Conodont Colour and Thermal Maturation in the Lower Carboniferous of North Wales

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Abstract: Conodont colour alteration index (CAI) values have been obtained for 20 localities in the Carboniferous of North Wales. In the area between the Dinorwic and Bala faults values range from 1 to 2 and can be accounted for by burial under an overburden of later Carboniferous and younger strata. Anomalously high values of 2.5 to 3 are recorded in eastern Anglesey, which is to the north of the Dinorwic Fault, and possibly to the south of the Bala Fault, near Llangollen. These enhanced values cannot be the result of burial, but the possible presence of a concealed granite beneath northwest Anglesey provides a partial explanation.

Very little has been published on the Carboniferous conodonts of North Wales. The first report was a listing of species from the Carboniferous Limestone succession of the outcrop between Prestatyn (NGR SJ 074 821) and Dyserth (SJ 063 790) in Clwyd by Aldridge *et al.* (1968). Subsequently, Reynolds (1970) described and illustrated specimens recovered from a borehole core drilled by the Institute of Geological Sciences (now the British Geological Survey) in the nearby Pentre Quarry, Gronant, Clwyd (SJ 0950 8279), and Austin and Aldridge (1973) listed and figured elements from a knoll limestone at Graig Fawr, Meliden, Clwyd (SJ 062 806). A single specimen of *Cavusgnathus* sp. was reported by Somerville *et al.* (1989) from the Foel Formation of Pentre-bach Quarry, Dyserth, Clwyd (SJ 061 782). All of these records come from a very restricted geographical area, and conodont elements have not been reported from any of the other extensive exposures of Carboniferous Limestone in North Wales.

Conodont elements are the microscopic remains of the feeding apparatuses of extinct eel-like chordates (Aldridge *et al.*, 1986). They are formed of layers of crystalline calcium phosphate, with interlamellar traces of organic material. If unweathered and thermally unaltered, conodont elements are pale yellow to light amber in colour, but heating causes them to darken through carbonisation of the organic matter. Epstein *et al.* (1977) demonstrated by field investigations and laboratory experiments that conodont element colour is largely dependent on the degree and duration of the heating to which the specimens have been subjected, and that it is possible to use colour variation as a semi-quantitative index of the thermal history of the host strata. From the results of their experiments, they introduced a Colour Alteration Index (CAI), with values related to particular temperature ranges. The unaltered, pale amber conodont elements are designated CAI 1, and with increasing temperature they turn dark amber (CAI 2), brown (CAI 3-4), then black (CAI 4-5). Where heating has persisted for a considerable time, as would be expected geologically, these changes correspond to a temperature range from less than 50°C to more than 300°C. CAI mapping is now widely employed as a tool in the elucidation of the thermal history of sedimentary basins, in the estimation of eroded overburdens and in the regional location of hydrocarbon reservoirs.

As part of a co-ordinated study of conodont colour in British Carboniferous strata, reconnaissance sampling has been undertaken in all the major outcrop belts in North Wales. This material has been supplemented by small undescribed collections housed at the Universities of Leicester and Southampton. Although the data base is now vastly improved, the investigation is still at a preliminary stage in this area, and many gaps remain to be filled. Values of the Conodont Alteration Index (CAI) of Epstein *et al.* (1977) assessed for the productive localities in the Carboniferous of North Wales are shown on figure 1. Samples collected to date from the Little Orme, Llandudno, Gwynedd (SH 814 823), from near Llysfaen, Clwyd (SH 893 766), and from the cliffs at Creigiau Eglwyseg, Llangollen, Clwyd (SJ 220 445), have failed to yield conodont specimens.

In recent years the stratigraphy of the Dinantian of North Wales has undergone considerable revision (Somerville and Strank, 1984a, b; Warren *et al.*, 1984; Somerville *et al.*, 1986; Davies *et al.*, 1989; Somerville *et al.*, 1989). Strata previously regarded as restricted to the Asbian and Brigantian stages (George *et al.*, 1976) are now recognised to span at least to the Chadian in some areas, and it has been suggested that the Basement Beds of the succession in the Prestatyn district may possibly be as old as latest Courceyan (Somerville *et al.*, 1986). The marine inundantion of North Wales apparently commenced in the Chadian, with peritidal and shallow marine limestones deposited from Prestatyn to south of Mold (Somerville *et al.*, 1989; Davies *et al.*, 1989). This initial transgressive pulse was followed by a larger Arundian transgression, which drowned a wide area of North Wales delimited by the Dinorwic fault in the north-east and the Bala fault in the south-east. Between these faults limestones accumulated in an area of subsidence termed the "Mold Gulf" by Somerville and Strank (1984a), with the surrounding platforms of Anglesey and the Llangollen area not being inundated until the Absian.

Material

Locality details are given in the appendix. The Prestatyn-Dyserth area remains the only intensively sampled Dinantian outcrop in North Wales, although reasonable numbers of conodont elements have been recovered from samples from Anglesey, from the Great Orme, Llandudno, and from Halkyn Mountain, north of Mold. In general, yields from North Wales samples have been low, and the other CAI values plotted in figure 1 are based on relatively small collections. These would clearly benefit from corroboration by additional samples.

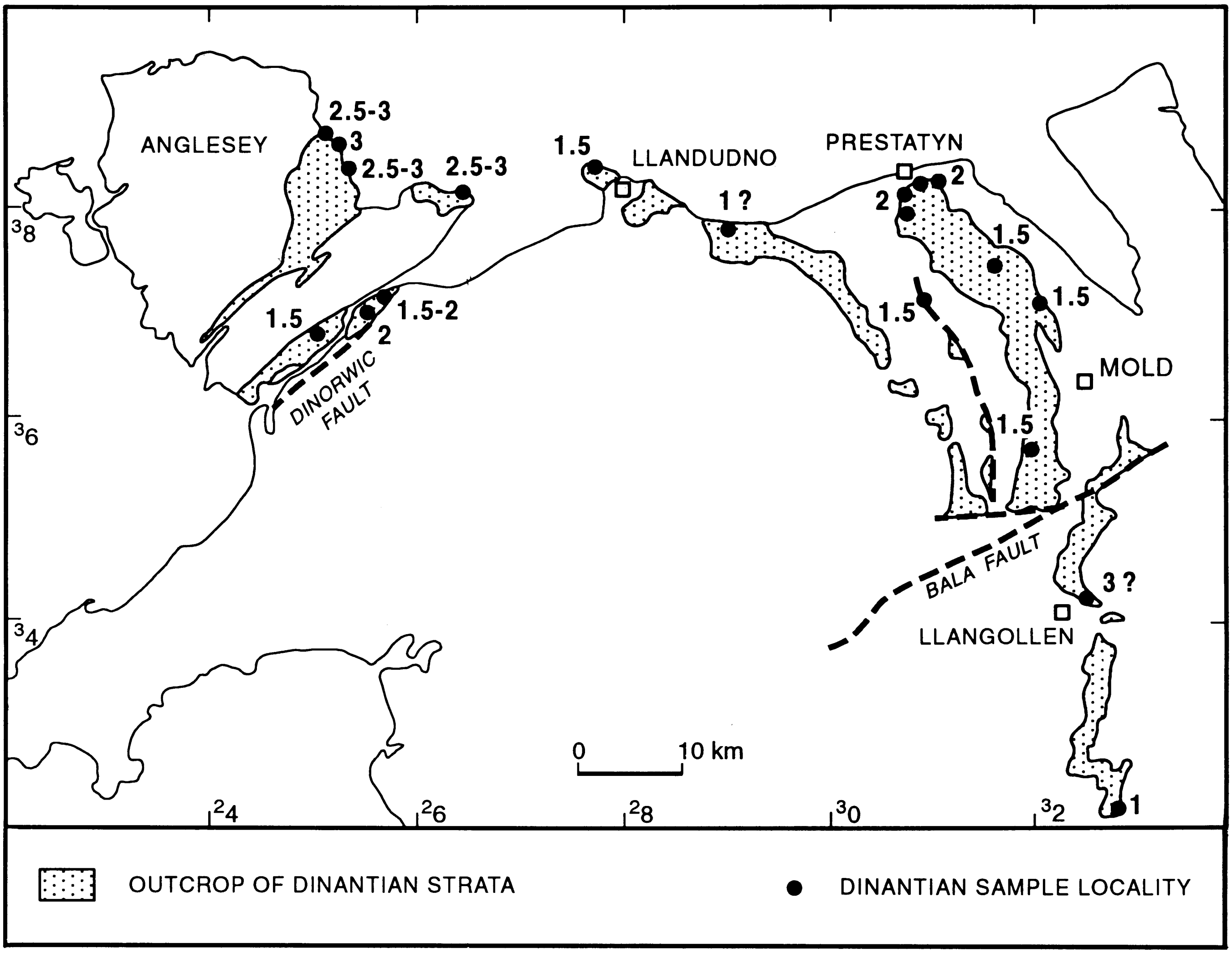

Fig. 1. Dinantian outcrops and conodont CAI values in North Wales. CAI values were, wherever possible, determined on elements of the genus *Gnathodus*, and measured between the basal cavity and the margin of the unit. In most cases, the value recorded is based on several specimens from each sample.

CAI Values

The conodont colour values in the Mold Gulf are universally low, ranging from 1 to 2. The lowest figure, from a single sample near the north coast at Old Colwyn (SH 890 783), is based on one fragmentary element only and must be regarded as equivocal. Otherwise, all samples gave a value of 1.5 or 2; this is equivalent to a temperature range of 50-140°C (Epstein *et al.*, 1977). To the north of the Dinorwic Fault, values range from 1.5 to 3 (50-200°C), with samples from the east coast of Anglesey providing a consistent indication of relatively high thermal maturation with figures in the range of 2.5 to 3. A sample from near Llangollen, south of the Bala Fault, provided a tentative value of 3 (110-200°C)., but this is based on fragmentary, delicate elements only and further collecting in this region is necessary to confirm this apparently high thermal maturation. Further south, at Llanymynech Hill, Powys (SJ 265 217), fragments recovered from thick-bedded dolomites showed a CAI of 1.

Discussion

The CAI values obtained from strata in the Mold Gulf are low enough to be attributable simply to burial under the known overburden. The higher values to the north of the Dinorwic Fault and at Llangollen are, however, anomalous and require an explanation other than burial heating. One possibility is that they relate to local heating during an episode of mineralization, but there is no independent evidence of this. Indeed, mineralization, of the Carboniferous Limestone in North Wales appears to have been concentrated in the Mold Gulf. Hydrocarbon minerals are recorded in association with the metallic ores in this area and their known distribution was reviewed by Parnell (1983). He noted that lead-zinc mineralization is particularly extensively developed around Halkyn Mountain, near Mold, where the CAI is only 1.5. Lead-zinc mining near Prestatyn has also produced associated hydrocarbon minerals, probably derived from the bituminous Carboniferous Limestone, but again CAI values in the area are not markedly elevated. The Great Orme, where samples collected to date give a CAI value of 1.5, is also the site of copper mineralization.

A similar, apparently anomalous, distribution of CAI values in late Viséan rocks of northern England was reported by Burnett (1987), who found palaeothermal highs over the Askrigg and Alton blocks and lower values in the surrounding trough sediments. He attributed the high values on the blocks to the channelling of mantle-derived heat through the Wensleydale and Weardale granite plutons that underlie them. A similar explanation for high CAI values in the Carboniferous strata of the Isle of Man has been forwarded by Swift (1993). On Anglesey, the late Precambrian Coedana granite crops out within ten kilometres of the exposures of Carboniferous Limestone on the east coast. Although originally thought to be intrusive (Callaway, 1902; Greenly, 1919), the granite is now regarded as a fault-bounded slice within the tectonic collage of the Mona Complex (Gibbons, 1984), and does not represent a more extensive submerged pluton. This interpretation is supported by the pattern of gravity anomalies, which show only a minor gravity low associated with the granite. A concealed granite body would be indicated by an area of low gravity on a Bouguer anomaly map, but the area of high CAI values in SE Anglesey is characterized by anomalously high gravity readings (Powell, 1956; Griffiths and Gibb, 1965; Reedman *et al.*, 1984). In contrast, a low gravity anomaly does occur to the south of the Dinorwic Fault, along the Padarn ridge, and this has been ascribed to an underground extension of the Twt Hill Granite of Caernarvon (Powell, 1956; Cornwell and Dabek, 1982), although Reedman *et al.* (1984) favoured an explanation involving a thick development of tuffs of the lower Cambrian Arfon Group. Low gravity is also recorded in the northwest of Anglesey, and this anomaly has, indeed, been recently interpreted as an indication of a buried granitic pluton beneath Holyhead Bay (Cornwell and Smith, 1993). Although this postulated pluton does not directly underlie the Carboniferous strata with raised CAI values, it may be close enough to account for the enhanced heatflow they record. The age of any granite is uncertain, but Cornwell and Smith (1993) favoured either a Precambrian/Cambrian or Caledonian age. If this is the case, then the colour of the Carboniferous conodonts cannot have been produced by direct heating from the intrusive pluton, but would be the result of mantle-derived heat channelled to the surface through the granite body.

The possible high CAI value at Llangollen does not coincide with a gravity low. An elongated anomaly is recognized just to the east of the Carboniferous Limestone outcrop, but this has been accounted for by a local thickening of the Namurian Cefn-y-Fedw Sandstone Group (Cornwell, 1987). The anomaly has a steep western margin, and it is apparent that the sandstones thinned rapidly towards the west and an enhanced thickness cannot be used in overburden calculations for the Llangollen limestones. Somerville (pers. comm. 1989) suggests that the thermal effects at Llangollen may relate to movement along a splay of the Llangollen Fault System which runs along the foot of the Eglwyseg Rocks. This explanation may be tested by a much more detailed examination of thermal maturation patterns in the area than has been attempted to date. At present, though, the high CAI values in Llangollen remain unexplained.

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Appendix: Sample localities, horizons and CAI values for North Wales

Localities are listed geographically from north-west to south-east.

1. South side of Lligwy Bay, Anglesey, SH 500 871. Carboniferous Limestone, Asbian. CAI 2.5-3.
2. Moelfre, Anglesey, SH 513 864. Carboniferous Limestone, Asbian/Brigantian. CAI 3 (sample collected and evaluated by Dr R. L. Austin).
3. Benllech, Anglesey, SH 525 824. Carboniferous Limestone, Brigantian. CAI 2.5-3 (sample collected and evaluated by Dr R. L. Austin).
4. Near Penmon, north coast of promontory at east tip of Anglesey, SH 637 815. Carboniferous Limestone, Brigantian. CAI 2.5-3.
5. Old quarry, near Bryn-Siencyn, Anglesey, SH 492 678. Carboniferous Limestone, ?Brigantian. CAI 1.5, but specimens somewhat leached and red-stained.
6. Roadside south of Britannia Bridge, Gwynedd, SH 544 707. Carboniferous Limestone, Brigantian. CAI 2.
7. West of Bangor, Gwynedd, SH 565 718. Carboniferous Limestone, ?Brigantian. CAI 1.5-2 (sample collected and evaluated by Dr R. L. Austin).
8. Great Ormes Head, Llandudno, Gwynedd, SH 767 833. Carboniferous Limestone, Brigantian. CAI 1.5.
9. Roadside near Old Colwyn, Clwyd, SH 890 783. Carboniferous Limestone, Arundian. CAI 1? (one fragment only).
10. Old quarry above Prestatyn, Clwyd, SJ 072 822. Carboniferous Limestone (Prestatyn Limestone Formation), Asbian. CAI 2.
11. Old quarry near Meliden, Clwyd, SJ 066 806. Carboniferous Limestone (Moel Hiraddug Limestone Formation), Arundian. CAI 2.
12. Graig Fawr, Meliden, Clwyd, SJ 062 806. Reef knoll in Carboniferous Limestone, Asbian. CAI 2.
13. Upper Dyserth Quarry, Dyserth, Clwyd, SJ 063 790. Carboniferous Limestone (Dyserth Quarry Limestone Formation), Arundian. CAI 2.
14. Gronant Borehole, Clwyd, SJ 0950 8274. Carboniferous Limestone, depth 345ft. to 467ft. Asbian and Brigantian. CAI 2.
15. Roadside quarry, near Pant-y Wacco, Clwyd, SJ 135 761. Carboniferous Limestone, Asbian. CAI 1.5.
16. Quarry east of Bodfari, Clwyd, SJ 095 704. Carboniferous Limestone, heavily sheared and veined, ?Asbian. CAI 1.5.
17. Old quarry on Halkyn Mountain, Clwyd, SJ 197 710. Carboniferous Limestone, Brigantian. CAI 1.5.
18. Old quarry north of Llanarmon-yn-Ial, Clwyd, SJ 190 573. Carboniferous Limestone (Llanarmon Limestone), Arundian. CAI 1.5 (one fragment only).
19. Old quarry at Trevor Uchaf, near Llangollen, Clwyd, SJ 243 425. Carboniferous Limestone, Asbian. CAI 3? (delicate fragments only).
20. Old quarry on Llanymynech Hill, Powys, SJ 265 217. Carboniferous Limestone, Asbian. CAI 1 (fragmentary specimens only).

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