 4.5 only in the central part and on the northern flank. These C.A.I.s conform to temperatures of 190-250°C. According to other C.A.I. maps the southern flank may be characterized by indices ranging between 2.0-3.0 and 3.0-4.0 (55-125°C and 125-190°C). Because Tournaisian and Visean formations in this area have been eroded completely, C.A.I. isograds are postulated, and thus should be examined and interpreted carefully. The C.A.I. lows (less than 3.0) occur north and west of the Caledonian Rocroi and Stavelot-Venn Massifs respectivily.

Important differences can be seen in the Namur Synclinorium, where C.A.I.s are ranging between 1.5 and 5.0. The lows occur just south of the Brabant Massif, between the cities of Kortrijk and Mons. C.A.I.s of 1.5 correspond to burial temperatures lower than 50°C. In the Mons area itself higher values are present (C.A.I. 4.0-5.0; 190-315°C).

Near the Netherlands a C.A.I. anomaly in the Visé area shows values up to 5.0 (Int. Rept. Belg. Geol. Surv.). This thermal high has already been outlined previously. In the Verviers Synclinorium, conodonts with C.A.I. 3.0-3.5 were recovered at several localitites.

INTERPRETATION OF THE PRELIMINARY C.A.I. MAPS FOR PALEOZOIC STRATA IN BELGIUM AND NORTHERNMOST FRANCE

A comparison of the C.A.I. maps for the Middle Devonian through Lower Carboniferous stages shows, local variations and stratigraphical differences, related to sedimentary overburden. The former may result from the combination sedimentary burial and Varistic deformation. In the present

paper, only these local variations will be discussed briefly.

In the Namur Synclinorium important differences between the northern and southern flank can be seen. In the western part of the former flank, close to the Caledonian Brabant Massif, Lower Carboniferous indices of 1.5 are common. These C.A.I. lows conform to temperatures of less than 50°C. They can be explained by the small sedimentary overburden and the little tectonism which characterize the area. The inverted southern flank shows higher values (C.A.I. 3.0-4.0; 120-190°C) due to an increasing sedimentary burial and tectonical cover by older strata. In the Visé area, east of the Brabant Massif, we recognized anomalous high C.A.I. values up to 5.0 (310°C) for Visean strata due to high heat flow. They correspond well to the available vitrinite reflectance records (Wolf, 1982; Wolf & Bless, 1987). Until now there is no real evidence for any intrusive activity (Bless *et al.*, 1980; Wolf, 1982).

Ordovician conodonts from the western part of the Condroz Massif show indices of 4.0. The corresponding temperatures (185-240°C) can be explained by a reduced Silurian and Devono-Carboniferous cover on the Condroz ridge (local high). In the Dinant Synclinorium the highest values (C.A.I. 4.5-5.0; 245-310°C) occur in the central part; e.g. north of Dinant Visean conodonts reach indices of 4.0-4.5 (195-250°C). In this area we assume a huge accumulation of Upper Carboniferous sediments (probably more than 4 km), maybe combined with thrust nappes (Varistic fold belt). Because the C.A.I. isograd patterns conform well to the geometry of the Synclinorium, the central part of the latter must have been the depocentre of the basin during Upper Carboniferous times.

Remarkable lower values (less than C.A.I. 3.0; 120°C) occur at the northwestern and western sides of the Caledonian Rocroi and Stavelot-Venn Massifs respectively. They can be explained by a reduced overburden and a short corresponding burial time. On the other hand, at the southeastern sides higher metamorphic grades have been reached; they have been ascribed to dynamo-metamorphism. Late Pridolian-early Lochkovian conodonts from Naux near Rocroi are texturally altered and show C.A.I.s of 5.5 (300-340°C). Close to the Stavelot-Venn Massif mineralogical and geochemical studies from Lochkovian shales even pointed out temperatures of 415°C (Fieremans & Bosmans, 1982). Comparing C.A.I. data, the Dinant and Verviers Synclinoria look very much alike. Indices in Paleozoic rocks in the latter are ranging between 3.0-4.0.

C.A.I. values of 2.5 recorded in Frasnian rocks in the Booischot borehole, Campine Basin, imply burial temperatures of 55-90°C. This conodont alteration conforms very well to the vitrinite reflectance data from the same borehole. Muchez *et al.* (1987) measured values of 0.95-1.43% Rmax on non-oxidized material from Visean limestones. Because the overburden of the present day for the Frasnian strata only reaches some 850 m, we consider that the missing parts of the Lower and Upper Carboniferous have been eroded and that the end of the Carboniferous was the time of maximum burial (with a corresponding burial depth of more than 2000 m).

C.A.I. VALUES FOR THE PALEOZOIC STRATA IN THE EIFEL HILLS, GERMANY (Fig. 2-4)

Just beyond the Belgian border, Lower Devonian rocks are exposed in the Eifel Hills. However, in some synclines (so-called Müldes) Middle and Upper Devonian formations have been spared from erosion. We examined conodonts from Upper Emsian through Frasnian stages. Alteration indices are ranging between 1.5 and 2.0 and differences in C.A.I. values between the stratigraphic units (e.g. Emsian-Frasnian) are rather small. The observed C.A.I.s correspond well to the vitrinite reflectance measurements of Teichmüller and Teichmüller (1979). In the Müldes they noted values of 0.6-1.4% Rmax, or burial temperatures less than 90°C. Furthermore, the Eifel Hills show lower magnetic values as well (Reich, 1935). In fact, the area is located between the positive magnetic anomalies of Ahrweiler and Kelberg in the east and the Our area in the west. Reich (1935) related those higher magnetic anomalies and some higher coalification measurements to the presence of Varistic plutons in the deeper subsurface. The burial depth of the Lower Emsian in the so-called North-South Zone of the Eifel Hills probably never exceeded 1000-1500 m (Teichmüller and Teichmüller, 1952). Indeed, Middle and Upper Devonian strata in this area are reduced to approximately 1000 m (Teichmüller and Teichmüller, 1979), while Carboniferous rocks may not have covered the Eifel Hills completely (Teichmüller and Teichmüller, 1952). The thickness of Triassic Buntsandstein and Muschelkalk formations may not have reached 200 m (after Schröder, 1951).

C.A.I. VALUES FOR THE PALEOZOIC STRATA IN THE BOULONNAIS AREA, FRANCE (Figs. 2-4)

In the Boulonnais, the northwesternmost part of France, both Devonian and Carboniferous formations can be sampled in the vicinity of Marquise. At Griset and Ferques (railway cut) the observed C.A.I. values for the Givetian and Frasnian rocks vary between 1.5 and 2.0. At the

Banc Noir quarry, located between Griset and Ferques, Givetian and Frasnian conodonts show similar values. These C.A.I.s correspond to burial temperatures of less than 55°C. Literature shows that maximum sedimentary burial of Givetian-Frasnian strata in the Boulonnais can be estimated somewhat around 2000 m (Bonte, 1936; Bonte and de Heinzelin, 1966; Bonte *et al.*, 1974; Bouroz, 1962; Brice *et al.*, 1976). Indeed, the horst-like Paleozoic Ferques Massif and its relatively thin post-Devonian cover (mainly shallow marine Jurassic sediments), support the hypotheses of a rather small burial depth (Chamley, 1988).

Between Douai and Béthune, France where Westphalian strata have been overthrusted by Silurian and Lower Devonian rocks, conodonts have been recovered from some boreholes at Beaumont-en-Artois, Liévin and Drocourt (Bultynck, 1977; Bultynck, 1982). The specimens we examined are Upper Silurian (Pridolian) and lowermost Devonian (Lochkovian) in age. They show C.A.I. values of 5.0-5.5, which imply burial temperatures of 300-340°C. We did not recognize any metamorphic features like those observed at conodonts from Naux.

CONCLUSIONS

The preliminary results discussed in the present paper lead to following conclusions.

Middle Devonian through Lower Carboniferous C.A.I.s in the Ardennes Hills are in general moderate to high (C.A.I. 3.0-5.0; 120-310°C).

The highs occur east of the Brabant Massif (Visé anomaly) and in the central part of the Dinant Synclinorium. The values in the latter should be explained by a huge Upper Carboniferous sedimentary overburden and Varistic deformation patterns.

C.A.I. lows (1.5-2.5; 50-90°C) are found in the western part of the Namur Synclinorium, close to the Caledonian Brabant massif, and in the Dinant Synclinorium north and west of the Caledonian Rocroi and Stavelot-Venn Massifs respectively. They probably indicate areas with little overburden and short corresponding burial time.

On the other hand, Upper Silurian-Lower Devonian conodonts which were found immediately south of the Rocroi Massif, show indices of 5.5. (300-340°C) and all kinds of metamorphic features due to dynamo-metamorphism.

C.A.I. values in the Eifel Hills, Germany and the Boulonnais area, France are ranging between 1.5 and 2.0 (burial temperatures lower than 55°C). They represent a reduced sedimentary overburden which probably never exceeded 1500 m.

ACKNOWLEDGMENTS

We are grateful to Prof. Dr. J. Bouckaert and Dr. E. Groessens (Belgian Geological Survey, Brussels) and to Dr. M. Coen-Aubert and Prof. Dr. P. Bultynck (Koninklijk Belgisch Instituut voor Natuurwetenschappen, Brussels) who made it possible to examine their conodont collections.

Many thanks are also due to Prof. Dr. P. Bultynck and V. Langenaeker for their interesting suggestions and the critical reading of the manuscript.

Finally, we want to thank Dr. A. Harris (U.S. Geological Survey) who kindly provided some of her specimens to make a C.A.I. reference set during a three weeks working visit in September 1990 at her laboratories in Reston, Virginia.

APPENDIX

List consulted conodont collections

INSTITUUT VOOR AARDWETENSCHAPPEN, K.U. LEUVEN

Collections G. Borremans, M. Bouharrak, S. Helsen, J. Laenen, A. Meurrens, A. Smolderen, E. Vandelaer, C. Vandormael: Pridolian-Lochkovian, Eifelian through Frasnian

Collections J. Bouckaert: Frasnian, Famennian

Collections R. Dreesen: Famennian

Collections M. Dusar: Frasnian through Visean

Collections E. Houlleberghs: Famennian

Collections E. Vandelaer: Frasnian

Collections M. Vansteenwinkel: Tournaisian

DEPT. OF PALEONTOLOGY, KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN, BRUSSELS

Collections P.Bultynck: Caradoc, Pridolian-Lochkovian, Emsian through Frasnian

Collections M. Coen-Aubert: Frasnian, Famennian

BELGIAN GEOLOGICAL SURVEY, BRUSSELS

Collections E. Groessens: Frasnian through Visean

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