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CONODONT COLOUR ALTERATION IN WAULSORTIAN BUILDUPS OF THE TYPE AREA (LOWER CARBONIFEROUS, BELGIUM)

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(8 figures)

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ABSTRACT. Massive carbonates of Waulsortian buildups in southern Belgium are characterised by anomalously high conodont colour alteration indices (CAI) of 6-7, as compared to the regional CAI of 4-4.5 which are dominant in the adjacent bedded carbonates. The highest CAI are related to shearing, fracturing and localised recrystallisation of the massive carbonates during Variscan deformation. Dolomitisation, present in the massive limestones and the stratified equivalents, is an additional factor in the conodont colour alteration.

KEYWORDS: Waulsortian buildups, conodont colour alteration index, shear zones, dolomitisation.

RESUME. Altération de couleur des conodontes (CAI) dans les bioconstructions waulsortiennes de la region-type (Carbonifère Inférieur, Belgique). Les indices d'altération de couleur des conodontes (CAI) dans les carbonates massifs des bioconstructions waulsortiennes du sud de la Belgique sont beaucoup plus élevés (6-7) que les CAI régionaux (4-4.5), caractérisant les roches stratifiées environnantes. Les CAI les plus élevés sont en rapport avec des zones cisaillées, fracturées et localement recristallisées dans les carbonates massifs durant la déformation varisque. La dolomitisation qui affecte localement les carbonates massifs et les roches stratifiées environnantes, constitue un facteur additionnel influençant le CAI.

MOTS-CLES: bioconstructions waulsortiennes, altération de couleur des conodontes, zones cisaillées, dolomitisation.

1. INTRODUCTION

The colour change of conodont elements is the result of thermal alteration of traces of organic matter dispersed in the lamellated apatite structure. Epstein *et al.* (1977) and Rejebian *et al.* (1987) produced the same colours as those found in nature by pyrolysis experiments and established a linear Colour Alteration Index (CAI) scale with a range from 1 through 8. During carbon-fixing processes the colour of immature conodont elements changes from pale yellow (CAI 1) through brown to black (CAI 5). The subsequent colour changes towards grey (CAI 6), white (CAI 7) and crystal clear (CAI 8) are the result of oxidation and volatilisation of the organic compounds, release of water of crystallisation and recrystallisation of the apatite. Above CAI 8 conodont elements disappear due to desintegration of the apatite matrix. Because conodont colour alteration covers a temperature range of more than 600°C, CAI has become an important palaeothermometer in both sedimentary and metamorphosed rocks, with numerous applications in hydrocarbon prospection and basin analysis (see Nowlan & Barnes, 1986 and Helsen & Königshof, 1994 for an overview).

However, Harris *et al.* (1990), Königshof (1992), Nowlan & Barnes (1987) and Rejebian *et al.* (1987), among others showed that the conodont apatite is frequently corroded and the organic matter oxidised by hydrothermal fluids and dolomitising solutions or other brines. Although the CAI hereby produced are anomalously high as well (CAI 6 through 8), they should not be used to determine temperatures of such altered rocks. In addition, alteration by saline low-temperature solutions often implies oxidation and rapid loss of near-surface organic matter by volatilisation, resulting in a dull lustre and a grey patina on the conodont surfaces (Rejebian *et al.*, 1987). Eventually, high CAI in dolomites may be related to brittle deformation and pressure-solution (Burnett, 1994).

Beside the anomalous colour alteration, conodonts from dolomitic rocks often display a variety of textural features on their surfaces, such as apatite precipitation (e.g. Rejebian *et al.*, 1987; March Benlloch & De Santisteban, 1993). Some aspects of textural alteration of conodonts from selected dolomites of Belgium are described by Helsen (1995). Königshof & Werner (1994) related high CAI and anomalous textural alteration of Devonian conodonts from the Eifel Hills, Germany to bentonite induced geochemical alteration.

2. WAULSORTIAN BUILDUPS AND THEIR LATERAL FACIES

The main geographical distribution of Waulsortian buildups in Belgium is somewhat limited to the southern Dinant Synclinorium, where they are concentrated in an east-west striking area between Furfooz and Walcourt (Lees *et al.*, 1977 and Fig. 1). Conodonts indicate a Late Tournaisian-Early Visean age (*Polygnathus communis carina* through *Gnathodus homopunctatus* Conodont Zones; Lees *et al.*, 1977; Webster & Groessens, 1990). Although some isolated "reefs" are rather small, composite mounds may exceed 1900 m in cross-section and may be 370 m thick (Brodkom, in press). These composite mounds consist of an accumulation of smaller lenticular buildups and their lateral stratified facies. Likely, the growth of the buildups initially started at some 300-400 m depth below sealevel, and continued into the photic zone in Early Visean times (Lees *et al.*, 1985; Lees & Miller, 1985).

In the Waulsortian buildups three facies are generally recognised (Fig. 2). At the base, a crinoidal facies is chiefly composed of packstones and wackestones. The central massive limestone facies (so-called "veines bleues" facies) is comprised by pale grey, partly recrystallised and dolomitised wackestones with abundant fenestrate bryozoans and large solution cavities. The latter are mostly filled with sparry cements of crypto-fibrous calcite. These calcite fabrics, which may be complex and of various shapes, are generally associated with fronds of fenestrate bryozoans (Lees *et al.*, 1977). In the "veines bleues" facies there are indications for depositional dips of at least 20°. Structural mapping of Waulsortian buildups in the Furfooz area nearby by Delcambre & Pingot (1993) showed slopes up to 33°. Towards the top of the buildup, a biomicrite facies with pale grey wackestones is recognised (Lees *et al.*, 1977).

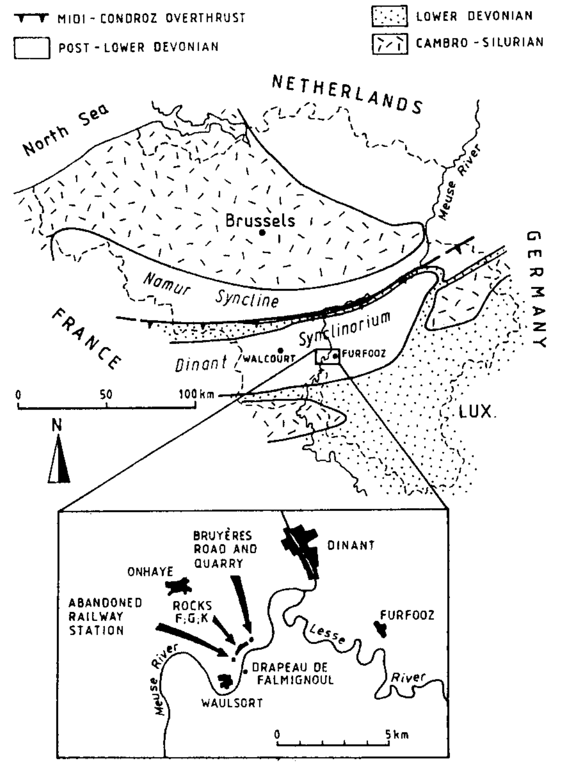

Figure 1. Geological setting of the Waulsort area.

The proximal Bayard, Leffe and Molignée facies include bedded limestones and dolomites (Fig. 2). In the basal Bayard facies, bedded crinoidal and bryozoan wackestones and packstones are common. These limestones are partly dolomitised and locally very cherty. The overlying Leffe facies is characterised by well-bedded, locally cherty, grey wackestones and mudstones, which are frequently dolomitised close to the buildups. In the Leffe facies graded beds, intraclasts, breccias and occasionally slumps are recognised. These structures are considered to be the result of the instability of the mounds. The Molignée facies is the youngest lateral equivalent of the Waulsortian "reef" and is restricted to the Lower Visean (Fig. 2). In this facies dark wackestones and mudstones show an alternation of thin, platy and more massive beds (Lees *et al.*, 1977). In the present paper Waulsortian "buildup" and "reef" are used for the massive core and thus comprise the crinoidal, the "veines bleues" and the biomicrite facies only.

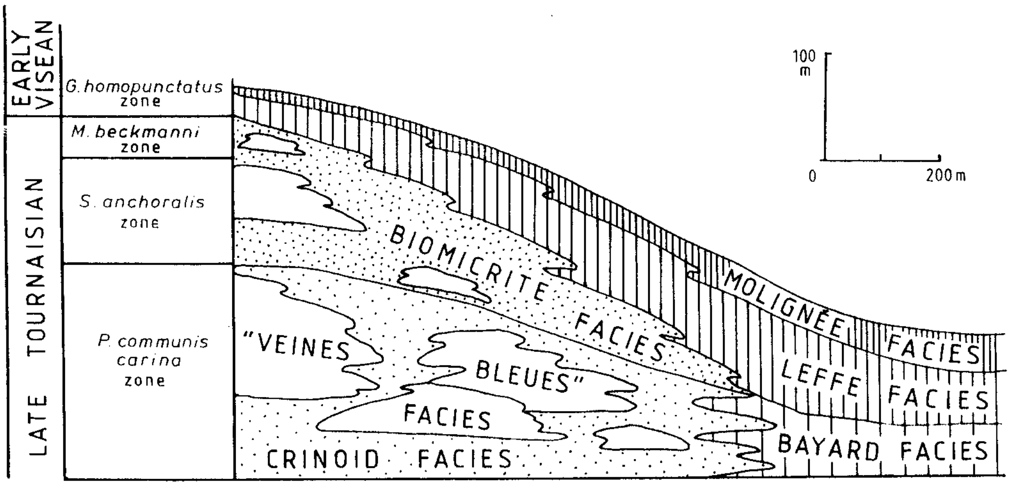

Figure 2. Idealised cross-section of a composite Waulsortian buildup and its proximal facies (after Lees *et al.*, 1977). Conodont zones are according to Webster & Groessens (1990).

3. STUDIED SECTIONS AND CONODONT COLLECTIONS

Conodonts have been examined from several locations along the Meuse River near Waulsort, Belgium (Fig. 1). The area is part of the Dinant Synclinorium and characterised by a series of folds and thrust faults, resulting from Variscan deformation. The studied outcrops include the section north of the old railway station, the adjacent rocks of Al'Rue, labeled F, G, K, plus the Bruyères Road and Quarry further north (for further details, see Dehantschutter, 1990 and Dehantschutter & Lees, in prep.). Dupont (1969) described the section at the abandoned railway station and adjacent rocks as the Pauquis section. In addition, the Bruyères Road and Quarry were labeled "Sommet des Pauquis".

The Pauquis section lies in a broad shallow syncline, and comprises three superimposed Waulsortian buildups in nearly subhorizontal position, which are alternated with bedded, cherty limestones of the Bayard facies (Fig. 3). A steeply dipping anticline separates the Pauquis section from the Bruyères Road and Quarry. Along the Bruyères road only one massive carbonate body is exposed. It is bordered at the base by the stratified Bayard facies and overlain by the Leffe facies, grading upwards into the Molignée facies. Dehantschutter & Lees (in prep.) consider the buildup at Bruyères as an equivalent of the youngest buildup at Pauquis.

For practical reasons CAI is determined on conodonts from collections of Dehantschutter (1990). However, some of the CAI were compared with data from remaining rock samples of the same beds. The collections of Dehantschutter (1990) are deposited in the Geology Department of the Université Catholique de Louvain.

4. CAI DISTRIBUTION

The studied sections at Waulsort show a relationship between the CAI and the type of carbonate rock (Figs 4-8). CAI of 6-7 are chiefly recorded in the massive carbonates, *i.e.* dolomites and partly recrystallised limestones. Similar CAI in Waulsortian buildups are reported by Plainchamp (1993) from the Drapeau de Falmignoul, Belgium (Fig. 1). In the samples with mixed CAI of 4-4.5 and 6-6.5, collected towards the top of the buildups, CAI 4-4.5 is determined on the more robust specimens.

On the other hand, regional CAI of 4-4.5 (see Helsen & Königshof, 1994) are most common in the thin-bedded, non-recrystallised carbonates of the proximal Bayard, Leffe and Molignée facies. However, in the stratified dolomitic beds, occasionally higher values of 6 and 6.5-7 are observed as well. These specimens generally have grey patinas due to rapid oxidation and volatilisation of near-surface organic compounds. In the bedded limestones only the more fragile, *i.e.* tiny and sometimes deformed conodonts have anomalously high CAI. Deformation of conodonts is observed in the bedded limestones at the base of the Bruyères Road section (Fig. 4), in the massive, dolomitised limestones at the base of Rock F (Fig. 6) and in the stratified dolomites of Rock G (Fig. 7).

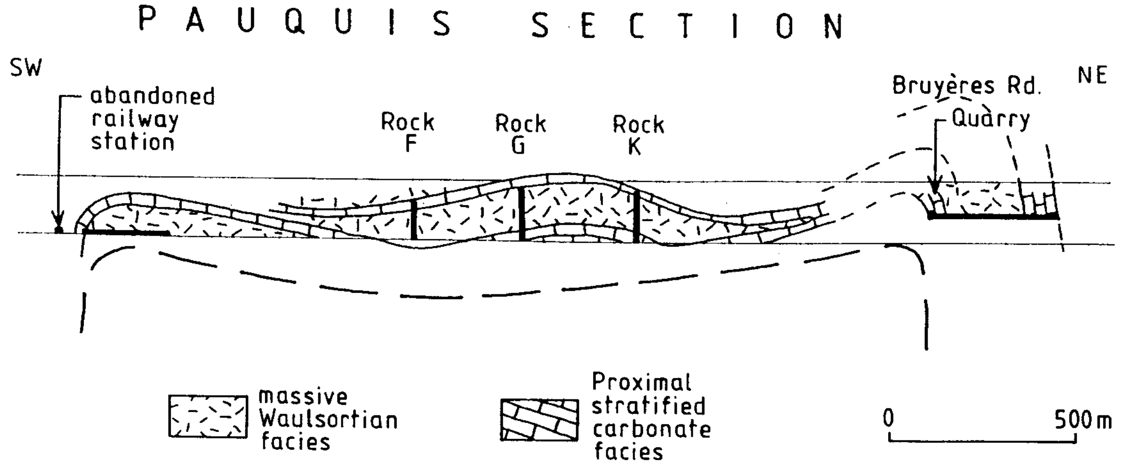

Figure 3. Schematic SW-NE cross-section, showing the location of the studied outcrops (after Dehantschutter & Lees, in prep.).

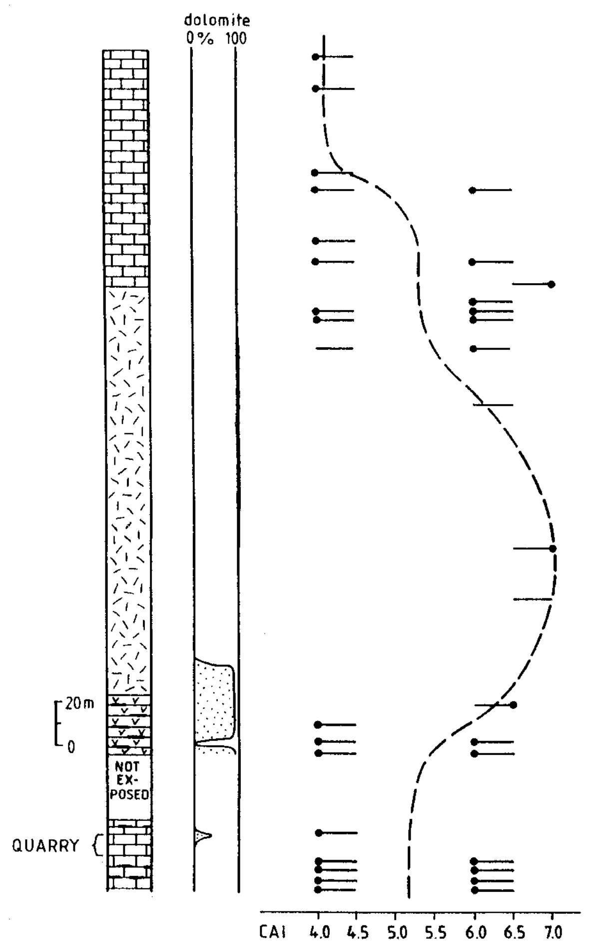

Figure 4. CAI distribution in the Bruyères Road section and the Bruyères Quarry (log and dolomite content after Dehantschutter, 1990). Horizontal lines represent CAI ranges within samples, dots indicate dominant CAI. The CAI curve (interrupted line) is somewhat generalised.

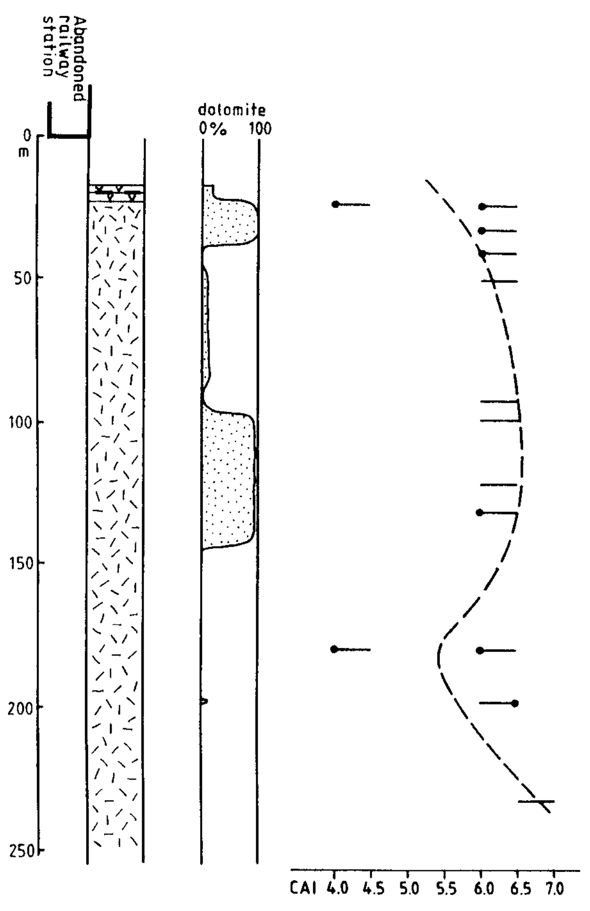

Figure 5. CAI distribution in the section near the abandoned Waulsort railway station (lithology and dolomite content after Dehantschutter, 1990). Horizontal lines represent CAI ranges within samples, dots indicate dominant CAI. The CAI curve (interrupted line) is somewhat generalised.

Some of the conodonts with CAI 6 show a brownish hue, which is probably caused by traces of non-oxidised organic matter in the apatite skeleton. The more reddish staining, observed on some of the conodonts from Rock K, is likely the result of haematite deposition. Burnett (1988, p. 92) suggested that much of the red-yellow staining of conodonts from a contact aureole in northern England and with CAI 7 is internal and thus rather the result of pervasion by metamorphosing fluids and/or enhanced porosity.

5. DISCUSSION

5.1. CAI AS A RESULT OF STRAIN

Because the lithological heterogeneity in an area is determining for the mechanical behaviour to tectonic stress, lenticular, massive "reefs" in composite Waulsortian buildups act as rigid bodies in an envelope of more stratified carbonate rocks. Consequently, the massive bodies deform by flattening and fracturation,

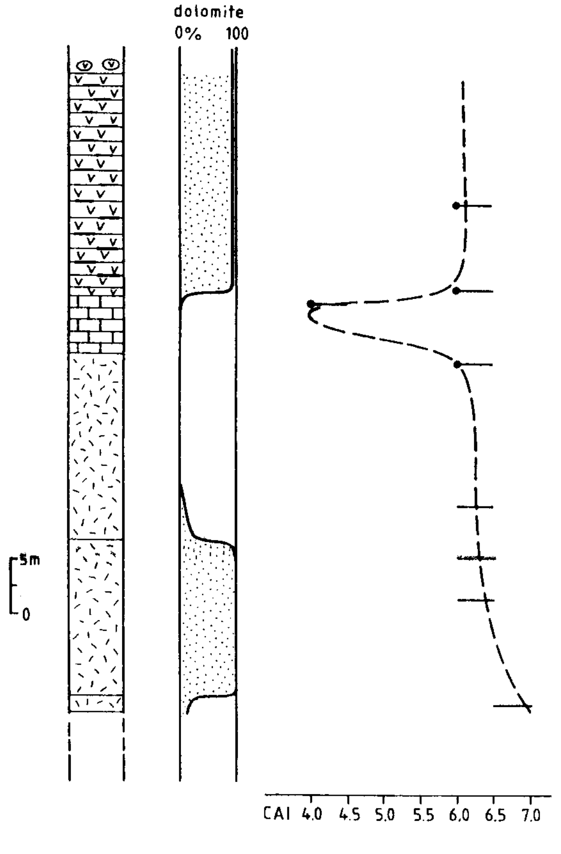

Figure 6. CAI distribution in Rock F (log and dolomite content after Dehantschutter, 1990). Horizontal lines represent CAI ranges within samples, dots indicate dominant CAI. The CAI curve (interrupted line) is somewhat generalised.

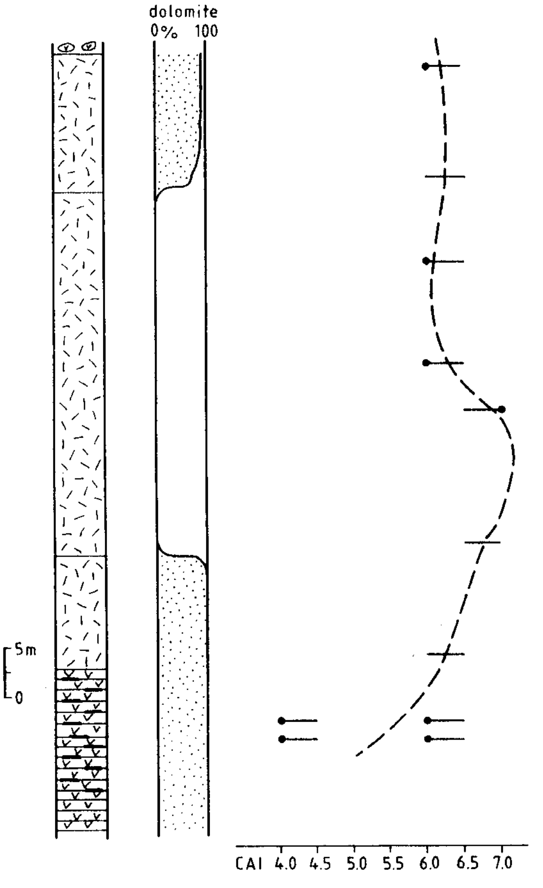

Figure 7. CAI distribution in Rock G (log and dolomite content after Dehantschutter, 1990). Horizontal lines represent CAI ranges within samples, dots indicate dominant CAI. The CAI curve (interrupted line) is somewhat generalised.

whereas adjacent bedded strata rather deform by folding and kinking (Brodkom, 1991). At present, major faults have not been mapped in the buildups at Waulsort. However, considering the adjacent fault zones of Onhaye and Waulsort (Delcambre & Pingot, 1993), their presence is not excluded. As a response to tectonic stress and due to the diversity in composition and texture of the carbonate rocks considered, shear zones and zones of diagenetic recrystallisation developed in the buildups. In the Waulsortian "reefs" of the Furfooz area shear zones were studied by Brodkom (in press). Internal deformation of massive limestones is chiefly observed close to the dolomitised parts, e.g. near the abandoned railway station (Dehantschutter, 1990; Dehantschutter & Lees, in prep.). Similar deformation zones adjacent to dolomites were reported by Lees & Hennebert (1982) from the Waulsortian buildup of Cannington Park, England. Mylonitisation in massive carbonates was recognised by De Roo *et al.* (1992) in a Devonian "reef complex" of the Warstein area, Germany.

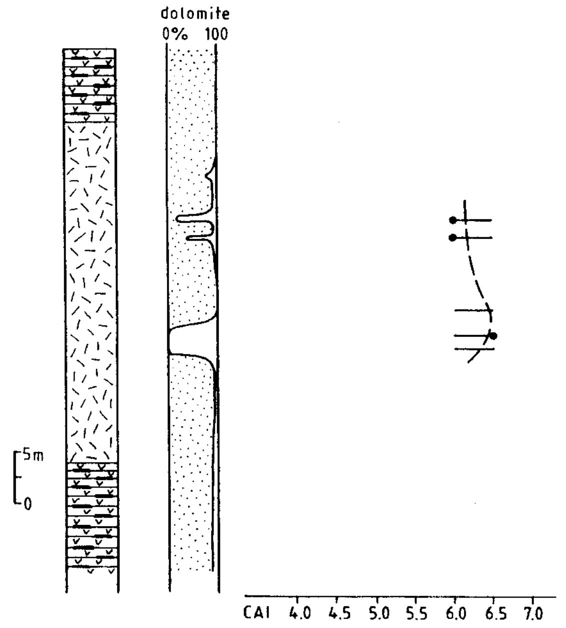

Figure 8. CAI distribution in Rock K (log and dolomite content after Dehantschutter, 1990). Horizontal lines represent CAI ranges within samples, dots indicate dominant CAI. The CAI curve (interrupted line) is somewhat generalised.

Due to brittle deformation conodonts from the massive carbonates got probably cracked, opening up their apatitic fabric to oxidation of enclosed traces of organic matter by migrating fluids. As a result, anomalously high CAI of 6-7 were produced. These high CAI are more common among fragile (tiny or deformed) conodont elements, as compared to the robust specimens in the same samples. However, deformation of conodonts is not unique to the massive carbonates as bended elements are recovered from stratified carbonates of the Bruyères Road and Rock G as well.

Stewart (1981) and Washington & McCarthney (1982) were among the first to record an increasing CAI with increasing strain in structurally deformed areas. Observed at outcrop or smaller scale, this increase in CAI is only of local importance and should not be mapped regionally. In SW-England most of the high CAI are related to intense shearing and pressure-solution. Near Launceston limbs of close isoclinal folds yield conodonts with CAI 5, whereas in the fold noses, typified by abundant solution planes and carbonate recrystallisation, CAI is 6 (Burnett *et al.*, 1994). At Cannington Park CAI of 6-7 are recorded in the dolomite-rich units of Waulsortian rocks. These values are considered to be the result of the brittle deformation of dolomite, or of pressure-solution, or of variable dolomite contents, or of a combination of these factors (Burnett, 1994). Likewise, in Southern Ireland, where strains have been fairly high, Waulsortian buildups bear conodonts with CAI 6-7 (G. Sevastopulo, pers comm., 1994). Other examples of anomalously high CAI in partly recrystallised buildups are from the Devonian of Montagne Noire, France (see Flajs & Hussner, 1993) and the Brooks Range, Alaska (A.G. Harris, pers. comm., 1994). In the Devonian "reefs" of southern Belgium only regional CAI are observed (Helsen & Königshof, 1994).

Because of the different deformation style of bedded rocks, fracturation and diagenetic alteration of the stratified limestones of the proximal Bayard, Leffe and Molignée facies, is less pronounced. Conodonts from these rocks are better preserved, *i.e.* less cracked, and thus showing regional CAI of 4-4.5.

5.2. CAI AS A RESULT OF DOLOMITISATION

In the bedded dolomites and dolomitic limestones from the Bayard, Leffe and Molignée facies dolomitisation likely altered the conodont colour. Grey patinas on some of the conodont surfaces and occasionally CAI of 6-6.5, mixed with regional CAI of 4-4.5, indicate a rapid oxidation of near-surface organic matter by dolomitising solutions (Rejebian *et al.*, 1987). In the buildups, dolomitisation masks the conodont colour alteration, produced by deformation and recrystallisation of the massive rock.

6. CONCLUSIONS

a) Differences in CAI, recognised between the massive, non-dolomitised Waulsortian limestones (CAI 6-7) and the proximal bedded equivalents (CAI 4-4.5), are related to the different deformation style of these two lithologies.

b) Dolomitisation in the bedded facies may have raised CAI up to 6-6.5.

c) In the dolomitised massive limestones, high CAI may result from deformation of the rock, or from dolomitisation, or from a combination of the above two factors.

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