Conodont Colour Alteration pattern in the Carboniferous of the Craven Basin and adjacent areas, northern England

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SUMMARY: Conodont Colour Alteration Indices (CAI) values in the Craven area show a general range of 2.5–3.5, the majority being a value of 3. The higher values generally occur in the south and south-west and low values are found on the Ashnott High (Ashnott Anticline and eastern closure of the Whitewell Anticline) and in Waulsortian limestones. These values are consistent with the limited vitrinite reflectance data and are a result of the Carboniferous sedimentary and tectonic history of the region. There is no evidence of significant modification by subsequent burial, igneous events, reheating or mineralization. Low values of CAI 2–2.5 on the Ashnott High are interpreted to be due to the thinner sedimentary cover in that area and possible insulation derived from underlying Waulsortian limestones. Relatively high values of CAI 4 for Dinantian strata in the Holme Chapel Borehole and 3.5 in the Silesian sediments to the south of the Craven Basin probably reflect a thicker Westphalian cover than further north.

Conodonts, an extinct group of Palaeozoic–Triassic elongate marine chordates (e.g. Sweet & Donoghue 2001), were soft-bodied animals, except for small phosphatic tooth-like elements that formed the feeding apparatus. The hard phosphatic elements of conodonts are generally found scattered in marine sedimentary rocks of Cambrian to Triassic age and have immense biostratigraphical utility. Preservation of soft body parts is rare and the first unequivocal soft bodied conodont was only described in 1983 (Briggs et al. 1983). The phosphatic elements of conodonts contain some organic material, and when the elements are heated in the subsurface, they progressively and irreversibly change colour with increased temperature and time (Fig. 1, Table 1). In addition, as conodonts are heated, or subject to metamorphism, their microstructure is altered texturally, and at very high temperatures and pressures, the conodont elements may be recrystallized, or become pitted, distorted and eventually destroyed. Studies of conodont colour and textural alteration have led to the establishment of a scale of Conodont Colour Alteration Indices (CAIs) and textural alteration types (Epstein et al. 1977; Rejebian et al. 1987). The progressive change in conodont colour has been used extensively in the petroleum industry as an index of thermal maturation, but has also been used to indicate temperatures of mineralization (Rejebian et al. 1987; Jones 1992). Conodont colour and levels and type of textural alteration can also be used in regional basin history and tectonic studies (e.g. Metcalfe 2003). We here present CAI data for the Carboniferous of the Craven Basin that has implications for sedimentary burial histories, basin evolution, hydrocarbon exploration and mineralization. The study area includes the Craven Basin of Hudson (1933), equivalent to the Bowland Basin of Ramsbottom (1974), and adjacent Silesian outcrops to the south.

CAI values reported in this study come from published biostratigraphical collections (Austin 1968; Higgins 1975; Metcalfe 1980, 1981; Metcalfe & Leeder 1979; Riley et al. 1987; Turner et al. 1979) and unpublished material held at the British Geological Survey, the University of New England, Armidale, Australia and Trinity College Dublin (see Appendix for listing and grid localities). The emphasis on Dinantian (Mississippian) CAI values is a consequence of the nature of these collections. Before discussing the CAI values in the region, a general outline is given of the Carboniferous successions, particularly that of the Dinantian, and its subsequent burial history.

1. POST DEVONIAN TECTONICS AND SEDIMENTATION

The principal anticlines that expose Dinantian rocks in the Craven Basin and the principal basement structures that
affected Carboniferous deposition are shown in Figure 2. The Craven Basin is a Dinantian depositional and structural basin trending SW. Like many contemporaneous basins in northern Britain, it is believed to have formed under an extensional tectonic regime produced by lithospheric stretching, possibly initiated during the late Devonian (Leeder 1982; Gawthorpe 1987), which may have been punctuated by a period of transpression in Visean and early Namurian times (Arthurton 1983, 1984; Arthurton et al. 1988). This tectonic regime resulted in basement rift faulting and the formation of an asymmetric graben, with a southward tilting floor, bounded by shallow basement comprising the Southern Lake District High and Askrigg Block to the north and the Central Lancashire High to the south (Miller & Grayson 1982). The western and eastern boundaries of the basin are unclear since exposure is lost beneath Permo-Triassic cover, but it extends towards Formby on the coast. Various models for the basement configuration in the region have been given by Miller & Grayson (1982), Gawthorpe (1987), Lawrence et al. (1987), Arthurton et al. (1988), Lee (1988), Leeder & McMahon (1988) and Gawthorpe et al. (1989). The regional depositional history of the Dinantian has been described in detail by Gawthorpe (1986, 1987) and Riley (1990).

The Dinantian succession that overlies the shallow basement at the basin margins comprises locally an initial sequence of red beds, marine peritidal limestones and evaporites (Stockdale Farm Formation of Arthurton et al. 1988), overlain by more widespread, shallow-water marine shelf and platform carbonates. These sequences contrast strongly with the Craven Basin, in which the sequence is much thicker, more complete and varied. Geophysical (gravity) evidence (Cornwell & Evans in Arthurton et al. 1988) suggests that at least 3 km of unexposed sediment overlie the basement in the Craven Basin and a further 3 km is known to have accumulated from mid-Courceyan to late Brigantian times (Charsley 1984; Kirby et al. 2000, map 4). The oldest exposed strata comprise the Chatsburn Limestone Group and consist of impure shallow water marine limestones and fine-grained terrigenous clastic sedimentary rocks. These sediments were rapidly deposited and there was little bathymetric variation across the basin. During Chadian times (Clitheroe Limestone Formation), the effects of basement rifting became more pronounced. This resulted in varied basin floor topography and a reduction in the deposition of shallow marine limestones, which were generally replaced by deeper water Waulsortian limestones. Widespread erosion occurred within the basin during the late Chadian, but by Arundian times, the basin was dominated by pelagic mudstone and limestone turbidite deposition (Hodder Mudstone, Hodderense Limestone, Pendleside Limestone and Bowland Shale formations). Intrabasinal topography was maintained by syndepositional movement along basement fractures in the graben floor.

During early Namurian times, the southern boundary of the basin became less distinct in terms of facies and sediment

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Table 1
Temperature calibration of conodont colour alteration index (CAI) and correlation with vitrinite reflectance values. Compiled from Epstein et al. (1977), Rejebian et al. (1987) and Jones (1992)

<table>
<thead>
<tr>
<th>CAI</th>
<th>Temperature Range °C</th>
<th>Mean temp °C</th>
<th>Vitrinite reflectance %R&lt;sub&gt;0&lt;/sub&gt;</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>50–80</td>
<td>65</td>
<td>0.8</td>
</tr>
<tr>
<td>1.5</td>
<td>50–90</td>
<td>70</td>
<td>0.7–0.85</td>
</tr>
<tr>
<td>2</td>
<td>60–140</td>
<td>100</td>
<td>0.85–1.3</td>
</tr>
<tr>
<td>3</td>
<td>110–200</td>
<td>160</td>
<td>1.4–1.95</td>
</tr>
<tr>
<td>4</td>
<td>190–300</td>
<td>245</td>
<td>1.95–3.6</td>
</tr>
<tr>
<td>5</td>
<td>300–400</td>
<td>330</td>
<td>3.6</td>
</tr>
<tr>
<td>6</td>
<td>350–435</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>6.5</td>
<td>425–500</td>
<td>460</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>480–610</td>
<td>550</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>&gt;600</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Fig. 2.
Sketch map of the Craven Basin showing principal anticlines and Carboniferous (Dinantian and Silesian) and Permo-Triassic outcrop. Inset map of NW England shows the principal basement features which controlled Carboniferous sedimentation. Abbreviations: AH, Ashnott High; BB, Boulsworth Borehole; FB, Fletcher–Bank Borehole; WB, Whitmoor Borehole.
thickness. Subsidence extended to areas of basement, such as the Central Lancashire High, which had previously been stable relative to the basin. This regional subsidence, attributed to thermal subsidence by Leeder (1982), resulted in the accumulation of at least 1.75 km of Namurian mudstones and sandstones, exposed in the Rossendale Anticline which overlies the Central Lancashire High (Ramsbottom et al. 1978). General Namurian cover across the study area was probably in the order of 1.5 km, with south-ea...ter of the study area, but the South Lancashire Coalfield comprises at least 1.84 km of sandstone, siltstone and mudstone-dominated strata (Ramsbottom et al. 1978). Since early Westphalian strata preserved in the Burnley Syncline and Ingleton-Austwick coalfields are thinner than the contemporary strata in southern and western parts of the Lancashire Coalfield, it is assumed that a Westphalian cover over the area was in the order of 1.5 km, resulting in an estimated general burial of the top Dinantian by approximately 3 km of Silesian sediments (Kirby et al. 2000).

Toward the close of the Carboniferous, compressional tec...nitions replaced thermal subsidence. This resulted in Hercynian reactivation of the Lower Palaeozoic basement structures, reactivation of those beneath the Central Lancashire High and the Craven Basin resulting in the formation of the Rossendale Anticline and Ribblesdale Fold Belt respectively (Leeder 1982; Kirby et al. 2000).

Sedimentation resumed upon the eroded Hercynian structures during the Permo-Triassic. Remnants of this cover remain in faulted outliers around Clitheroe and Ingleton, suggesting post-Triassic fault activity in the region. It is unclear how much Permo-Triassic sediment accumulated, but Jackson et al. (1987) gave a total thickness of around 5 km for Permo-Triassic sediments in the East Irish Sea Basin, which lies offshore to the west of the study area. However, the observed CAI values suggest that post-Carboniferous burial in the study area was much less than 5 km and generally less than 1 km (Kirby et al. 2000), and was insufficient to affect the CAI values already attained during the Carboniferous.

Cenozoic tectonic activity can be deduced from the intrusion of two igneous dykes, one in the Grindleton Anticline [SD 7540 4710] and the other in the Lancaster Fells at Caton Moor [SD 5632 6302] (Brandon et al. 1988). From fission track analysis, Green (1986) considered that the Lake District, to the north (Burnett 1987; Armstrong & Purnell 1993). However, the precise location, stratigraphic horizon and lithology for each value are given in the Appendix. Apart from the Holme Chapel borehole [SD 8608 2878], all the samples are from surface sections or shallow boreholes.

There is generally little variation in the CAI values across the area, with a range of between 2 and 3.5, apart from a single exceptional value of CAI 4 recorded in the Holme Chapel borehole. The higher values generally occur in the south and SW and low values are found on the Ashnott High (Ashnott Anticline and eastern closure of the Whitwell Anticline) and in Waulsortian limestones. Because of the generally consistent CAI values and the lack of a comprehensive geographical coverage, no attempt has been made to draw CAI isograds. The values observed are in broad agreement with expected values for the Carboniferous, as indicated by regional studies to the north (Burnett 1987; Armstrong & Purnell 1993).

3. INTERPRETATION OF THE CAI PATTERN

3.1. Facies effect

The effect of facies on CAI values has already been demonstrated by Mayr et al. (1978) and it appears that conodonts from black shales can show CAI values one unit higher than those from limestones. Almost all the conodonts used in this study come from limestones (mainly packstones), and Silesian samples were obtained mainly from wackestone nodules ('bullions'). In general, there is a variation of about half a CAI unit value within samples at any given locality, except for Waulsortian limestone facies where there is a variation of one CAI value. In the Clitheroe area, for example, the Waulsortian limestones of the Clitheroe Limestone Formation show a CAI value of 2.5 whereas crinoidal limestones in the overlying Hodder Mudstone Formation yield conodonts with CAI values of 3.0–3.5. This variation may be due to a number of possible causes, including: (a) the type and amount of organic matter incorporated into the conodont elements by the animals living in these different environments; (b) differences in conodont element growth rates; (c) differences in thermal conductivity of the various limestones and adjacent strata; (d) differential effects of migrating fluids due to variations in porosity and permeability in the different facies; and (e) early cementation of the Waulsortian limestones (Miller & Lees 1985).

3.2. Burial and uplift

As already noted, the top Dinantian was probably buried by c. 3 km of Silesian sediments. Most of the observations in this study are of mid-Dinantian sediments, generally around 0.8 km below the top of the Dinantian succession. Since the present tectonic pattern was established by Permo-Triassic times, the burial time for the late Dinantian would be approximately 30 million years. Most of the CAI values in the Craven Basin range between 2.5–3.5 and are most commonly 3.0. Epstein et al. (1977) suggest a minimum temperature of 110°C to c. 190°C for a CAI value of 3. However, with a burial time of 30 million years, this CAI value indicates temperatures of near 125°C (Epstein et al. 1977). Since most of the samples are from the mid-Dinantian, heating time may have been a little longer, suggesting temperatures in the region of 110–120°C for the Dinantian. Given an assumed geothermal gradient of 30°C/km, typical for extensional basins, the Craven area CAI
values are not in general anomalously high and are consistent with their burial-uplift history.

The relatively high CAI value of 4 recorded from Dinantian limestones at a depth of 5875 ft (1790.7 m) in the Holme Chapel Borehole, and CAI values of 3.5 in Namurian and early Westphalian sediments south of the Craven Basin, are probably a result of greater Westphalian cover, now removed, compared to further north. The lower CAI values of 2–2.5 seen over the Ashnott High are probably due to a combination of both relatively lower depth of burial, since this site accumulated a condensed sequence from mid-Dinantian until early Namurian times, and the proximity of thick Waulsortian limestones, which, as already noted, possibly inhibited thermal conduction.

3.3. Basin tectonics

We consider the development of the Craven Basin to follow the model of McKenzie (1978), involving lithospheric thinning due to extension followed by thermal subsidence. Observed CAI values agree moderately well with McKenzie’s (1981) computation of temperatures within a sediment pile following extension. McKenzie (1981) concluded that maximum temperatures for shallow burial at less than 4km were attained much later than the onset of subsidence. For a stretching factor (β) of 2, applied by Dewey (1982) to the Silesian sequence in this region, and 3 km of burial, a maximum temperature of 150°C at top Dinantian would be attained after 45 million years. Clearly the Hercynian uplift and folding, which occurred some 20 million years after the onset of thermal subsidence (Leeder 1988), prevented the maximum temperatures from being achieved. It appears, therefore, that McKenzie’s (1981) modelled temperatures can be applied in a truncated form to the regional CAI values.

3.4. Igneous rocks

The only igneous rocks recorded in the area comprise two Cenozoic olivine–basalt dykes, located in the Grindleton Anticline and at Caton Moor respectively (Eccles 1870). Conodont samples are not yet available from these sites and the local CAI value of 3–3.5 is likely to be exceeded only within a few metres of these intrusions, when compared to other examples outside the study area (Armstrong & Strens 1987). The regional CAI values do not appear to have been modified by igneous activity.
3.5. Mineralization and fluid processes

Mineralization in the area is of lead-zinc-copper type with associated baryte and fluorite. CAI values in mineralized areas, for example at Raygill [SD 9400 4520] (CAI value of 3.0), Skeleron [SD 8140 4520] (CAI value of 3.0) and Ashnott [SD 6970 4860] (CAI values of 2.0–2.5), are within the regional range and do not appear to be affected by the mineralization. This is as expected, since fluid inclusion studies indicate mineralization temperatures of between 104–138°C (Rogers 1977), which are too low to have increased the CAI values already attained.

Evidence of late Carboniferous diagenesis by dolomitizing fluids is provided by the recognition of remagnetization of late Dinantian/lower Namurian (Pendleian) strata at Sykes et al. (1985) and around Skipton (Turner et al. 1979). It is unclear whether these fluids have had any influence on the CAI values.

The relatively high present day heat flows of over 80mW/m² observed in the Bowland Fells (Lee et al. 1987) cannot be explained by underlying granite (as in the Askrigg and Alston Blocks). These values are probably caused by circulating groundwater (Downing et al. 1987), which relates either to a Carboniferous aquifer or to a localized concentration of fracturing.

4. OTHER SOURCES OF MATURITY DATA AND CORRELATION WITH CAI VALUES

Published information on independent maturity data in the study area is sparse and is largely limited to vitrinite reflectance. Shelley’s (1967) volatile matter and fixed carbon data, from coal seams in the Great Scar Limestone north of the Ingleton Coalfield, suggests a vitrinite reflectance of approximately 1.2% \( R_o \). This corresponds to a CAI value of 2, which is broadly consistent with CAI data reported here. Similar data reported by Shelley (1967) from the Ingleton coalfield suggests a vitrinite reflectance of \( c. 0.5\% \ R_o \), corresponding to a CAI of 1. Trotter (1954) reported volatile matter and other data that represent vitrinite reflectance values of 1.25–1.35% \( R_o \) from the Westphalian of the Burnley Syncline, equivalent to CAI 2. Lawrence et al. (1987) reported values of 0.7–1.09% \( R_o \) (= CAI 2) from Namurian strata at Abbeyhead [SD 5700 6400] in the Bowland Fells, 0.7–0.99% \( R_o \) (= CAI 2) from subcropping Dinantian/lower Namurian (Pendlestrata) at Sykes [SD 6250 5200], and two values from the Whitmoor Borehole [SD 5874 6315], 0.91% \( R_o \) (= CAI 2) from the lower Namurian (Pendlestrata) at 865 ft (263.65 m) and 1.46% \( R_o \) (= CAI 3) from the late Dinantian (Asbian) Pendleside Limestone at 3830 ft (1167.38 m). These vitrinite reflectance data are in general agreement with the observed CAI values in the Bowland–Lancaster Fells, if allowance is made for the fact that the observed values are slightly higher due to the facies effect of the black shale nodular limestones from which they were obtained.

5. HYDROCARBON OCCURRENCE

The observed CAI values correspond to a range from the base of the oil window into the condensate/dry gas sectors of Heroux et al. (1979). Hydrocarbon shows are reported from a number of localities in the area, but these tend to be minor and of no commercial value. Most of the shows are of oil or gas associated with past coal mining, for instance oil at Huncoat Colliery near Blackburn and from pits around Burnley (Strahan 1920), and gas at Birstall Smitheries near Huddersfield (Wray et al. 1930) and in the Bradford area (Stephens et al. 1953). Methane dissolved in groundwater from Carboniferous strata was responsible for the underground pipeline explosion at Abbeyhead in 1984.

Oil seeps have been reported at surface in the Formby area (Wray & Wolverson Cope 1948), where there is also a small oilfield (Falcon & Kent 1960). There the reservoir comprises Triassic strata, but it is generally thought that the source is Carboniferous. Stephens et al. (1953) reported oil in Namurian bullions at Moor Houses, near Skipton. Solid bitumen veinlets are known from the Haw Bank Limestone (Courseyan), which forms the core of the Skipton Anticline (Lees & Cox 1937). In addition, one of us (NRJ) has observed liquid hydrocarbons (light oil) to be common on vein surfaces and in vugs in bullions from black shales. In the Ashnott and Cow Ark anticlunes, liquid hydrocarbons and pyrobitumen, within cavities and fractures associated with mineralization, have also been noted in boreholes penetrating Waulsortian limestones. The occurrence of thermal maturity values extending into the condensate dry/gas phase suggests that the region is prospective for shale gas exploration.

6. CONCLUSIONS

CAI values in the Craven area show a general range of 2.5–3.5, the majority being a value of 3. These values are consistent with the limited vitrinite reflectance data and are a result of the Carboniferous sedimentary and tectonic history of the region. There is no evidence of significant modification by subsequent burial, igneous events, reheating or mineralization. Low values of CAI 2–2.5 on the Ashnott High are interpreted to be due to the thinner sedimentary cover in that area and possible insulation derived from underlying Waulsortian limestones. Relatively high values of CAI 4 (Dinantian) in the Holme Chapel Borehole and 3.5 in the Silexian sediments to the south of the Craven Basin probably reflect a thicker Westphalian cover than further north. Observed CAI values in the Craven basin can therefore be explained as being entirely due to depth of burial and pre-date Permian extension.

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REFERENCES


**APPENDIX**

The following sample localities used in this study are listed below in ascending lithostratigraphic order, together with their national grid reference, the range of CAI values observed and chronostratigraphic division(s). In cases where a spread of values was observed at one locality, only the dominant value was plotted on Fig. 3. Repositories are referred to in brackets at the end of each entry. The abbreviations BGS, TCD, UNE refer to geological collections held at the British Geological Survey, Trinity College Dublin and University of New England respectively.

**Dinantian**

**Chatburn Limestone Group**

1. Chatburn, SD 7742 4416, CAI 2.5–3.0, Chadian–Chadian (BGS).
2. Chatburn By-pass, SD 7737 4409, CAI 3.0, Chadian–Chadian (BGS).
3. Skelerton Quarry, SD 8180 4490, CAI 3.0, Chadian (BGS).
4. Swinden, railway cutting, SD 8675 543, CAI 3.0, Chadian (UNE).
5. Haw Bank Quarry, SE 0150 5320, CAI 2.5, Courcyean (UNE).
6. Gisburn, railway cutting, SD 8030 4750, CAI 2–2.5, Courcyean (UNE).
7. Gisburn, railway cutting, SD 8025 4750, CAI 3.0, Courcyean (BGS).
8. Low Searth Barn, SD 8884 5983, CAI 3–3.5 Chadian (BGS).

**Clitheroe Limestone Formation**

10. Winterburn Grange, SD 9399 5786, CAI 3.0, Chadian (BGS).
11. Hetton, SD 9556 5838, CAI 3.0, Chadian (BGS).
12. Swinden Gill, SD 8691 5389, CAI 3.0, Chadian (BGS).
13. Swinden Gill, SD 8678 5393, CAI 3.0, Chadian (BGS).
14. Low Searth Barn, SD 8884 5983, CAI 3–3.5 Chadian (BGS).
15. Crake Moor Farm, SD 8774 6033, CAI 3.0, Chadian (BGS).
17. Scotchpop House, SD 8888 5987, CAI 2.5–3.0, Chadian (BGS).
18. Knoll Wood, SD 6837 5005, CAI 3, Chadian (BGS).
19. Salthill Quarry, SD 7550 4260, CAI 3.0, Chadian (UNE).
20. Twiston Hill, SD 8090 4430, CAI 3.0, Chadian (UNE).
21. Smellows North Quarry, SD 9420 5207, CAI 2.5, Chadian (UNE).
22. Smellows South Quarry, SD 9425 5225, CAI 2.5, Chadian (UNE).
23. Butler Haw, SD 9370 5255, CAI 2.5, Chadian (UNE).
24. Worsaw Hill, SD 7780 4310, CAI 2.5, Chadian (UNE).
25. Townfield Rock Quarry, SD 8990 5670, CAI 2.5, Chadian (UNE).
26. Sykes Knoll, SD 7990 4420, CAI 2.5, Chadian (UNE).
27. Cobbers Laithie, SD 8630 5370, CAI 2.5, Chadian (UNE).
29. Clitheroe By-pass, SD 7740 4450, CAI 2.5, Chadian (UNE).
30. Broughton Quarry, SD 9470 5273, CAI 3.0, Chadian (UNE).
31. Butterhaw Quarry, SD 9409 5301, CAI 3.0, Chadian (UNE).
32. Eller Beck, SD 9940 5300, CAI 3.0, Chadian (UNE).

**Hodder Mudstone Formation**

33. River Hodder, Buck Hill, SD 6830 4270, CAI 3–3.5, Arundian (BGS).
34. Green Bank Gill, SD 9359 5959, CAI 3.0, Arundian (BGS).
35. Brockbank Gill, SD 9346 5674, CAI 3.0, Chadian (BGS).
36. Winterburn Beck, SD 9440 5989, CAI 3.5, Arundian (BGS).
37. Haw Crag Quarry, SD 9135 5640, CAI 3–3.5, Arundian with reworked Chadian, (BGS).
38. Bell Busk Bridge, SD 9082 5669, CAI 3–3.5, Arundian (BGS).
41. Rylstone, railway cutting, SD 9633 5811, CAI 2.5–3.0, Arundian-Holkerian (BGS).
42. Leagram Brook, SD 6350 4510, CAI 3.0, Arundian (BGS).
43. Leagram Brook, SD 6353 4435, CAI 2.5–3.0, Chadian (BGS).
44. Ashnott, SD 6970 4862, CAI 1.5–2.5, Chadian (BGS).
45. Ashnott, SD 6943 4833, CAI 1.5–2.0, Chadian (BGS).
47. Dinckling Green, SD 6455 4760, CAI 3–3.5, Chadian (BGS).
48. Whitemore Knott, SD 6467 4790, CAI 3.0, Arundian (BGS).
49. Low Cocks, SD 7495 4600, CAI 3–3.5, Arundian (BGS).
52. Porter Wood, SD 6600 4705, CAI 1.5–2.0, Chadian (BGS).
53. Ashnott, SD 6945 4834, CAI, 2.5–3.0, Chadian (BGS).
54. Sandal Holme, SD 6802 4338, CAI 3.0, Arundian (BGS).
55. Hall Hill, SD 6685 4695, CAI 2.5–3.0, Chadian (BGS).
56. King Syke, SD 7120 5150, CAI 2.5–3.0, Arundian (BGS).
57. River Hodder, Agden, SD 6845 4275, CAI 2.5–3.0, Arundian (BGS).
58. River Hodder, Higher Hodder, SD 6977 4125, CAI 2.5–3.0, Holkerian (BGS).
59. Worston, SD 7680 4310, CAI 3.0, Chadian, (UNE).
60. Ings Beck, SD 8160 4470, CAI 3.0, Holkerian (UNE).
62. Ray Gill Quarry, SD 9400 4275, CAI 2.5–3.0, Arundian (UNE).
63. River Hodder, Great Falls, SD 7040 3890, CAI 2.5–3.0, Holkerian (BGS).
64. Hellifield, SD 8630 5641, CAI 3.0, Arundian–Holkerian (TCD).

Hodderense Limestone Formation
65. Ashnott, SD 6897 4815, CAI 2–2.5, Holkerian (BGS).

Pendleside Limestone Formation
66. Draughton, SE 0342 5249, CAI 2.5, Ashbian (TCD).
67. Ryldstone, SD 9727 5788, CAI 3.0, Ashbian (BGS).
68. Clints Rock Quarry, SD 9669 5734, CAI 2.5–3.0, Ashbian (BGS).
69. River Hodder, Great Falls, SD 7025 4000, CAI 2.5, Holkerian (BGS).
70. Pendle Hill, 7850 4170, CAI 3.0, Holkerian (UNE).
71. Hambleton Quarry, SE 0580 5340, CAI 2.5, Ashbian (UNE).
72. Rad Brook, SD 7900 4260, CAI 3.0, Holkerian–Ashbian (UNE).

Malham Formation
73. Swinden Quarry, SD 9815 6176, CAI 2.5–3.0, Ashbian (BGS).

Bowland Shale Group
74. River Wharfe, Bolton Abbey, SE 0755 5424, CAI 2.5–3.5, Brigantian (BGS).
75. Orms Gill, SD 8705 5980, CAI 3–3.5, Ashbian–Brigantian (BGS).
76. Banks Gill, SE 0500 5250, CAI 2.5, Brigantian (UNE).
77. Leagram, SD 6279 4378, CAI 3.5, Ashbian (BGS).
78. Dobson Brook, SD 6201 4415, CAI 2.5, Ashbian (BGS).

Dinantian (undiifferentiated)
79. Holme Chapel Borehole, SD 8608 2878, 1790.70 m depth, CAI 4.0 (UNE).

Namurian
Bowland Shale Group
80. Light Clough, SD 7513 3765, CAI 3–3.5, Pendleian (BGS).
82. Bolton Abbey, SE 0750 5450, CAI 2.5–3.0, Pendleian (UNE).

Roeburndale Formation
83. Pedders Wood, SD 5120 4785, CAI 3.0, Arnsbergian (BGS).

Caton Shale Formation
84. River Hyndburn, Wray, SD 6487 6468, CAI 3.0, Arnsbergian (BGS).
85. Salter Fell, SD 6300 6073, CAI 3.5, Arnsbergian (BGS).

Sabden Shale Formation
86. Samlesbury Bottoms, SD 6170 2920, CAI 3–3.5, Kinderscoutian (BGS).

Kinderscout Grit Group

Middle Grit Group
88. Sabden Brook, Cock Bridge, SD 7462 3438, CAI 3–3.5, Marsdenian (BGS).
89. Blue Scar Beck, Keighley, SE 0002 3993, CAI 3.5, Marsdenian (BGS).

Rough Rack Group
90. Nab Scar, Oxenhope, SE 0353 3287, CAI 3.5, Yeadonian (BGS).
91. Winter Hill, SD 6590 1480, CAI 3–3.5, Yeadonian (TCD).

Westphalian
Lower Coal Measures
92. Burnley, SD 8450 3360, CAI 3.5, Langsettian (BGS).

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