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Palaeoecology of the *Chaetetes*- Band: a marine biostrome in the Carboniferous, basal Namurian (basal Serpukhovian) Great Limestone of northern England.

Land and Resources Directorate

Internal Report IR/07/023R

BRITISH GEOLOGICAL SURVEY

LAND AND RESOURCES DIRECTORATE

INTERNAL REPORT IR/07/023R

Palaeoecology of the *Chaetetes*-Band: a marine biostrome in the Carboniferous, basal Namurian (basal Serpukhovian) Great Limestone of northern England.

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Contents

Acknowledgements	i
Contents	i
Summary	iii
1 Introduction	1
2 Sections visited and samples collected	1
3 Faunas of the various facies as sampled at each locality	11
3.1 ‘Planar-bedded’ limestone	11
3.2 ‘Bioclastic’ limestone	12
3.3 ‘Wavy-bedded’ limestone.....	12
3.4 ‘ <i>Chaetetes</i> -band’ limestone	13
3.5 ‘ <i>Chaetetes</i> – bioclastic transitional’ limestone	15
3.6 ‘Coral-band’ limestone	15
3.7 ‘Coral-band and bioclastic’ limestone	16
3.8 ‘Planar – wavy transitional’ limestone	16
3.9 ‘Planar-bedded limestone/sandstone’	17
3.10 Sandstone	17
4 Palaeoecology: an introduction	18
4.1 The palaeoecology of some Carboniferous fossils	18
4.2 The palaeoecology and facies control of some Carboniferous conodonts	22
5 Palaeoecological interpretations for each facies	28
5.1 ‘Planar-bedded’ limestone	28
5.2 ‘Bioclastic’ limestone	28
5.3 ‘Wavy-bedded’ limestone.....	29
5.4 ‘ <i>Chaetetes</i> -band’ limestone	29
5.5 ‘ <i>Chaetetes</i> – bioclastic transitional’ limestone	29
5.6 ‘Coral-band’ limestone	30
5.7 ‘Coral-band and bioclastic’ limestone	30
5.8 ‘Planar–wavy transitional’ limestone	31

5.9 ‘Planar-bedded limestone/sandstone’ 31
5.10 Sandstone 32
6 Conclusions 32
Appendix 1 34
Appendix 2 37
References 44

FIGURES

Figure 1 Sections MD123 – MD129 at the base of the Great Limestone collected for macrofossils and conodonts 4
Figure 2 Field sketch of MD128 Chestergarth Quarry (disused) [NY 9431 4189] showing the development of the different facies and the samples collected. 9
Figure 3 Field sketch of MD129 Killhope roadside exposure [NY 822 434] showing the the development of the different facies and the samples collected. 10

TABLES

Table 1 Summary percentage occurrences of each macrofossil genus, in each facies of the *Chaetetes*-Band, as sampled in hand specimen. For key see text 27
Table 2 Summary percentage occurrences of each conodont genus, in each facies of the *Chaetetes*-Band, as sampled. For key see text 28

Summary

The *Chaetetes*-Band commonly occurs near the base of the basal Namurian (basal Serpukhovian) Great Limestone in northern England and classically comprises compact ‘bands’ of the sclerosponge *Chaetetes depressus* and the colonial coral *Diphyphyllum lateseptatum*. Samples have been collected from seven sections in the Alston area and the macrofossils and conodont elements from each limestone facies of the *Chaetetes*-Band (as it exists at those localities) have been identified. Based largely on the palaeoecological interpretations of Carboniferous macrofossils by Wilson (1989) and conodonts as synthesised by Dean (1987) a fuller understanding has been gained of the environmental setting and community structure of each fossil assemblage from each limestone facies of the *Chaetetes*-Band. Work on the amalgamated assemblages (palaeocommunities) suggests the following:

‘Planar-bedded’ limestone has a dominant macrofauna of crinoids and brachiopods, and a dominant conodont fauna of genera *Lochriea* and *Gnathodus* with *Syncladagnathus*. The environmental setting appears to have been one of firmer substrates and clearer, current affected waters on the marine shelf.

‘Bioclastic’ limestone has a dominant macrofauna of crinoids with productoid brachiopods and corals, and a dominant conodont fauna of genera *Gnathodus* and *Lochriea* with *Syncladagnathus* and *Vogelgnathus*. The environmental setting appears to have been one of relatively firm to sporadically relatively soft substrates and clearer, calm to current-affected waters on the marine shelf. It was probably shallower than the ‘Planar-bedded’ limestone environment.

‘Wavy-bedded’ limestone has a dominant macrofauna of *Diphyphyllum* with *Chaetetes* and the brachiopod *Eomarginifera*, and a conodont fauna comprised solely of genus *Cavusgnathus*. The environmental setting appears to have been one of relatively soft substrates beneath generally clearer, possibly wave-agitated waters on the marine shelf.

‘*Chaetetes*-band’ limestone has a dominant macrofauna of *Chaetetes* with brachiopods, crinoids and corals, and a dominant conodont fauna of genera *Gnathodus* with *Cavusgnathus* and *Syncladagnathus*. A biohermal palaeoenvironment is suggested with firm substrates and clearer, apparently calm to current affected, perhaps sub-tidal and sporadically wave-agitated, waters on the marine shelf.

‘*Chaetetes*-bioclastic transitional’ limestone has a dominant macrofauna of *Chaetetes* with crinoids and productoid brachiopods, and a dominant conodont fauna of genera *Gnathodus* with *Syncladagnathus* and *Lochriea*. An environmental setting transitional to those of the ‘*Chaetetes*-band’ and ‘Bioclastic’ limestones is suggested.

‘Coral-band’ limestone has a dominant macrofauna of *Diphyphyllum* with other corals, *Chaetetes*, and brachiopods, and a dominant conodont fauna of genera *Kladognathus* with *Gnathodus* and *Vogelgnathus*. A biohermal, lower reef slope or shelf setting is suggested, with relatively firm or soft substrates beneath clear, shallow, low energy marine waters.

‘Coral-band and bioclastic’ limestone has a dominant macrofauna of *Diphyphyllum* and crinoids, and a dominant conodont fauna of genera *Gnathodus* and *Lochriea* with *Cavusgnathus*, *Syncladagnathus* and *Vogelgnathus*. An environmental setting transitional to those of the ‘Coral-band’ and ‘Bioclastic’ limestones is suggested.

‘Planar-wavy transitional’ limestone has a dominant macrofauna of crinoids with productoid brachiopods, and a dominant conodont fauna of genera *Gnathodus* with *Syncladagnathus*, *Lochriea* and *Vogelgnathus*. An environmental setting transitional to those of the ‘Planar-bedded’ and ‘Wavy-bedded’ limestones is suggested.

'Planar-bedded limestone/sandstone' has a dominant macrofauna of crinoids with productoid brachiopods, the rhynchonellid brachiopod *Pleuropugnoides* and burrow traces, and a dominant conodont fauna of genera *Gnathodus* with *Syncladagnathus* and *Cavusgnathus*. The environmental setting appears to have been varied, including firm to soft substrates and clear to muddy, low to high-energy waters, off to near shore on the marine shelf. A minor biohermal presence is also suggested.

'Sandstone' has a flora of plant debris and roots and may represent an environment of a possibly emergent, prograding, lobate delta.

This research remains a 'work in progress' and lists of Great Limestone and therefore possible *Chaetetes*-Band exposures in the Northern England Province are included for possible future study. A poster (Dean, 2006) complements this report. A copy, with illustrations of *Chaetetes* sp. and *Diphyphyllum* spp., and typical examples of the dominant conodont genera found in the *Chaetetes*-Band can be found at the BGS Intranet address:

<\\mhsan\WorkSpace\GLN\NorthernEngland\Reports\Conferences\Posters>

The poster was displayed at The First International Conodont Symposium (ICOS 2006) from 17 – 21 July 2006 at the University of Leicester.

1 Introduction

Johnson (1958; see also Fairburn, 2001) recognized three marine biostromes within the basal Namurian (basal Serpukhovian) Great Limestone of northern England: the *Chaetetes*-Band occurring near the base; the Brunton Band (with calcareous algae) situated below the centre of the limestone and only recognizable by the study of thin sections; and the Frosterly Band occurring above the centre of the limestone, characterized by the presence of numerous *Dibunophyllum* corals. This work describes the *Chaetetes*-Band, its variable development and detailed palaeoecology.

According to Fairburn (2001, p. 271) the *Chaetetes*-Band includes the fossils *Chaetetes depressus* and *Diphyphyllum lateseptatum* commonly in compact 'bands'. However, their distribution is variable. For example, on the Alston Block, *Chaetetes* can form thick masses at some locations, whilst on the Askrigg Block it is not common. Samples have so far been collected from seven localities in the Alston area but much more collecting, hopefully representative of the whole of northern England, is still required (see 0), so this study remains a work in progress.

The localities visited and samples collected for fossils are given in Section 2. The faunas of the various limestone facies at the seven newly sampled localities are listed in Section 3, and the percentage of each genus represented therein is summarised in Tables 1 and 2. A palaeoecological interpretation of each of the limestone facies (based on the information provided in Section 4) is given in Section 5.

2 Sections visited and samples collected

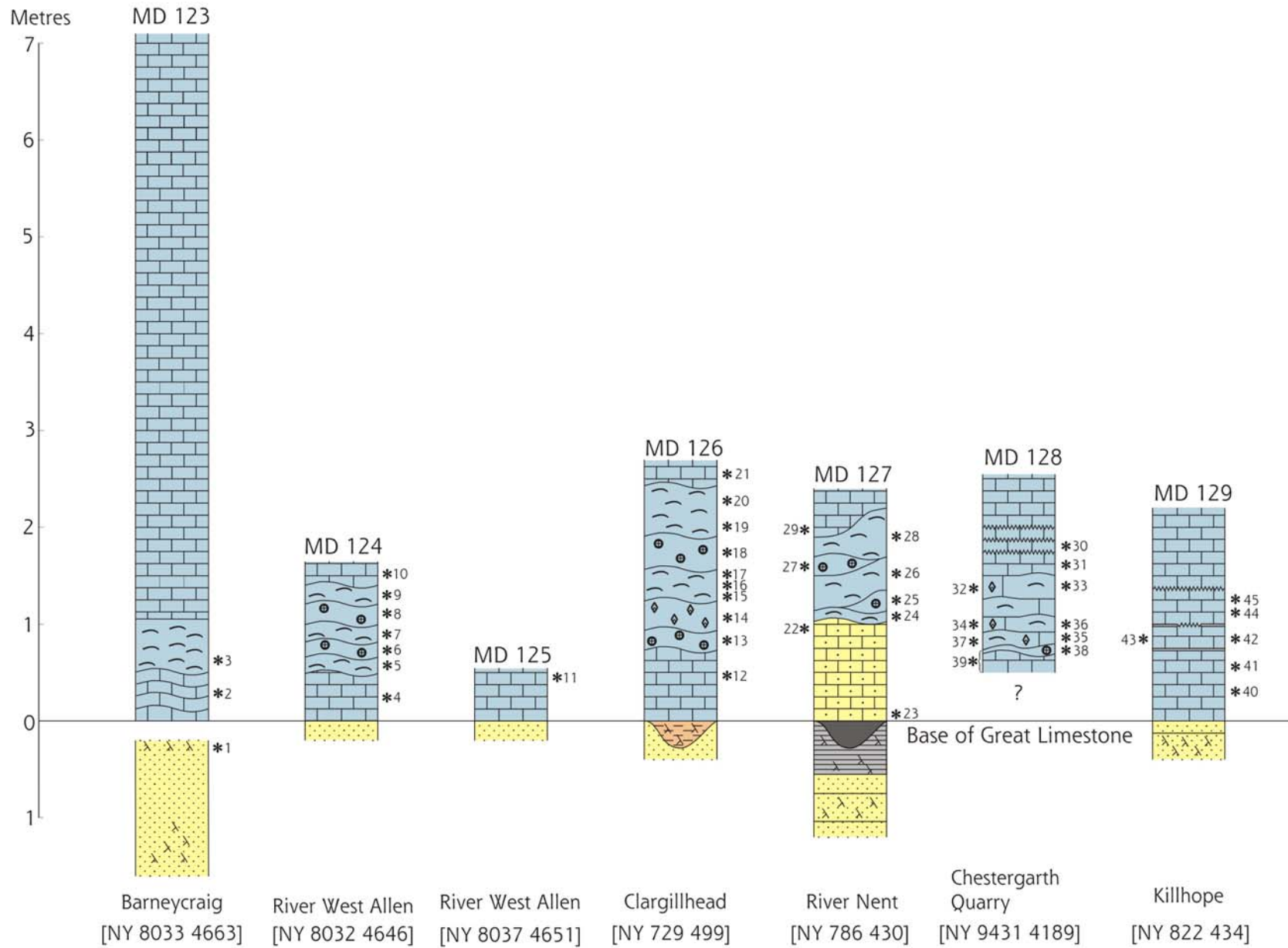
Section (described from top to base) in the Great Limestone at Brunton Bank Quarry [NY 9287 7001] c. 1.0 km southeast of Chollerford Bridge:

	m (thickness)
Limestone, scattered corals at base, with fossil samples WP637 – WP640: <i>Dibunophyllum bipartitum bipartitum</i> , <i>Dielasma</i> sp., <i>Solemya costellata</i>	c. 3.0
Limestone, <i>Chaetetes</i> -Band c. 1.0 m from base, with WP641 – WP655: <i>Chaetetes depressus</i> , <i>Actinocyathus floriformis laticlavia</i> , <i>Dibunophyllum bipartitum bipartitum</i> , <i>Dibunophyllum bipartitum</i> cf. <i>bipartitum</i> , <i>Diphyphyllum lateseptatum</i> , <i>Koninckophyllum</i> cf. <i>interruptum</i> , <i>Alitaria panderi</i> , <i>Brachythyris</i> sp., <i>Dielasma</i> sp., <i>Martinia</i> sp., orthotetoid, <i>spiriferid</i> (small)	c.8.0 – 9.0

Comments: See Frost and Holliday (1980, pp. 40 – 42, 51, 96 – 97, fig. 22, plate 7). J Pattison collected the macrofossils for D Holliday in 1972. The original identifications have been retained but the taxonomy is updated.

Brunton Quarry was designated type locality of the *Chaetetes*-Band (Johnson, 1958). During this study, difficulties of access hindered further collecting from the quarry, which was considered

desirable for better stratigraphical refinement. However, several other sites (MD123 – MD129) were successfully visited and collected by the author (see Figure 1).



Key:



'Planar-bedded' limestone



'Wavy-bedded' limestone



Sandstone



Siltstone

Including seatearth (▲)



Mudstone

(Including shale partings)



Dirty coal



'Chaetetes-band' limestone



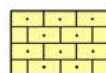
'Coral-band' limestone



'Bioclastic' limestone



Stylolites



'Planar-bedded limestone/sandstone'

* Fossil sample

Fossil Samples:

	Macrofossils	Conodonts		Macrofossils	Conodonts
1	MTD 1551-2		23	MTD 1727-32	MPA 51744
2	MTD 1553-4	MPA 51724-5	24	MTD 1734-46	MPA 51745
	MTD 1556-61		25	MTD 1748-50	MPA 51746
3	MTD 1563-5	MPA 51726	26	MTD 1752-4	MPA 51747
4	MTD 1567-8	MPA 51727	27	MTD 1756-62	MPA 51748
5	MTD 1570-1	MPA 51728	28	MTD 1764-70	MPA 51749
6	MTD 1573-92	MPA 51729	29	MTD 1772-6	MPA 51750
7	MTD 1594-5	MPA 51730	30	MTD 1778-84	MPA 51751
8	MTD 1597-601		31	MTD 1786-90	MPA 51752
9	MTD 1602-11	MPA 51731	32	MTD 1792-9	MPA 51753
10	MTD 1613-4	MPA 51732	33	MTD 1801-11	MPA 51754
11	MTD 1616-8		34	MTD 1813-20	MPA 51755
12	MTD 1619-22	MPA 51733	35	MTD 1822-7	MPA 51756
13	MTD 1624-9		36	MTD 1829-41	MPA 51757
14	MTD 1630-6	MPA 51734	37	MTD 1843-9	MPA 51758
15	MTD 1638-43	MPA 51735	38	MTD 1851-8	MPA 51759
16	MTD 1645-56	MPA 51736	39	MTD 1860-4	MPA 51760
17	MTD 1658-70	MPA 51737	40	MTD 1866-72	MPA 51761-2
18	MTD 1672-8	MPA 51738-9		MTD 1874-80	
	MTD 1680-7		41	MTD 1882-4	MPA 51763
19	MTD 1689-93	MPA 51740	42	MTD 1886-94	MPA 51764
20	MTD 1695-704	MPA 51741	43	MTD 1896-903	MPA 51765
21	MTD 1706-12	MPA 51742	44	MTD 1905-11	MPA 51766
22	MTD 1714-25	MPA 51743	45	MTD 1913-8	MPA 51767

Figure 1 Sections MD123 – MD129 at the base of the Great Limestone collected for macrofossils and conodonts

MD123. Section at the base of the Great Limestone in an abandoned quarry at Barneycraig, Carrshield, West Allendale [NY 8033 4663]:

	m (thickness)
Limestone, 'planar-bedded'	c. 6.0
Limestone, a ' <i>Chaetetes</i> -band' with MTD1563 – MTD1566 (including MPA51726) near base of bed	c. 0.5
Limestone, 'wavy-bedded' with MTD1553 – MTD1562 (including MPA51724 and MPA51725) through < 0.15 m gap	c. 0.6 c. 0.2
Sandstone, medium-bedded, fossil root-casts in top part, becoming seatearth-like downward, rooty in lower parts with MTD1551 – MTD1552	1.4 +

MD124. Section at the base of the Great Limestone in the northwest bank of the River West Allen, Carrshield, West Allendale [NY 8032 4646]:

	m (thickness)
Limestone, 'planar-bedded' with MTD1613 – MTD1615 (including MPA51732) c. 0.3 m above base	-
Limestone 'wavy-bedded', variably developed as:	
a ' <i>Chaetetes</i> -band' with MTD1602 – MTD1612 (including MPA51731)	to c. 0.2
a 'coral-band' with MTD1597 – MTD 1601	to c. 0.15
a ' <i>Chaetetes</i> -band' with MTD1594 – MTD1596 (including MPA51730)	to c. 0.2
a 'coral-band' with MTD1573 – MTD1593 (including MPA51729)	to c. 0.2
a ' <i>Chaetetes</i> -band' with MTD1570 – MTD1572 (including MPA51728)	to c. 0.15
Limestone, 'planar-bedded' with MTD1567 – MTD1569 (including MPA51727)	0.5
Sandstone	-

MD125. Section at the base of the Great Limestone in the eastern bank of the River West Allen, Carrshield, West Allendale [NY 8037 4651]:

	m (thickness)
Limestone, 'planar-bedded' with MTD1616 – MTD1618 at top	0.5
Sandstone	-

MD126. Stream section at the base of the Great Limestone at Clargillhead, Alston [NY729 499]:

	m (thickness)
Limestone, 'planar-bedded' with MTD1706 – MTD1713 (including MPA51742) at base of bed	-
Limestone, 'wavy-bedded', variably developed as:	
a 'Chaetetes-band' with MTD1695 – MTD1705 (including MPA51741) from upper part, and MTD1689 – MTD1694 (including MPA51740) from lower part	c. 0.5
a 'coral-band' with MTD1672 – MTD1688 (including MPA51738 and MPA51739)	c. 0.3 (very variable)
a 'Chaetetes-band' with MTD1658 – MTD1671 (including MPA51737) from top, MTD1645 – MTD1657 (including MPA51736) from upper part, and MTD1638 – MTD1644 (including MPA51735) from lower part	c. 0.35 (very variable)
'Bioclastic' limestone with MTD1630 – MTD1637 (including MPA51734)	c. 0.3
a 'coral-band' with MTD1624 – MTD1629	c. 0.15 (variable)
Limestone, 'planar-bedded' with MTD1619 – MTD1623 (including MPA51733) at 0.47 m above base	0.82
Seatearth, rooty	0? – c. 0.3
Sandstone	-

MD127. Section at the base of the Great Limestone in the River Nent, Nenthead [NY 786 430]:

	m (thickness)
Limestone, 'planar-bedded' with MTD1772 – MTD1777 (including MPA51750) at base	-
Limestone, 'wavy-bedded', comprising:	
a 'Chaetetes-band' with MTD1764 – MTD1771 (including MPA51749)	c.0.2 - 0.55
a 'coral-band' with MTD1756 – MTD1763 (including MPA51748)	0 – c. 0.2
a 'Chaetetes-band' with MTD1752 – MTD1755 (including MPA51747)	c. 0.3

a 'coral-band' with MTD1748 – MTD1751 (including MPA51746)	0 – c. 0.15
a ' <i>Chaetetes</i> -band' with MTD1734 – MTD1747 (including MPA51745)	c. 0.15
'Limestone/sandstone', planar-bedded with MTD1714 - MTD1726 (including MPA51743) at top and MTD1727 – MTD1733 (including MPA51744) at base	c. 1.05
Coal, very poor ('dirt')	0? – c. 0.3
Seatearth, muddy, rooty	c. 0.6
Sandstone	0.15
Seatearth, sandy, rooty	c. 0.33
Sandstone	-

MD128. Section at the base of the Great Limestone at Chestergarth Quarry (disused), Rookhope, Weardale [NY 9431 4189] (see also Figure 2):

	m (thickness)
Limestone, 'planar-bedded', vuggy, stylolitic with MTD1778 – MTD1791 (including MPA51751 and MPA51752)	1.0 +
Limestone, 'wavy' and 'planar' beds including 'massive' <i>Chaetetes</i> mounds with MTD1801 – MTD1812 (including MPA51754) and MTD1843 - MTD1850 (including MPA51758) that pass laterally with MTD1822 – MTD1842 (including MPA51756 and MPA51757) into 'planar', jointed, 'bioclastic' limestone with MTD1792 – MTD1800 (including MPA51753), and MTD1813 – MTD1821 (including MPA51755). A 'coral-band' is seen near the exposed base with MTD1851 – MTD1859 (including MPA51759) and MTD1860 – MTD1865 (including MPA51760) which includes both the 'coral-band' and a '?planar' 'bioclastic' limestone bed below it	1.2 + (base not seen)

MD129. Roadside section at the base of the Great Limestone at Killhope, Weardale [NY 822 434] (see also Figure 3):

	m (thickness)
Limestone, 'planar-bedded', with stylolites, and MTD1913 – MTD1919 (including MPA51767) at base	0.95 +
Limestone, 'planar-bedded', in places less evenly bedded than the beds above, with stylolites, shaley partings and possible sporadic and poorly developed <i>Chaetetes</i> patches. No 'coral – bands' seen. 'Spotting' noted on joint surfaces possibly associated with ankerite mineralisation and/or lichen. Collections include MTD1905 – MTD1912 (including MPA51766) near top, MTD1882 – MTD1904 (including MPA51763 - MPA51765), and MTD1866 – MTD1881 (including MPA51761 and MPA51762) towards base	c. 1.2
Sandstone, well jointed	0.12
Seatearth, sandy, soft, rooty	0.2 +
(Scree bank to road level	c. 2.5 m)

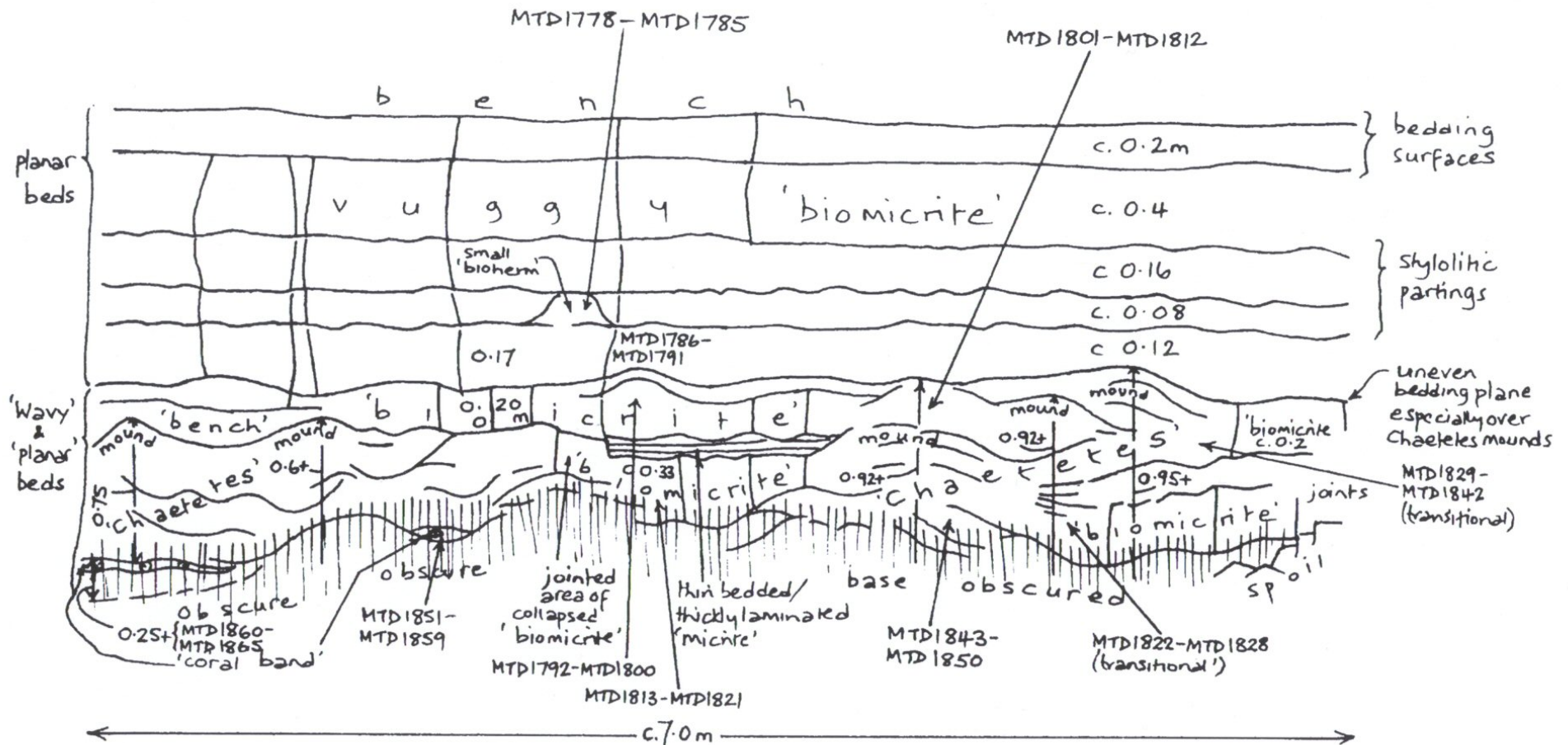


Figure 2 Field sketch of MD128 Chestergarth Quarry (disused) [NY 9431 4189] showing the development of the different facies and the samples collected.

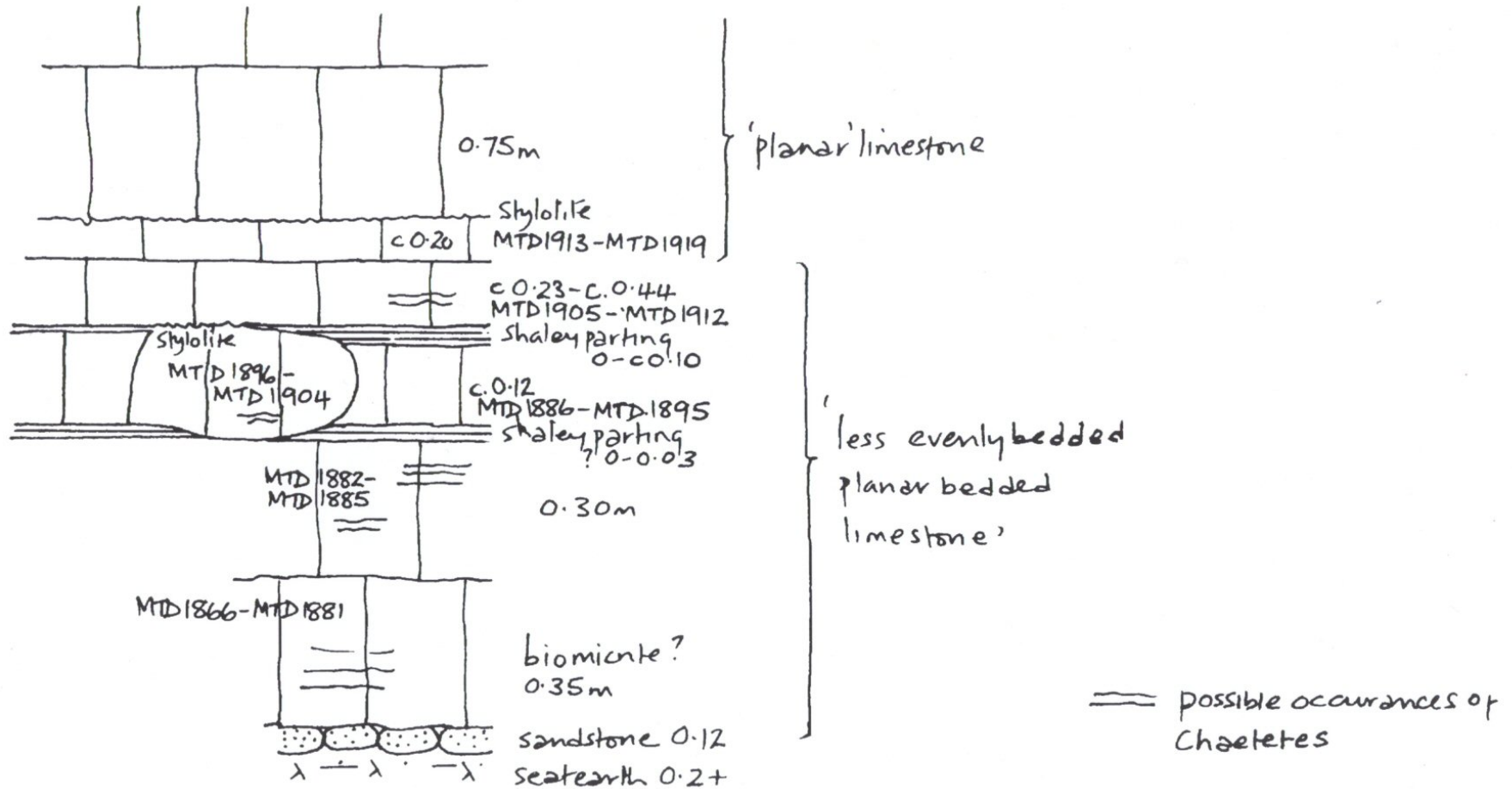


Figure 3 Field sketch of MD129 Killhope roadside exposure [NY 822 434] showing the the development of the different facies and the samples collected.

3 Faunas of the various facies as sampled at each locality

3.1 'PLANAR-BEDDED' LIMESTONE

MD124: MTD1567 – MTD1569 with bryozoan, *Overtonia fimbriata*, gastropod? mould, echinoid? fragments, crinoid columnals, infilled linear burrows.

MD124: MPA51727 (MTD1569) with *Gnathodus girtyi girtyi?*, *?Hindeodus cristulus*, *Kladognathus tenuis*, *Lochriea* sp. *Synclydagnathus scitulus*.

MD124: MTD1613 – MTD1615 with *Avonia* sp., *?Phricodothyris* sp.

MD124: MPA51732 (MTD1615) with *Gnathodus girtyi*, *Synclydagnathus scitulus*.

MD125: MTD1616 – MTD1618 with *Chaetetes* sp., *Dibunophyllum* sp., *Diphyphyllum* sp., *Lonsdaleia* sp., brachiopod fragment (indeterminate), crinoid columnal

MD126: MTD1619 – MTD1623 with foraminifera, brachiopod (juvenile), brachiopod fragments (indeterminate), gastropod? moulds, ostracods, crinoid columnals, fish fragments.

MD126: MPA51733 (MTD1623) with *?Cavusgnathus naviculus*, *Gnathodus bilineatus bilineatus*, *Kladognathus tenuis*, *Lochriea nodosa?*

MD126: MTD1706 – MTD1713 with foraminifera (abundant), stick bryozoan?, orthotetoid, productoid, *Rugosochonetes celticus*, crinoid columnals, fish material.

MD126: MPA51742 (MTD1713) with *?Gnathodus bilineatus*, *Lochriea mononodosa*, *L. nodosa*, *Synclydagnathus libratus?*, *?S. scitulus*,

MD127: MTD1772 – MTD1777 with orthotetoid, ostracod, crinoid columnals, fish material.

MD127: MPA51750 (MTD1777) with *Gnathodus bilineatus bilineatus?*, *G. girtyi girtyi*, *Kladognathus tenuis*, *Lochriea commutata*, *L. mononodosa*, *Synclydagnathus libratus*.

MD128: MTD1778 – MTD1791 with algal growths, foraminifera, compound coral (indeterminate), *Latiproductus* sp., *Phricodothyris* sp., ostracod, crinoid columnals, fish material.

MD128: MPA51751 (MTD1785) with *Gnathodus girtyi girtyi*, *Lochriea commutata*, *L. mononodosa*, *L. nodosa*, *Synclydagnathus libratus*.

MD128: MPA51752 (MTD1791) with *Gnathodus bilineatus bilineatus?*, *G. girtyi girtyi*, *?Kladognathus* sp., *Lochriea commutata*, *L. mononodosa*, *Syncladagnathus* sp.

MD129: MTD1913 – MTD1919 with *Phricodothyris* sp., productoid, echinoid? fragment, crinoid columnals, fish material.

MD129: MPA51767 (MTD1919) with *Gnathodus girtyi collinsoni?*, *G. g. girtyi?*, *Lochriea commutata*, *L. mononodosa*, *L. nodosa*, *Syncladagnathus cuspidatus*, *S. libratus?*, *S. petilus*, *S. scalenus?*, *S. scitulus*, *Vogelgnathus campbelli*.

3.2 'BIOCLASTIC' LIMESTONE

MD126: MTD1630 – MTD1637 with foraminifera, coral (indeterminate), *?Beecheria* sp., productoid spines, gastropod fragments, ostracods, crinoid columnals, fish fragments.

MD126: MPA51734 (MTD1637) with *?Cavusgnathus* sp., *Gnathodus girtyi collinsoni?*, *G. g. girtyi?*, *Hindeodus cristulus*, *Lochriea commutata*, *L. nodosa*, *Syncladagnathus cuspidatus*, *S. scitulus*.

MD128: MTD1792 – MTD1800 with *?bryozoa*, *Avonia* sp., *Phricodothyris* sp., *Rugosochonetes* sp., ostracods, crinoid columnals, fish material, spicule (indeterminate).

MPA51753 (MTD1800) with *Gnathodus bilineatus bilineatus*, *G. girtyi collinsoni*, *G. g. girtyi?*, *G. g. rhodesi?*, *Hindeodus cristulus*, *Lochriea commutata*, *L. nodosa*, *Syncladagnathus petilus?*, *S. scitulus*, *Vogelgnathus campbelli*.

MD128: MTD1813 – MTD1821 with *Diphyphyllum* sp., *?bryozoan* fragment, orthotetoid, rhynchonellid, *?Sinuatella* sp., crinoid columnals, fish material.

MD128: MPA51755 (MTD1821) with *Cavusgnathus* sp., *Gnathodus girtyi girtyi?*, *Kladognathus tenuis*, *?Ligonodina fragilis*, *Lochreia* sp., *Vogelgnathus campbelli*.

3.3 'WAVY-BEDDED' LIMESTONE

MD123: MTD1553 – MTD1562 with *Chaetetes septosus*, *Diphyphyllum fasciculatum*, bryozoa, *?Composita* sp., *Eomarginifera* sp., rhynchonellid, *?echinoid* fragments.

MD123: MPA51724 (MTD1556) with *?Cavusgnathus* sp.

MD123: MPA51725 (MTD1562) with *Cavusgnathus naviculus*?

3.4 'CHAETETES-BAND' LIMESTONE

MD123: MTD1563 – MTD1566 with *Chaetetes septosus*, *Phricodothyris* sp., *Limipecten* sp., ?echinoid fragments, fish fragment.

MD123: MPA51726 (MTD1566) with indeterminate conodont S? element.

MD124: MTD1570 – MTD1572 with *Chaetetes septosus*, *Clisiophyllum* sp. bryozoan, echinoid? fragments.

MD124: MPA51728 (MTD1572) with no conodonts.

MD124: MTD1594 – MTD1596 algal patches, *Diphyphyllum* sp., gastropod whorl (indeterminate), shell fragments (indeterminate), crinoid columnals, fish fragments.

MD124: MPA51730 (MTD1596) with *Synclydagnathus cuspidatus*.

MD124: MTD1602 – MTD1612 with *Chaetetes* sp., *Dibunophyllum* sp., *Antiquatonia* cf. *hindi*, athyrid, *Avonia youngiana*, ?*Beecheria* sp., *Gigantoproductus* sp., ?*Productus* sp., *Rugosochonetes* sp., *Sinuatella sinuata*, gastropod? fragments (indeterminate), *Dunbarella*? cf. *radiatus*, *Streblochondria* sp., trilobite pygidium, echinoid? fragment, crinoid columnals, fish fragments.

MD124: MPA51731 (MTD1612) with *Kladognathus tenuis*.

MD126: MTD1638 – MTD1644 with foraminifera, *Chaetetes* sp., ?*Dibunophyllum* sp., gastropod fragment (indeterminate), shell fragments (indeterminate), ostracod?, crinoid columnals, fish material.

MD126: MPA51735 (MTD1644) with *Vogelgnathus campbelli*.

MD126: MTD1645 – MTD1657 with foraminifera, *Chaetetes* sp., corals (indeterminate), cylindrical coral (indeterminate), *Brochocarina* sp., *Rugosochonetes* sp., *Schellweinella* sp., *Schizophoria* sp., ostracods, crinoid columnals, fish material.

MD126: MPA51736 (MTD1657) with *Cavusgnathus* sp., *Gnathodus girtyi collinsoni*, *G. g. rhodesi*?, *Synclydagnathus scitulus*, ?*Vogelgnathus campbelli*.

MD126: MTD1658 – MTD1671 with *Chaetetes* sp., *Actinocyathus floriformis*, *Syringopora* sp., ?*Avonia* sp., *Brochocarina* sp., *Pugilis* cf. *pugilis*, fish material.

MD126: MPA51737 (MTD1671) with ?*Cavusgnathus naviculus*, *Gnathodus girtyi collinsoni*, *Kladognathus tenuis*.

MD126: MTD1689 – MTD1694 with foraminifera, *Chaetetes* sp., *Actinoconchus* sp., productoid spines, crinoid columnals, fish material.

MD126: MPA51740 (MTD1694) with *Gnathodus girtyi collinsoni*, *Kladognathus complectens*?

MD126: MTD1695 – MTD1705 with *Chaetetes* sp., coral fragment (indeterminate), ?bryozoa, *Cleiothyridina* sp., orthotetoid, productoid, ostracods, crinoid columnals, fish material.

MD126: MPA51741 (MTD1705) with *Cavusgnathus naviculus*, ?*Kladognathus tenuis*.

MD127: MTD1734 – MTD1747 with *Chaetetes* sp., ?*Aulophyllum* sp., ?*Dibunophyllum* sp., *Schellweinella* cf. *crenistria*, *Schizophoria* cf. *resupinata*, gastropods (indeterminate), ostracod?, crinoid columnals, ?fish material.

MD127: MPA51745 (MTD1747) with *Cavusgnathus naviculus*, *Gnathodus girtyi girtyi*.

MD127: MTD1752 – MTD1755 with *Chaetetes* sp., gastropods (indeterminate), ?fish material.

MD127: MPA51747 (MTD1755) with no conodont elements.

MD127: MTD1764 – MTD1771 with *Chaetetes* sp., adherant bryozoan, *Latiproductus* cf. *latissimus*, ?*Productus* sp., crinoid columnals, fish material.

MD127: MPA51749 (MTD1771) with no conodont elements.

MD128: MTD1801 – MTD1812 with *Chaetetes* sp., orthotetoid, productoid, ?*Edmondia* sp., ostracods, crinoid columnals.

MD128: MPA51754 (MTD1812) with *Gnathodus girtyi girtyi*, *Kladognathus clarkei*?, *Lochreia* sp., *Syncladagnathus petilus*, *S. scalenus*, *S. scitulus*, *Vogelgnathus campbelli*.

MD128: MTD1843 - MTD1850 with *Chaetetes* sp., *Diphyphyllum* sp., *Syringopora* sp., productoid, ostracods, ?echinoid spine, crinoid columnals, fish material.

MD128: MPA51758 (MTD1850) with *Cavusgnathus naviculus?*, *Gnathodus girtyi collinsoni*, *G. symmutatus*, *Hindeodus cristulus*, *Kladognathus tenuis*, *Synclydagnathus* spp., *Vogelgnathus campbelli*.

3.5 'CHAETETES – BIOCLASTIC TRANSITIONAL' LIMESTONE

MD128: MTD1822 – MTD1828 with *Chaetetes* sp., athyrid, productoid.

MD128: MPA51756 (MTD1828) with *G. girtyi collinsoni?*

MD128: MTD1829 – MTD1842 with *Chaetetes* sp., athyrid, *Avonia youngiana?*, *Rugosochonetes* sp., *?Sinuatella* sp., crinoid columnals, fish material.

MD128: MPA51757 (MTD1842) with *Gnathodus bilineatus bilineatus*, *G. g. collinsoni?*, *G. g. girtyi?*, *G. symmutatus*, *?Idioproniodus healdi*, *Kladognathus tenuis*, *Lochriea commutata*, *Synclydagnathus scitulus*, *Vogelgnathus campbelli*.

3.6 'CORAL-BAND' LIMESTONE

MD124: MTD1573 – MTD1593 with algal patches, *Chaetetes septosus*, *Actinocyathus* sp., *Dibunophyllum bipartitum*, *Diphyphyllum fasciculatum*, *D. cf. lateseptatum*, *Lonsdalia* sp., *Fenestella* sp., athyrid, *Brochocarina* sp., *Merospirifer insolita?*, *Schellweinella* sp., gastropod? fragments indeterminate, *Streblochondria* sp., ostracods, echinoid spines, fish fragments.

MD124: MPA51729 (MTD1593) with *Gnathodus bilineatus bilineatus*.

MD124: MTD1597 – MTD 1601 with *Chaetetes* sp., *Diphyphyllum furcatum?*

MD126: MTD1624 – MTD1629 with *Dibunophyllum* sp., *Diphyphyllum cf. furcatum*, *D. cf. lateseptatum*, *Lonsdaleia* sp., brachiopod (juveniles), brachiopod fragments (indeterminate), crinoid columnals.

MD126: MTD1672 – MTD1688 with foraminifera, *Chaetetes* sp., *Actinocyathus floriformis*, *?Dibunophyllum* sp., *Diphyphyllum lateseptatum*, *Siphonodendron* sp., trepostomatous bryozoan, shell fragments (indeterminate), crinoid columnals, fish material.

MD126: MPA51738 (MTD1679) with *Kladognathus* sp., *Vogelgnathus campbelli*.

MD126: MPA51739 (MTD1688) with *?Kladognathus tenuis*.

MD127: MTD1748 – MTD1751 with *Chaetetes* sp., coral (indeterminate), trepostomatous bryozoan, gastropod (indeterminate), crinoid columnal, fish material.

MD127: MPA51746 (MTD1751) with *Gnathodus bilineatus*, *Hindeodus cristulus*, *Kladognathus tenuis?*, *Lochriea mononodosa*, *Synclydagnathus cuspidatus*, *Vogelgnathus campbelli*.

MD127: MTD1756 – MTD1763 with *Diphyphyllum* sp., crinoid columnals.

MD127: MPA51748 (MTD1763) with conodont element fragments (indeterminate).

MD128: MTD1851 – MTD1859 with *Actinocyathus floriformis?*, *?Dibunophyllum* sp., *Diphyphyllum* cf. *furcatum*, crinoid columnals.

MD128: MPA51759 (MTD1859) with indeterminate conodont fragments.

3.7 'CORAL-BAND AND BIOCLASTIC' LIMESTONE

MD128: MTD1860 – MTD1865 with *Diphyphyllum* sp., *?Avonia* sp., *?echinoid* spine, crinoid columnals, fish material.

MD128: MPA51760 (MTD1865) with *Cavusgnathus naviculus?*, *Gnathodus bilineatus bilineatus?*, *G. girtyi girtyi?*, *G. symmutatus*, *Kladognathus tenuis*, *?Lochriea commutata*, *L. nodosa*, *Synclydagnathus cuspidatus?*, *S. scitulus*, *Vogelgnathus campbelli*.

3.8 'PLANAR – WAVY TRANSITIONAL' LIMESTONE

MD129: MTD1866 – MTD1881 with foraminifer, *?scolecodont* element, bryozoan, orthotetoid, productoid, *?Rugosochonetes* sp., high spired gastropod, ostracods, echinoid spine, crinoid columnals, fish? material.

MD129: MPA51761 (MTD1873) with *Cavusgnathus naviculus*, *Gnathodus bilineatus bilineatus?*, *G. girtyi girtyi?*, *Idioprioniodus healdi*, *Kladognathus tenuis*, *Lochriea commutata*, *Synclydagnathus cuspidatus*, *S. scalenus?*, *S. scitulus*, *Vogelgnathus campbelli*.

MD129: MPA51762 (MTD1881) with *Cavusgnathus naviculus*, *Gnathodus bilineatus bilineatus*, *G. girtyi girtyi*, *Kladognathus tenuis*, *?Lochriea commutata*, *L. mononodosa*, *Synclydagnathus chauliodus?*, *S.cuspidatus*, *S. libratus*, *S. petilus*, *S. scitulus*, *Vogelgnathus campbelli*.

MD129: MTD1882 – MTD1885 with brachiopod fragment, gastropod fragments, echinoid? fragments, crinoid columnals, fish fragments.

MD129: MPA51763 (MTD1885) with *Cavusgnathus naviculus*, *Kladognathus tenuis*, *Lochriea* sp., *Synclydagnathus cuspidatus*?

MD129: MTD1886 – MTD1895 with ?*Actinoconchus* sp., athyrid (juveniles), *Latiproductus latissimus*, orthotetoid, gastropod fragments, echinoid? fragments, crinoid columnals, fish fragments.

MD129: MPA51764 (MTD1895) with *Cavusgnathus naviculus*, *Gnathodus girtyi collinsoni*?, *G. g. girtyi*?, *Kladognathus clarkei*?, *Lochriea commutata*, *L. mononodosa*, *L. nodosa*, *Synclydagnathus libratus*, *S. petilus*, *S. scitulus*.

MD129: MTD1896 – MTD1904 with bryozoan? indeterminate, *Overtonia* cf. *fimbriata*, gastropod fragment indeterminate, ostracods, echinoid? spines, crinoid columnals, fish material.

MD129: MPA51765 (MTD1904) with *Gnathodus girtyi girtyi*?, *Kladognathus tenuis*.

MD129: MTD1905 – MTD1912 with *Overtonia fimbriata*, gastropod moulds, echinoid spines, crinoid columnals, fish fragments.

MD129: MPA51766 (MTD1912) with *Cavusgnathus naviculus*, *Gnathodus girtyi girtyi*, ?*Kladognathus* sp., *Synclydagnathus cuspidatus*?, *S. scitulus*, *Vogelgnathus campbelli*.

3.9 'PLANAR-BEDDED LIMESTONE/SANDSTONE'

MD127: MTD1714 - MTD1726 with *Pleuropugnoides* cf. *pleurodon*, *Productus* cf. *carbonarius*, *Edmondia sulcata*, fish fragments, burrow traces.

MD127: MPA51743 (MTD1726) with no conodont elements.

MD127: MTD1727 – MTD1733 with foraminifer, *Chaetetes* sp., corals (indeterminate), stick bryozoan, productoid spine, gastropods (indeterminate), shell fragments (indeterminate), crinoid columnals, fish material.

MD127: MPA51744 (MTD1733) with *Cavusgnathus naviculus*, *Gnathodus bilineatus bilineatus*, *G. girtyi girtyi*, *Kladognathus* sp., *Synclydagnathus petilus*.

3.10 SANDSTONE

MD123: MTD1551 – MTD1552 with plant debris, roots.

4 Palaeoecology: an introduction

Palaeoecology is primarily concerned with determining the ecosystem of fossil communities and their environments. It is not an exact science as there are too many unknown factors involved (see Wilson, 1989, p. 110). Much of the information available for the study of modern ecosystems is simply not preserved in ancient ones (for example soft bodied animals or animal soft parts), transport may have occurred and fossil assemblages may be mixed or incomplete. Ideally we need to be studying assemblages (collections of fossils made from a single horizon or bed) and palaeocommunities (assemblages that represent a former community). Each assemblage should be an in-situ life assemblage showing no sign of prolonged transport, a long residence time on the sea floor, or vertical mixing. A full understanding of taphonomic processes is therefore necessary (see Clarkson, 1979, p. 10; Brenchley and Harper, 1998, p. 230).

The sediments of the continental shelf include those of the littoral (intertidal), lagoonal, shallow subtidal, median and outer shelf realms (Clarkson, 1979, p. 11). Wilson (1989, fig. 9) recognised in the Dinantian of central Scotland a muddy nearshore zone (represented by mudstones), an intermediate zone (represented by calcareous mudstones) and a clearer water, offshore or near-shore zone (represented by limestones). The first mentioned provided less firm substrates with dominant infaunal forms and the last mentioned gave more firm substrates with dominant epifaunal forms. It should be noted that ancient water depth is very difficult to determine, even in an approximate way, from marine fossil assemblages (Raup and Stanley, 1978, p. 255).

Modern trophic (feeding) relationships involve a web of trophic levels including primary producers (plankton and seaweeds), primary consumers (herbivores and detritus eaters), secondary consumers (carnivores) and tertiary consumers (top carnivores). In the marine environment the primary consumers include the infaunal or epifaunal filterers or suspension feeders, the epifaunal 'collectors' or detritus feeders that sweep up organic material from the sea floor, the swallows or deposit feeders that are infaunal animals that scoop up mud rich in organic material, and the grazers, which feed by selectively removing organic surface films (chiefly algal coatings) from the substratum. The primary consumers are normally most commonly preserved because of the sheer number of individuals (see Clarkson, 1979, p. 12, Raup and Stanley, 1978, pp. 236 – 239, Brenchley and Harper, 1998, pp. 240 - 241).

In the summary palaeoecologies discussed below mainly suspension-feeders are described. These were particularly characteristic of Palaeozoic shelf environments. The primary producers will have been phytoplankton, which were consumed by zooplankton. The plankton and organic detritus will have been consumed by a variety of suspension feeders (brachiopods, bivalves, bryozoans, sponges, corals and crinoids) that in turn may have been consumed by predators such as fish (see Brenchley and Harper, 1998, pp. 242 – 243).

4.1 THE PALAEOECOLOGY OF SOME CARBONIFEROUS FOSSILS

The short summary presented here is based on Wilson (1989) and a perusal of Bayer et al. (1956), Brand (1970), Clarkson (1979), Cox et al. (1969), de Laubenfels (1955), Haq & Boersma (1978), Hill (1938 - 1941), Hill (1981), Loeblich & Tappan (1964), Moore et al. (1952), Muir-Wood & Cooper (1960), Newell (1937), and Williams et al. (1965). The environmental zones of Wilson (1989, figure 9) are shown by the letters M for mudstone (indicative of his muddy nearshore zone), L for limestone (indicative of his clear water, off shore or near shore zone) and CM for calcareous mudstone (indicative of his intermediate zone).

Foraminiferida

Foraminifera: Apparently benthonic crawlers that enjoyed soft to firm substrates in lagoonal, biohermal, lower-reef slope and shelf settings. They evidently preferred well-lit, high-energy marine water but apparently also occurred in brackish and non-marine environments.

Porifera

Chaetetes: L (to CM?). Epifaunal, encrusting. Biohermal. Probably enjoyed low energy conditions in the marine environment.

Anthozoa

Clisiophyllum: L (to CM?). An epifaunal suspension feeder that lived partly buried in relatively soft to relatively firm substrates. Apparently enjoyed shallow, clear and well-lit marine waters of low energy, and low sedimentation rates in biohermal, lower reef slope and shelf settings.

Dibunophyllum: L to CM. An epifaunal sessile to partly buried, semi-infaunal suspension feeder. Enjoyed relatively firm to relatively soft substrates in shallow, clear and well-lit marine waters of low energy and low sedimentation rates in near to offshore, biohermal, lower reef slope, probably shelf, and open sea settings.

Diphyphyllum: Evidently L to CM. Apparently an epifaunal sessile to partly buried, semi-infaunal benthonic suspension feeder. *D. fasciculatum* was possibly encrusting. Probably enjoyed relatively firm to relatively soft substrates in shallow, clear and well-lit marine waters of low energy and low sedimentation rates in near to offshore, biohermal, lower reef slope and probably shelf settings. Currents were however required to provide nutrients in the form of plankton.

Siphonodendron: L to CM. An epifaunal sessile (possibly encrusting) to partly buried, semi-infaunal benthonic suspension feeder. Probably enjoyed relatively firm to relatively soft substrates in shallow, clear and well-lit marine waters of low energy and low sedimentation rates in near to offshore, lagoonal, biohermal, lower reef slope and probably shelf settings.

Syringopora: Probably L to CM. Apparently fixed sessile, encrusting epifauna on relatively firm substrates. Probably enjoyed clear and well-lit marine waters of low energy, in near to offshore, biohermal to possibly shelf settings.

Bryozoa

Fenestella: L to CM. Apparently a semi-infaunal suspension feeder that enjoyed relatively firm to perhaps relatively soft substrates in the clearer marine water of the near shore or off-shore zones.

Stick bryozoan: Probably a fixed epifaunal sessile to semi-infaunal suspension feeder that enjoyed soft to firm substrates in shallow, clear, low energy marine waters, of intermediate proximity to the shore.

Trepostomatous bryozoan: L to CM. Epifaunal sessile benthos on firmer substrates of the marine shelf. Relatively shallow, clear and calm waters.

Brachiopoda

Actinoconchus: Possibly epifaunal, partly buried.

Antiquatonia: L to CM. Epifaunal sessile benthos on firmer substrates of the marine shelf. A suspension feeder preferring clearer waters.

athyrid (including *Composita*): L to CM. Partly buried in the sediment, presumed a sessile, benthonic suspension feeder on the marine shelf, preferring clearer waters.

Avonia: L to CM. Epifaunal sessile benthos on firm substrates of the marine shelf. A suspension feeder preferring clearer waters.

Buxtonia: L to CM. Epifaunal sessile benthos on firm substrates of the marine shelf. A suspension feeder preferring clearer waters.

Cleiothyridina: L (to M). Apparently epifaunal anchored by spines on relatively firm substrates. Enjoyed clear water of the offshore to intermediate zones.

Eomarginifera: L & CM to M. Anchored by spines in a relatively soft substrate. Presumed a sessile benthonic suspension feeder on the marine shelf, preferring clearer, but tolerating more muddy waters.

Gigantoproductus: L to CM. Stabilised by mass and strong spines on a firm substrate. Presumed a sessile benthonic suspension feeder on the marine shelf, preferring clearer, well lit waters and capable of tolerating variable energy.

Latiproductus: L to CM. Epifaunal sessile benthos on firm substrates of the marine shelf. A suspension feeder preferring clearer waters.

Lingula: M to CM. Infaunal in soft substrates. Nearshore on the shallow marine shelf or in brackish lagoons.

Martinia: presumably epifaunal sessile benthos on firmer substrates of the marine shelf, a suspension feeder preferring clearer waters.

Merospirifer: Possibly partly buried epifauna.

orthotetoid (including *Schellweinella*): L to CM. Epifaunal, probably lying on the sediment surface of the marine shelf. Presumably a sessile benthonic suspension feeder that preferred clearer waters.

Overtonia: Evidently epifaunal, lying on the sediment surface, anchored by spines.

Phricodothyris: L to CM: Presumably epifaunal sessile benthos on firmer substrates of the marine shelf. A suspension feeder preferring clearer waters.

Pleuropugnoides: L & CM to M. Epifaunal, to possibly embedded in the sediment. Presumably a sessile benthonic suspension feeder that preferred clearer, but tolerated more muddy waters of the marine shelf.

productoid: includes from this list *Antiquatonia*, *Avonia*, *Buxtonia*, *Eomarginifera*, *Productus* and *Pugilis*; also *Gigantoproductus* and *Latiproductus*.

Productus: L & CM to M. Pedicle valve buried within the soft sediment of the marine shelf. A sessile benthonic suspension feeder tolerant of muddy to clear waters.

Pugilis: L to CM. Epifaunal sessile benthos on firm substrates of the marine shelf. A suspension feeder preferring clearer waters.

Rhipidomella: presumably epifaunal sessile benthos on firmer substrates of the marine shelf, a suspension feeder preferring clearer waters.

Rugosochonetes: L to CM. Epifaunal, probably lying on the sediment surface of the marine shelf. Presumably a sessile benthonic suspension feeder that preferred clearer waters.

Schizophoria: L & CM to M. Presumably epifaunal, probably lying on firm to less firm substrates of the marine shelf. Likely a sessile benthonic suspension feeder that preferred clearer, but tolerated more muddy waters.

Sinuatella: Apparently epifaunal sessile, fixed by spines to the sediment surface.

Spirifer (including *Angiospirifer*): L & CM to M. Partly buried in the sediment of the marine shelf. Presumably a sessile benthonic suspension feeder that preferred clearer, but tolerated more muddy waters.

Spiriferellina: partly buried in the sediments of the marine shelf. Presumably a sessile benthonic suspension feeder that preferred clearer, but tolerated more muddy waters.

Gastropoda

Bellerophon: CM to M. Epifaunal benthos that preferred to graze softer substrates nearshore.

Euphemites: M & CM. Infaunal or semi-infaunal benthos that ploughed through nearshore shallow marine, possibly brackish, muds.

Naticopsis: CM to M. Presumably epifaunal benthos that preferred to graze softer substrates nearshore.

Scaphopoda

Dentalium: presumably an epifaunal benthonic grazer that preferred softer substrates.

Bivalvia

Cardiomorpha: infaunal to epifauna, an endobysate shallow burrower partly buried in softer substrates of the marine shelf.

Edmondia: CM (to M & impure L). Infaunal to epifauna, an endobysate shallow burrower in softer substrates at intermediate depth on the marine shelf.

Aviculopecten: CM (to M & impure L). Epifaunal, byssally attached to free swimming at intermediate depth on the marine shelf.

Dunbarella: M to L. Apparently periodically neritic (free-swimming) and periodically an epifaunal, byssally-attached, semi-infaunal suspension feeder. Preferred relatively soft substrates in the muddy near-shore to intermediate zones of the marine environment.

Limipecten: M to L. Apparently periodically neritic (free swimming near the bottom) and periodically a semi-infaunal or epifaunal sessile suspension feeder, lying on, or byssally attached to, the sediment surface. Enjoyed relatively soft to relatively firm substrates in the muddy near-shore to clear off-shore zones of the marine environment.

Posidonia corrugata: M & CM. Benthonic, byssally attached. Preferred softer substrates of the marine shelf in low energy waters of shallow (nearshore) to intermediate depth.

Sanguinolites: CM to M. Infaunal to epifaunal. Probably burrowed softer substrates of the marine shelf. May have been endobysate. Inhabited muddy waters nearshore to clearer waters of intermediate depth.

Streblopteria: M. Epifaunal, byssally attached to free swimming. Restricted to the darker mudstones of presumably the nearshore shallow marine shelf.

Sulcatopinna: CM & L. Endobysate within or partly within especially the soft calcareous muds of the marine shelf.

Trilobita

Trilobites: L & CM to M. Epifaunal scavengers? Probably crawled or swam on firm substrates beneath clearer waters of the marine shelf.

Crinoidea

Crinoids: L & CM. Epifaunal sessile benthonic suspension feeders, apparently anchored to the firm substrate, commonly in high energy, current affected marine waters.

Miscellanea

Burrow traces: Most likely to have required a relatively soft substrate.

4.2 THE PALAEOECOLOGY AND FACIES CONTROL OF SOME CARBONIFEROUS CONODONTS

A short summary is presented here based on Dean (1987, pp. 120 - 130). According to Clark (1981) conodonts probably ranged from pelagic to benthic environments, most may have lived from just off the sea floor to much higher in the water column. They were probably active, free moving animals and are likely to have had pelagic larvae (Barnes and Fahraeus, 1975, p. 145). In general they were fairly shallow water, near-shore dwellers confined to the marine environment where they lived in association with many other diverse organisms. Most conodonts were probably stenohaline but some were probably tolerant of low salinity (Austin and Higgins, 1985, p. 22), whilst others it has been suggested, were possibly euryhaline (Barnes and Fahraeus, 1975) and some capable of withstanding hypersaline conditions (von Bitter, 1976). Conodonts seem to have been most abundant in warm, oxygenated, marine waters of low latitude in which nutrients were plentiful.

The widespread occurrence of conodonts in various coeval marine rocks, and their bilateral symmetry led to the belief that most were pelagic – a view considerably strengthened by the find of Briggs et al. (1983; see also Aldridge et al., 1986). Supportive evidence for such an existence also came from the study of depositional environments. Seddon and Sweet (1971) for example proposed depth stratification as an explanation for the pattern of conodont distribution in different rock types and concluded that conodonts were planktonic to semiplanktonic organisms whose depth was controlled by *inter alia*, temperature, light intensity and nutrient supply. Later workers noted a restriction by facies. Druce (1973, p. 211) recognized three main conodont biofacies through the upper Palaeozoic to Triassic and implied a relationship to distance from shore. Such biofacies he suggested were caused by salinity, water depth and depth stratification (Druce, 1973, p. 218). Fahraeus and Barnes (1975) recognized lateral segregation in conodont communities in Ordovician faunas. They saw the animals as almost totally nektobenthic with lateral segregation being controlled by environmental factors such as water depth and bottom conditions (see also Fahraeus, 1976; Le Fevre et al., 1976; Klapper and Barrick, 1978).

Interpretation of conodont palaeoecology requires a detailed regional description of lithologies and faunas through a continuous sequence (see for example Aldridge, 1976). In the Carboniferous, such described sequences are very rare (see for example von Bitter, 1976) but from knowledge so far accumulated it would appear that the ecological models involving lateral segregation of conodont faunas away from the shoreline most appropriately serve in the interpretation of Dinantian and early Namurian (Mississippian) conodont distribution (Austin, 1976, p. 213; von Bitter, 1976, p. 237).

With the rapid increase in available data from the 1960's onwards, it became clear that Carboniferous conodont distribution was facies influenced (see for example Merrill, 1962; Aldridge et al., 1968). Two dominant regimes were recognized representing shelf and basin

environments respectively. Austin (1976, pp. 208 – 211) provided a simplified sedimentological framework to which he related the distribution of British Dinantian platform conodont genera. He proposed that certain genera were relatively more abundant in shallow, high-energy environments (those with large basal cavities) whilst others were more abundant in the low energy, usually basinal environments (those with narrow or restricted cavities). This distinction has largely been substantiated by later publications. (see Austin and Davies, 1984, pp. 196 – 197 for summary).

Austin and Davies (1984) tried to establish a detailed model of conodont palaeoecology for the Dinantian (Lower and Middle Mississippian) of the British SW Province in terms of the stages erected by George et al. (1976), but due to a lack of available data they could do no more than recognize broad relationships between environments (as inferred from lithofacies) and conodont faunas. They recognized relatively few biofacies (Austin and Davies, 1984, fig. 21) but realized the important effect sedimentological processes had on conodont distribution across the platform (Austin and Davies, 1984, p. 213).

Evidence from the Namurian (Upper Mississippian to Lower Pennsylvanian) led Higgins (1981, p. 49) to suggest that some conodont genera (for example *Cavusgnathus*, *Synclydagnathus*, *Mestognathus*, *Lambdagnathus* and *Adetognathus*) were nektobenthic since they were abundant in shallow water, but rare or absent in deep water environments. Other genera (for example *Gnathodus*, *Lochriea* and *Idioprioniodus*) he saw as pelagic since they were found in both environments – their distribution being controlled more by ocean currents and temperature than by bottom conditions.

Higgins (1981, pp. 38, 41 – 42) recognized that Clarke's (1960) Scottish Carboniferous conodonts were from shallow marine waters and identified both a high energy shelf environment with a dominantly gnathodid and lochreid fauna, and a quiet, restricted back reef or lagoonal environment having a synclydagnathid and cavusgnathid fauna, with *Lochriea commutata* and rarely *Gnathodus girtyi*. Horowitz and Rexroad (1982, pp. 967 – 968) believed that the association of *Gnathodus*, *Lochriea* and *Idioprioniodus* represented one biofacies, whilst the association of inter alia *Cavusgnathus*, *Kladognathus*, *Hindeodus* and probably *Synprioniodina*? represented another.

The influence of the depositional environment on Carboniferous conodonts is considered below on a generic basis based on Dean (1987, and references listed therein). Only the major taxa are considered at this stage:

Cavusgnathus. This genus was environmentally controlled to a high degree. It was probably nektobenthic, euryhaline, thriving in littoral (wave agitated) inner shelf waters (though it has also been found in lagoonal, 'refoid', subtidal and basinal environments). *C. naviculus* is typical of the genus. In Scotland, Dean (1987) noted that it was abundant in mid grey, questionably dolomitised biomicrites with abundant crinoid and brachiopod debris. The apparent dolomitisation he suggested may indicate a peritidal environment.

Gnathodus. This was apparently a dominantly off shore, pelagic genus. It characterized basinal environments but has commonly been found nearer shore in inner shelf, back reef and lagoonal facies. It enjoyed a quiet, stable environment of normal salinity. *G. bilineatus* was probably a basinal species that inhabited deep water, but it is also found in shallow water sediments of the inner shelf environment. This suggests that reduced energy was an important controlling factor in the distribution of the species. In his study of Scottish Carboniferous conodonts, Dean (1987) noted that *G. bilineatus* was most abundant in light to mid grey biomicrites crowded with mainly fine crinoid and shelly debris. *G. girtyi* is also believed to have been an open sea species, but it may have inhabited nearer surface waters than *G. bilineatus* (Austin and Davies, 1984, p. 216). Its presence in basinal, inner shelf, back reef and lagoonal environments is strong evidence for a pelagic existence, independent of bottom conditions. In Scotland, Dean (1987) noted that *G. girtyi* was most abundant in mid to dark grey biomicrites and associated with much crinoid and questionably brachiopod debris. *G. symmutatus* has also been found in rocks representing deep

and shallow water environments, and its habitat must have been very similar to *G. girtyi*. In Scotland, Dean (1987) noted that the species was also found in mainly mid to dark grey biomicrites of the inner shelf environment, containing the usual comminuted macrofauna of crinoids and brachiopods.

Hindeodus. *H. cristulus* is a restricted species that was confined to the near shore, shallow marine environment, below wave base. It was an aerobic, euphotic species that probably tolerated fluctuating salinities and energies, since it has been found in 'reefoid', intertidal, lagoonal, oolite shoal, littoral delta front and Yoredale facies. In Scotland, Dean (1987) noted that *H. cristulus* was found most abundantly in inner shelf light to mid grey biomicrites in association with an abundant macrofauna of fine crinoid ossicles and comminuted, questionably brachiopod debris.

Idioproniodus. This genus has previously been recovered from both carbonate and shale facies apparently representing shallow shelf, deep shelf and basinal environments. It is a problematic genus appearing to some (for example Merrill and von Bitter, 1975; 1976) to have enjoyed quiet, relatively reducing conditions, whilst to others (for example Higgins, 1981) it may have been pelagic and independent of bottom conditions. In Scotland, Dean (1987) noted that *I. healdi* was locally abundant in mid grey biomicrites associated with generally abundant, fine to fairly coarse crinoid ossicles and brachiopod debris. Such a bio-lithotype, he suggested, must represent a shallow water, high energy, aerobic shelf environment, giving circumstantial support to a pelagic existence.

Kladognathus. This genus, which was probably pelagic, has previously been reported from shelf facies (coral/brachiopod carbonates and Yoredale mudstones and ironstones) and from basinal facies (goniatite bullion shales). Whilst its multi-element make up is problematic, the elements assigned to *K. tenuis* by Dean (1987) were most abundant in Scotland in inner shelf mid grey biomicrites with abundant small crinoid ossicles and finely comminuted, questionably brachiopod debris.

Lochriea. This genus is found in both shallow and deeper water facies, but characterizes, with *Gnathodus*, deep shelf and basinal environments. *L. commutata*, which was probably a pelagic species inhabiting the near surface zone, is cosmopolitan, being also found in quiet back reef and lagoonal facies, and high energy, inner shelf facies. The ornamented species, *L. mononodosa* and *L. nodosa* (together with *L. commutata*) are dominantly found in basinal facies where they are associated with nektonic faunas. This suggests that the ornamented species were also pelagic, independent of inhospitable bottom conditions, but inhabiting a zone below that of *L. commutata*. In Scotland, Dean (1987) noted that all three species were generally found closely associated in inner shelf, light to mid grey biomicrites containing much fine crinoid and shell debris.

Synclidagnathus. The genus, including *S. scitulus*, was environmentally controlled to a high degree (Higgins and Varker, 1982, p. 156). It may dominate littoral, back reef and lagoonal facies, and ranges into off shore, subtidal (Yoredale) facies. It occasionally occurs in basinal environments, but was most tolerant of quiet to turbulent, shallow to very shallow, aerobic waters of normal to mixed salinities, and has been found most commonly in bioclastic limestones with a rich benthic macrofauna (brachiopods, corals and crinoids). It has also been found in (*inter alia*) back reef lagoonal bioclastics, off shore neritic oolites and littoral/delta front dolomites. In Scotland, Dean (1987) noted that *S. scitulus* and the other *Synclidagnathus* species generally occurred together, but whilst common they never dominated the fauna. They were most abundant in grey biomicrites containing much crinoid and shelly (questionably brachiopod) debris.

Vogelgnathus. *V. campbelli* has previously been recovered mainly from lagoonal, oolitic, and intertidal facies representing shallow, near shore marine environments, but it has also proved locally abundant in nodular limestones of deeper platforms deposited at depths ranging from a few tens of metres to less than 200 m (Tucker and Kendall, 1973 and Tucker, 1974 both in

Higgins, 1981, p. 43). In Scotland, Dean (1987) noted that the species was most commonly found in shaley or muddy, mid grey biomicrites associated with crinoid and shelly debris. Such a facies may represent a quieter shallow shelf environment.

Asymmetry in platform conodonts of Carboniferous age is apparently mainly associated with shallow water environments, whilst basinal faunas are dominated by symmetrical or highly ornamented platform elements (Higgins and Varker, 1982, p. 156). Between these two environments, on the inner to outer shelf, corresponding with Druce's (1973) biofacies II, there will be a mixing of platform element symmetries and ornamentation. The relative abundance of species of *Gnathodus* and *Lochriea* in particular should provide an index of more basin-ward, deeper water deposition. Likewise, the relative abundance of especially *Cavusgnathus* should give a measure of shoreward deposition in shallow water (see also von Bitter, 1976, pp. 235 – 238).

Genus	P	B	W	C	C-B	Co	Co-B	P-W	LS	S
algae	1			1		1				
plants										33
roots										67
foraminifera	7	2				2		1	4	
<i>Chaetetes</i>	1		17	30	45	17			9	
<i>Actinocyathus</i>				1		11				
<i>Aulophyllum</i>				1						
<i>Clisiophyllum</i>				1						
<i>Dibunophyllum</i>	1			2		6				
<i>Diphyphyllum</i>	1	4	33	1		33	38			
<i>Lonsdaleia</i>	1					2				
<i>Siphonodendron</i>						2				
<i>Syringopora</i>				3						
compound coral	1									
cylindrical coral				1						
coral (indet.)		2		2		1			9	
<i>Fenestella</i>						1				
adherent bryozoan				1						
stick bryozoan	1								4	
trepostomatous bryozoan						2				
bryozoa	1	2	8	1				3		
scolocodont								1		
<i>Actinoconchus</i>				1				1		
athyrid (including:			-8	1(1)	7(7)	1(1)		3(3)		
<i>Composita</i>)			8							
<i>Beecheria</i>		2		1						
<i>Cleiothyridina</i>				1						
<i>Gigantoproductus</i>				1						
<i>Latiproductus</i>	3			1				4		
<i>Merospirifer</i>						1				

Genus	P	B	W	C	C-B	Co	Co-B	P-W	LS	S
orthotoid (including:	3(3)	2(2)		1(5)		(3)		3(3)		
<i>Brochocarina</i>				2		1				
<i>Schellweinella</i>)				2		2				
<i>Phricodothyris</i>	4	2		1						
productoid (including:	3(5)	4(6)	(17)	2(10)	3(10)		(13)	6(9)	4(13)	
<i>Antiquatonia</i>				2						
<i>Avonia</i>	1	2		4	7		13			
<i>Eomarginifera</i>			17							
<i>Overtonia</i>	1							3		
<i>Productus</i>				1					9	
<i>Pugilis</i>)				1						
Rhynchonellid (including:		2(2)	8(8)						(13)	
<i>Pleuropugnoides</i>)									13	
<i>Rugosochonetes</i>	1	2		2	7			1		
<i>Schizophoria</i>				2						
<i>Simuatella</i>		2		2	3					
brachiopod (indet.)	4					2		1		
gastropod (indet.)	3	2		1		1		7		
<i>Dunbarella</i>				1						
<i>Edmondia</i>				1					4	
<i>Limipecten</i>				1						
<i>Streblochondria</i>				1		1				
shell frags (indet.)				1					4	
trilobite				1						
ostracods	4	13		3		1		3		
echinoid	3		8	2		1	13	7		
crinoid columnals	47	49		16	24	8	25	46	26	
Fish material	3	4		3	3	1	13	7		
burrows	1								13	

Table 1 Summary percentage occurrences of each macrofossil genus, in each facies of the *Chaetetes*-Band, as sampled in hand specimen. For key see text.

Genus	P	B	W	C	C-B	Co	Co-B	P-W	LS	S
<i>Cavusgnathus</i>	1	5	100	19			13	7	17	
<i>Gnathodus</i>	36	32		31	65	17	38	40	42	
<i>Hindeodus</i>	1	5		6		8				
<i>Idioproniodus</i>					5			1		
<i>Kladognathus</i>	4	5		11	5	25	6	5	8	
<i>Ligonodina</i>		2								
<i>Lochriea</i>	43	23		2	10	8	19	13		
<i>Syncladagnathus</i>	14	18		15	10	8	13	22	25	
<i>Vogelgnathus</i>	1	10		9	5	17	13	12		
conodont element (indet.)				1		17				
No conodont elements				6					8	
Not sampled for conodonts										100

Table 2 Summary percentage occurrences of each conodont genus, in each facies of the Chaetetes-Band, as sampled. For key see text.

5 Palaeoecological interpretations for each facies

5.1 'PLANAR-BEDDED' LIMESTONE

See Column P on Table 1. The macrofauna, dominated by crinoid columnals, with foraminifera, productoid brachiopods (including the genera *Latiproductus*, *Avonia* and *Overtonia*), *Phricodothyris* and ostracods, indicates that the environment was characterised by epifaunal, sessile, benthonic suspension feeders that preferred firm substrates and clearer waters off- or near-shore on the marine shelf. Predominant are the crinoids that were apparently anchored to the substrate, commonly in high-energy, current affected waters.

See Column P on Table 2. The conodonts are dominated by genera *Lochriea* (including *L. commutata*, *L. mononodosa* and *L. nodosa*) and *Gnathodus* (including *G. bilineatus bilineatus*, *G. girtyi collinsoni* and *G. g. girtyi*) with subsidiary *Syncladagnathus* (including *S. libratus*, *S. petilus*, *S. scalenus* and *S. scitulus*). All three genera have been found previously in shallow water, inner shelf, back reef and lagoonal facies. Apparently nektobenthic *Syncladagnathus* will have been environmentally controlled to a large degree, but probably-pelagic *Lochriea* and *Gnathodus* will have inhabited nearer surface waters and lived independently of bottom conditions. *Lochriea* and *Syncladagnathus* may have tolerated high-energy water, but *Gnathodus* seems to have preferred a quieter environment.

5.2 'BIOCLASTIC' LIMESTONE

See Column B on Table 1. The macrofauna, dominated by crinoid columnals, with ostracods, presumably smaller productoid brachiopods (including the genus *Avonia*), and corals (including genus *Diphyphyllum*), indicates that the environment was characterised by epifaunal, sessile, benthonic suspension feeders that generally preferred relatively firm substrates and clearer waters off- or near-shore on the marine shelf. *Diphyphyllum*, however, may have been partly buried and semi-infaunal in co-existing but sporadic, relatively soft substrates. Predominant are the crinoids that were apparently anchored to the substrate, commonly in high-energy, current affected waters that provided nutrients.

See Column B on Table 2. The conodonts are dominated by genera *Gnathodus* (including *G. bilineatus bilineatus*, *G. girtyi collinsoni*, *G. g. girtyi* and *G. g. rhodesi*) and *Lochriea* (including *L. commutata* and *L. nodosa*) with subsidiary *Syncladagnathus* (including *S. cuspidatus*, *S. petilus?*, and *S. scitulus*) and *Vogelgnathus* (including *V. campbelli*). The environment appears to have been very similar to that of the ‘Planar-bedded’ limestone facies, though the bias of *Gnathodus* over *Lochriea* suggests in general a relatively quieter habitat. The presence of *Vogelgnathus* (and *Hindeodus cristulus*) supports a shallow nearshore environment, with *Cavusgnathus* sp. suggesting it was close to wave base.

5.3 ‘WAVY-BEDDED’ LIMESTONE

See Column W on Table 1. The macrofauna, dominated by the coral genus *Diphyphyllum*, with the sclerosponge *Chaetetes* and the smaller productoid brachiopod *Eomarginifera*, indicates a preference for a sessile epifauna, on relatively soft substrates beneath generally clearer waters off- or near-shore on the marine shelf. *Diphyphyllum* may have been partly buried and semi-infaunal, but like *Chaetetes* it lived in a biohermal setting and may similarly have been encrusting.

See Column W on Table 2. The conodonts are represented solely by genus *Cavusgnathus*. Only 1 element was recovered from 0.92 kg of limestone of this lithofacies and positively identified as *Cavusgnathus naviculus?* The presence of this nektobenthic, euryhaline genus seems to confirm the biohermal (‘refoid’) setting and suggests the possibility of wave agitation.

5.4 ‘CHAETETES-BAND’ LIMESTONE

See Column C on Table 1. The macrofauna is dominated by the sclerosponge *Chaetetes* (including *C. septosus*), but there are also brachiopods (including orthotetoids and productoids), crinoid columnals and corals. *Chaetetes* encrusted bioherms, preferring low energy, clearer waters, whilst the brachiopods were mainly suspension feeding, epifaunal, sessile benthos living mostly on firm substrates in clearer waters. The crinoids will probably have been anchored to the substrate enjoying higher energy, current affected waters.

See Column C on Table 2. Where elements exist in the samples the conodont genera are dominated by genus *Gnathodus* (including *G. girtyi collinsoni*, *G. g. girtyi*, *G. g. rhodesi?*, and *G. symmutatus*) with lesser *Cavusgnathus* (including *C. naviculus*), *Syncladagnathus* (including *S. cuspidatus*, *S. petilus*, *S. scalenus*, and *S. scitulus*), *Kladognathus* (including *K. clarkei?*, *K. complectens?* and *K. tenuis*) and *Vogelgnathus* (including *V. campbelli*). *Gnathodus* was probably pelagic and lived independently of bottom conditions, but *Cavusgnathus* and *Syncladagnathus* were probably nektobenthic and environmentally controlled to a high degree. All three genera have been previously recovered from inner shelf, ‘refoid’ to back reef and lagoonal facies. Whilst *Gnathodus* apparently preferred a reduced energy environment, *Syncladagnathus* could tolerate quiet to turbulent water, and *Cavusgnathus* thrived in littoral water. The conodonts suggest that perhaps in general, this was a quiet, subtidal, biohermal environment that was subjected to sporadic wave agitation.

5.5 ‘CHAETETES – BIOCLASTIC TRANSITIONAL’ LIMESTONE

See Column C-B on Table 1. The macrofauna is dominated by the sclerosponge *Chaetetes*, with crinoid columnals, and the presumably smaller, shelf-dwelling, productoid brachiopods including genus *Avonia*. All are epifaunal marine, but the transitional nature of this facies is illustrated by the two dominant forms present. *Chaetetes* encrusted bioherms, preferring low energy, clearer waters, whilst the crinoids probably anchored themselves to a firm substrate, commonly in high-energy, current affected, generally clear waters that provided nutrients.

See Column C-B on Table 2. The conodonts are dominated by genus *Gnathodus*, with subsidiary *Syncladagnathus* and *Lochriea*. They too reflect the transitional nature of this facies. Open sea species *Gnathodus bilineatus*, *G. girtyi* and *G. symmutatus* (all represented in this facies) have commonly also been found in inner shelf and back reef facies. *G. girtyi* (and probably *G. symmutatus*) may have inhabited nearer surface waters than *G. bilineatus* whose distribution may have been controlled by reduced energy. *G. girtyi* probably existed independently of bottom conditions. Genus *Lochriea* characterizes, with *Gnathodus*, deep shelf and basinal environments. *L. commutata* (represented in this facies), was probably a pelagic species inhabiting the near surface zone. It is cosmopolitan, being also found in quiet back reef and lagoonal facies, and high-energy, inner shelf facies. The genus *Syncladagnathus*, (including *S. scitulus*) was environmentally controlled to a high degree. It may dominate littoral, back reef and lagoonal facies, and ranges into off shore, subtidal (Yoredale) facies. Whilst occasionally occurring in basinal environments it was most tolerant of quiet to turbulent, shallow to very shallow, aerobic waters of normal to mixed salinities, and has been found most commonly in bioclastic limestones with a rich benthic macrofauna (including brachiopods and crinoids). It has also been found in back reef lagoonal bioclastics and other facies.

5.6 'CORAL-BAND' LIMESTONE

See Column CO on Table 1. The macrofauna is dominated by *Diphyphyllum* (including *D. fasciculatum*, *D. furcatum?* and *D. lateseptatum*) and other corals including *Actinocyathus floriformis*, the sclerosponge *Chaetetes* (including *C. septosus*) and brachiopods. The macrofaunal evidence shows that the palaeoenvironment was shallow marine, favouring a biohermal, lower reef slope or shelf setting of mainly intermediate to offshore proximity. It also suggests that the waters were clear and of low energy. The carbonate-favouring macrofauna appears to have been capable of tolerating a range of clastic content, and the relatively firm or soft substrate favoured a sessile, suspension feeding epifauna that included partly buried forms.

See Column CO on Table 2. The conodont genera, where identified, are dominated by genus *Kladognathus* (including *K. tenuis?*) with subsidiary *Gnathodus* (including *G. bilineatus bilineatus*) and *Vogelgnathus* (including *V. campbelli*). *Kladognathus* was probably pelagic and lived independently of bottom conditions. It has been found previously in shelf facies, including coral/brachiopod carbonates. *Gnathodus* apparently enjoyed quieter conditions and was common on the shelf in back reef and lagoonal facies. *Vogelgnathus* has previously been recovered from what have been considered quieter, shallow shelf environments. The conodont fauna therefore largely supports the macrofaunal environmental interpretation.

5.7 'CORAL-BAND AND BIOCLASTIC' LIMESTONE

See Column CO-B on Table 1. The transitional nature of this facies is illustrated by the two dominant macrofaunal forms present, *Diphyphyllum* and crinoid columnals. Whilst both preferred clearer marine waters, *Diphyphyllum* was apparently mainly an epifaunal sessile to partly buried, semi-infaunal benthonic suspension feeder that probably enjoyed relatively firm to relatively soft substrates, shallow, well-lit marine waters, low energy, low sedimentation rates, and near to offshore, biohermal, lower reef slope and probably shelf settings. Crinoids, however, were epifaunal sessile benthonic suspension feeders, apparently anchored to a firm substrate, commonly in high energy, current affected marine waters. Whilst *Diphyphyllum* preferred low energy environments, currents would have been required to provide nutrient in the form of plankton.

See Column CO-B on Table 2. The conodonts are dominated by genera *Gnathodus* and *Lochriea*, with subsidiary *Cavusgnathus*, *Syncladagnathus* and *Vogelgnathus*. They too reflect the transitional nature of this facies. Open sea species *Gnathodus bilineatus*, *G. girtyi* and *G. symmutatus* (all represented in this facies) have commonly also been found in inner shelf and

back reef facies. *G. girtyi* (and probably *G. symmutatus*) may have inhabited nearer surface waters than *G. bilineatus* whose distribution may have been controlled by reduced energy. *G. girtyi* probably existed independently of bottom conditions. Genus *Lochriea* characterizes, with *Gnathodus*, deep shelf and basinal environments. *L. commutata* was probably a pelagic species inhabiting the near surface zone. It is cosmopolitan, being also found in quiet back reef and lagoonal facies, and high-energy, inner shelf facies. *L. nodosa* was also pelagic, independent of inhospitable bottom conditions, but inhabiting a zone below that of *L. commutata*. The genus *Synclidagnathus* (including *S. scitulus*) was environmentally controlled to a high degree. It may dominate littoral, back reef and lagoonal facies, and ranges into off shore, subtidal (Yoredale) facies. Whilst occasionally occurring in basinal environments it was most tolerant of quiet to turbulent, shallow to very shallow, aerobic waters of normal to mixed salinities, and has been found most commonly in bioclastic limestones with a rich benthic macrofauna (including brachiopods and crinoids). It has also been found in back reef lagoonal bioclastics and other facies. *Cavusgnathus* was environmentally controlled to a high degree. It was probably nektobenthic, euryhaline, thriving in littoral (wave agitated) inner shelf waters (though it has also been found in peritidal, lagoonal, 'refoid', subtidal and basinal environments). *Vogelgnathus* has previously been recovered from lagoonal, oolitic, intertidal and nodular limestone facies representing shallow shelf, near shore and deeper platform environments.

5.8 'PLANAR-WAVY TRANSITIONAL' LIMESTONE

See Column P-W on Table 1. The macrofauna is dominated by crinoid columnals, with productoid brachiopods (including the genera *Latiproductus*, and *Overtonia*), indicating that the environment was characterised by epifaunal, sessile, benthonic suspension feeders that preferred firmer substrates and clearer waters off- to near-shore on the marine shelf. Predominant are the crinoids that were apparently anchored to the substrate, commonly in high-energy, current affected waters.

See Column P-W on Table 2. The conodonts are dominated by genera *Gnathodus*, with *Synclidagnathus* and subsidiary *Lochriea* and *Vogelgnathus*. They reflect the transitional nature of this facies. Open sea species *Gnathodus bilineatus* and *G. girtyi* (both represented in this facies) have commonly also been found in inner shelf and back reef facies. *G. girtyi* may have inhabited nearer surface waters than *G. bilineatus* whose distribution may have been controlled by reduced energy. *G. girtyi* probably existed independently of bottom conditions. The genus *Synclidagnathus* was environmentally controlled to a high degree. It may dominate littoral, back reef and lagoonal facies, and ranges into off shore, subtidal (Yoredale) facies. Whilst occasionally occurring in basinal environments it was most tolerant of quiet to turbulent, shallow to very shallow, aerobic waters of normal to mixed salinities, and has been found most commonly in bioclastic limestones with a rich benthic macrofauna (including brachiopods and crinoids). It has also been found in back reef lagoonal bioclastics and other facies. Genus *Lochriea* characterizes, with *Gnathodus*, deep shelf and basinal environments. *L. commutata* was probably a pelagic species inhabiting the near surface zone. It is cosmopolitan, being also found in quiet back reef and lagoonal facies, and high-energy, inner shelf facies. *L. mononodosa* and *L. nodosa* were also pelagic, independent of inhospitable bottom conditions, but inhabiting a zone below that of *L. commutata*. *Vogelgnathus* has previously been recovered from lagoonal, oolitic, intertidal and nodular limestone facies representing shallow shelf, near shore and deeper platform environments.

5.9 'PLANAR-BEDDED LIMESTONE/SANDSTONE'

See Column LS on Table 1. The macrofauna comprises mainly crinoid columnals, with smaller productoid brachiopods (including genus *Productus*), the rhynchonellid brachiopod *Pleuropugnoides* and burrow traces. This indicates that the varied environment was characterised by epifaunal (including partly buried) sessile, benthonic suspension feeders that preferred firm to

soft substrates and clear to muddy waters of the off to near-shore marine shelf. Predominant are the crinoids that apparently anchored to a firm substrate, commonly in high-energy, current affected generally clear waters that provided nutrients. Of minor, but perhaps significant occurrence are the indeterminate corals and genus *Chaetetes*. The latter encrusted bioherms, preferring low energy and clearer waters.

See Column LS on Table 2. A varied environment is also indicated by the conodonts present. Where they existed, the conodonts are dominated by the genus *Gnathodus*, with subsidiary *Syncladagnathus* and *Cavusgnathus*. *Gnathodus* was probably pelagic and lived independently of bottom conditions. The forms present, *G. bilineatus* and *G. girtyi* are open sea species, but they have commonly also been found in inner shelf and back reef facies. *G. girtyi* probably inhabited nearer surface waters than *G. bilineatus* whose distribution may have been controlled by reduced energy. Genus *Syncladagnathus* (represented here by *S. petilus*) was environmentally controlled to a high degree. It may dominate littoral back reef and lagoonal facies and ranges into off shore, subtidal (Yoredale) facies. Whilst occasionally occurring in basinal environments it was most tolerant of quiet to turbulent, shallow to very shallow, aerobic waters of normal to mixed salinities, and has been found most commonly in bioclastic limestones with a rich benthic macrofauna (including brachiopods and crinoids). It has also been found in back reef, lagoonal bioclastics and other facies. Genus *Cavusgnathus* (represented here by *C. naviculus*) was environmentally controlled to a high degree. It was probably nektobenthic, euryhaline, thriving in littoral (wave agitated) inner shelf waters (though it has also been found in peritidal, lagoonal, 'refold', subtidal and basinal environments).

5.10 SANDSTONE

See Column S on Tables 1 and 2. The plant debris and roots present suggest the sandstone was deposited as a possibly emergent, prograding, lobate delta. This bio/lithofacies was not considered suitable for processing for conodonts.

6 Conclusions

- The *Chaetetes* –Band is variably developed and consists of several limestone facies.
- New collections at 7 localities on the Alston Block, have shown that each main facies of the *Chaetetes*-Band had its own environmental setting, as deduced from the palaeoecology of its fossil community.
- The 'Planar-bedded' limestone facies was developed on firmer substrates in clearer, current-affected waters on the marine shelf. Crinoids and brachiopods, and the conodont genera *Lochriea* and *Gnathodus* with *Syncladagnathus* dominated it.
- The 'Bioclastic' limestone facies was developed on mainly relatively firm substrates in clearer, mixed energy waters on the marine shelf. Crinoids with productoid brachiopods and corals, and the conodont genera *Gnathodus* and *Lochriea* with *Syncladagnathus* and *Vogelgnathus* dominated it.

- The 'Wavy-bedded' limestone facies was developed on relatively soft substrates beneath generally clearer waters on the marine shelf. *Diphyphyllum* with *Chaetetes* and the brachiopod *Eomarginifera* dominated the fauna with the sole conodont genus *Cavusgnathus*.
- The 'Chaetetes-band' limestone facies was developed in a biohermal setting with firm substrates and clearer, calm to perhaps wave-agitated waters on the marine shelf. *Chaetetes* with brachiopods, crinoids and corals, and the conodont genera *Gnathodus* with *Cavusgnathus* and *Synclydagnathus* dominated it.
- The 'Coral-band' limestone facies was developed in a biohermal, lower reef slope or shelf setting with relatively firm or soft substrates beneath clear, shallow, low energy marine waters. *Diphyphyllum* with other corals, *Chaetetes*, and brachiopods, and the conodont genera *Kladognathus* with *Gnathodus* and *Vogelgnathus* dominated it.
- Facies intermediate to the main ones listed above appear to show transitional environmental settings with a mixing of the dominant faunas.
- The main macrofaunal elements referred to above were largely benthonic and sessile, but the conodonts were probably nektobenthic or pelagic. *Cavusgnathus* and *Synclydagnathus* will have lived in shallow water and have been environmentally controlled to a large degree, whilst *Gnathodus* and *Lochriea* will have lived higher in the water column, independent of bottom conditions. The relative abundance of these genera apparently indicates distance from shore and water depth. They may provide a means to measure eustacy and cyclicity in Yoredale facies.
- Lists of about 200 sections and boreholes in the Great Limestone are included to encourage further study of the palaeogeography of the *Chaetetes*-Band and its variable development across Northern England.

Appendix 1

Fossil inventory

ALGAE

algal material

PLANTAE

plant material

roots

FORAMINIFERIDA

foraminifera

PORIFERA

Chaetetes depressus (Fleming 1828)

Chaetetes septosus (Fleming 1828)

ANTHOZOA

Actinocyathus floriformis (Martin 1809) *laticlavia* Smith 1916a

Aulophyllum sp.

Clisiophyllum sp.

cylindrical coral (indeterminate)

Dibunophyllum bipartitum (McCoy 1849)

Diphyphyllum fasciculatum (Fleming 1828)

Diphyphyllum furcatum (Thompson 1887)

Diphyphyllum lateseptatum McCoy 1849

Koninckophyllum interuptum Thomson and Nicholson 1876

Lonsdaleia sp.,

Siphonodendron sp.,

Syringopora sp.

ANNELIDA

scolecodont element

BRYOZOA

adherent bryozoan

Fenestella sp.

stick bryozoan

trepostomatous bryozoan

BRACHIOPODA

Actinoconchus sp.

Alitaria panderi (Muir-Wood and Cooper 1960)

Antiquatonia hindi (Muir-Wood 1928)

Avonia youngiana (Davidson 1860)

Beecheria sp.

Brachythyris sp.

Brochocarina sp.

Cleiothyridina sp.

Composita sp.

Dielasma sp.

Eomarginifera sp.

Gigantoproductus sp.

Latiproductus latissimus (J Sowerby 1822)

Martinia sp.

Merospirifer insolata Reed 1949

orthotetoid

Overtonia fimbriata (J de C Sowerby 1824)

Phricodothyris sp.

Pleuropugnoides pleurodon (Phillips 1836)

Productus carbonarius de Koninck 1842

Pugilis pugilis (Phillips 1836)

Rugosochonetes celticus Muir-Wood 1962

Schellweinella crenistria (Phillips 1836)

Schizophoria resupinata (Martin 1809)

Sinuatella sinuata (de Koninck 1851)

spiriferid

GASTROPODA

gastropod material

BIVALVIA

Dunbarella radiatus (Phillips 1836)

Edmondia sulcata (Fleming 1828)

Limipecten sp.

Solemya costellata (McCoy 1844)

Streblochondria sp.

ARTHROPODA

trilobite pygidium,

ostracods

CRINOIDEA

crinoid columnals

ECHINOIDEA

echinoid material

PISCES

fish material

CONODONTA

Cavusgnathus naviculus (Hinde 1900)

Gnathodus bilineatus (Roundy 1926) *bilineatus* Bischoff 1957

Gnathodus girtyi Hass 1953 *collinsoni* Rhodes, Austin & Druce 1969

Gnathodus girtyi Hass 1953 *girtyi* Rhodes, Austin & Druce 1969

Gnathodus symmutatus Rhodes, Austin & Druce 1969

Hindeodus cristulus (Youngquist & Miller 1949)

Idioproniodus healdi (Roundy 1926)

Kladognathus clarkei (Rhodes, Austin & Druce 1969)

Kladognathus tenuis (Branson & Mehl 1941a)

Ligonodina fragilis Hass 1953

Lochriea commutata (Branson & Mehl 1941c)

Lochriea mononodosa (Rhodes, Austin & Druce 1969)

Lochriea nodosa (Bischoff 1957)

Synclydagnathus chauliodus Varker 1967

Synclydagnathus cuspidatus Varker 1967

Synclydagnathus libratus Varker 1967

Synclydagnathus petilus Varker 1967

Synclydagnathus scalenus Varker 1967

Synclydagnathus scitulus (Hinde 1900)

Vogelgnathus campbelli (Rexroad 1957)

ICHNOFOSSILS

burrow traces

Appendix 2

A provisional list, compiled from the literature, of Great Limestone and possible *Chaetetes*-Band exposures in the Northern England Province.

Tyne to Stainmore (Alston Block) district (Sheets 19 and 25, and parts of 13, 24, 26, 31, 32)

Dunham (1990) referred to Hodge (1965) for “all available sections of the limestone” and Fairburn (1978) for the *Chaetetes*-Band. He gave the following sections in the Great Limestone, without mention of the *Chaetetes*-Band:

Allenheads No. 2 Borehole [no NGR given]

Barneycraig East [NY 804 466] (already collected for this study)

Bollihope [NZ 004 349]

Brandon Walls Mine, Rookhope [NY 947 412]

Burtree Pasture Mine [no NGR given]

Carricks Mine [NY 861 380]

Chopwell Borehole [NZ 1438 5734]

Coldberry Mine [no NGR given]

Collier Law Borehole [no NGR given]

Cross Fell and Dun Fell [no NGR given] (see Johnson and Dunham, 1963)

Coalcleugh [NY 801 451]

Crook Borehole [no NGR given] (see Woolacott, 1923)

Deadfriars Borehole [no NGR given]

Greenlaws Mine/Vein [no NGR given]

Harehope Gill [NZ 032 353]

Hunstanworth (Taylor and other shafts) [no NGRs given]

Lintz Ford Boring, near Chopwell [NZ 1438 5743]

Lodge Gill Mine [no NGR given]

Lunehead Mine, Teesdale [NY 846 205]

Middle Tongue Beck, near [NY 703 317]

Mohopehead Mine, West Allendale [NY 759 500]

Middle Fell and Nenthead (*Chaetetes*-Band already collected from the latter at [NY 785 430] for this study)

Roddymoor Boring, Crook [NZ 1513 3635]

Sipton Shaft, East Allendale [NY 8468 4987]

Stanhope quarries [no NGR given, but questionably in the area of NY 99 39]?

Sunnyside Shaft and Borehole [no NGR given]

Swinhope Boreholes [no NGR given] (see Dunham and Johnson, 1962; Brand, 2004)

Woodland [NZ 1513 3635]

Woodland Borehole [no NGR given] (see Mills and Hull, 1968)

Is the *Chaetetes*-band present at any of these localities?

Maryport district (Sheet 22)

Eastwood (1930, pp. 21 - 27) gave details of the First Limestone, but did not refer to the *Chaetetes*-Band. He listed exposures at:

Broughton Craggs quarries c. 410 m NW of Papcastle Station

Brigham Quarries, Brigham

Ellerbeck Quarry, c. 230 m SW of Ellerbeck, near Brigham.

The first two of these exposures appear promising, but is the *Chaetetes*-Band present there?

Cockermouth and Caldbeck district (Sheet 23)

Eastwood et al. (1968, p. 161) stated that the Great Limestone is characterised by a distinct faunal assemblage that includes (amongst other taxa) *Chaetetes septosus*. That fossil was mentioned at the following localities:

- 5 Isel Park
- 13 Dobby Quarry
- 65 Uldale Mill
- 87 Baggra Yeat
- 88 Snowhill [NY 268 381]? (see locality 199 below)
- 97 Bankhouse
- 193 Wellrash, quarry at [NY 2402 4132]

The Great Limestone was also exposed at the following fossil localities:

- 188 Close, quarry at [NY 2343 4160]
- 189 Daleside, north quarry at [NY 2706 3941]
- 190 Daleside, south quarry at [NY 2705 3934]
- 194 Sandale [NY 2471 4077]
- 197 Daleside, crags at [NY 2645 3858]
- 198 Seat, quarry in swallow hole at [NY 2908 4048]
- 199 Snowhill, quarry at [NY 268 381]
- 200 Parkhead, quarry at [NY 3371 4037]
- 201 Parkhead, quarry at [NY 3393 4044]
- 202 Ryelands, quarry at [NY 3331 4071]
- 203 Chalk Beck, old quarry on right bank at [NY 3417 4714]

Is the *Chaetetes*-Band present at any of these localities?

The Great Limestone was also exposed at the following field localities:

Angerton Bank Quarry, apparently at [NY 252 411]

Brocklebank, southern quarry [NY 3054 4292]

Cald Beck. Note that there is a quarry in the Tyne Bolton Limestone at [NY 3413 3980]

Faulds Brow. Note that there is a quarry in the Jew Limestone at [NY2978 3992]

Headend Quarry, apparently at [NY 250 408]

Kirkstead, old quarry [NY 3418 4715]. It is not known if the Great Limestone is fully exposed here.

Lowling, old quarry. Presumably the NGR is the same as that for the Lowling boreholes. It is not known if the Great Limestone is fully exposed here.

Lowling No. 3 Borehole [NY 3149 4676]

Lowling No. 5 Borehole [NY 3143 4646]

Newbiggin Grange, stream section and quarry, apparently at [NY 2168 4066]

River Caldw. Note there is a quarry in the Jew Limestone at [NY3415 3952]

Seat, quarry (worked in 1968) [NY 2835(or 9) 4010]

Townthwaite Beck, apparently at [NY 2898 4210]

Is the *Chaetetes*-Band present at any of these localities?

Penrith district (Sheet 24)

See also Brand (2003c). Arthurton & Wadge (1981, p. 54) stated that the best exposures of the Great Limestone are in disused quarries and stream sections near Meathaw Hill on the Penrith – Alston road, and in Crowdundle Beck, east of Blencarn. The *Chaetetes*-Band is mentioned at Crowdundle Beck, Cross Fell [NY 6969 3353 – NY 6895 3281] (see Arthurton & Wadge, 1981, pp. 150 - 151; Johnson and Dunham, 1963).

Arthurton & Wadge (1981) referred (with maps and sections) to other sections in the Great Limestone (without referring to the *Chaetetes*-Band) at:

Croglin Water river cliff [NY 6322 4661]

Green Fell Scar [NY 6674 3610] (where the Frosterly Band was mentioned)

Hartside House disused quarry [NY 6898 4346]

High Head No. 2 Borehole [NY 4115 4434]

IGS Barrock Park Borehole [NY 4613 4660] (see also Brand, 2003a)

Knar Burn (head of) [NY6505 4783] (where the limestone was noted as heavily faulted, and no mention was made of the underlying beds)

Meathaw Hill disused quarry [NY 6791 4249]

Newton Rigg, Penrith (borehole at) [NY 4932 3103]

Penrith – Alston road scarp [NY 689 433]

Raehow End, Cross Fell [NY 679 366]

Raven Beck (tributary of) [NY 6337 4488]

Rowgill Burn (headwaters of) [NY 6585 4225]

Thornhope Burn [NY 6774 4850] (where the limestone was noted as faulted, and no mention was made of the underlying beds)

Is the *Chaetetes*-band present at any of these localities?

West Cumbria district (Sheet 28)

Akhurst et al. (1997, p. 56) mentioned that the First Limestone contains the *Chaetetes*-Band near its base, and referred to an active quarry at Tendley Hill [NY 088 286]. Is the *Chaetetes*-band present there?

Eastwood (1930, p. 23) referred to “fine quarries of Hotchberry Brow, questionably at the northern margin of Sheet 28. Is the *Chaetetes*-band present there?

Brough-under-Stainmore district (Sheet 30)

Burgess & Holliday (1979, p. 64) referred to the *Chaetetes*-Band being well developed in the Brough-under-Stainmore district. Exposures included in Dowgill Beck [NY 8488 1460].

They referred (pp. 105 - 107) to other sections in the Great Limestone, but without referring to the *Chaetetes*-Band, at:

Easter Beck c. [NY 8990 2523]

Hudeshope Beck? (and River Tees) c. [NY 946 253]

Mousegill c. [NY 8255 1297]

North Skears? c. [NY 953 288]

Shields Beck? c. [NY 9695 2295]

Sleightholme Beck c. [NY 9671 1241]

Snaisgill Sike? c. [NY 953 269]

Wemmergill Beck? c. [NY 885 247]

Wester Beck c. [NY 8950 2542]

Yosgill Sike c. [NY 7883 1543]

Is the *Chaetetes*-Band present at any of these localities?

Stainmore to Craven (Askrigg Block) district (Sheets 40, 41 and 50, and parts of 31, 32, 51, 60 and 61)

Dunham & Wilson (1985, pp. 23, 52, table 5, fig. 11) referred to the *Chaetetes*-Band at Swinner Gill, Swaledale [NY 9118 0118] and stated that the *Chaetetes* Biostrome occurs throughout most of Mallerstang (Turner, 1962). They also mentioned the following exposures and sections in the Great (and Main) Limestone:

Blea Grin Gill [SD 7862 8771]

Browna Gill [SE 0098 9702]
Chantry Borehole, Middleton Tyas [NZ 2469 0705] [NZ 2467 0755]
Church Gill [NZ 1429 0055]
Coverham [no NGR given]
Deep Gill [NY 7778 0031]
East Gill [NY 8975 0202]
Fairfold Hush, Swaledale [NY 9417 0135]. Where the Main Chert is exposed at [NY 9420 0142]
Fell End Hush [NZ 021 024]. The main reference is to the Main Chert.
Fossdale Gill [SD 8638 9551]
Fountains Fell [SD 8744 7124]
Grainy Gill [SD 8706 9708]
Great Shunner Fell [no NGR given]
Great Sleddale Beck [NY 8320 9910]
Greenseat Beck [SD 8975 9643]
Greensett Crags, Whernside [SD 748 817] (see Hughes, 1909; Hicks, 1959)
Gunnarside Gill, Swaledale [no NGR given]
High Clint, Stags Fell [SD 880 922]
High Clint Wensleydale [no NGR given]
Kisdon, Swaledale [no NGR given] (see Rowell & Scanlon, 1957)
Little Punchard Gill [NY 9592 0355]. The main reference is to the Main Chert.
North Rake Hush, Arkengarthdale [no NGR given]
Oxnop No.2 Borehole [SD 9311 9470]
Parpin Gill Moss, Sleddale [SD 8521 8437]
Pen-y-ghent [SD 8428 7346]
Redmire Quarry [SE 0470 9300]
Satron High Walls, Swaledale [no NGR given]
Slei (Furn) Gill [NZ 0216 0323]
Stainmore Outlier [no NGR given] (see Owens & Burgess, 1965)
Stodart Hush, Arkengarthdale [NY 9823 0300]. The main reference is to the Main Chert.
Summer Lodge Beck [SD 9643 9516]
Swarth Fell [no NGR given] (see Rowell & Scanlon, 1957; Hicks, 1957)
Widdale Fell [SD 7853 8768]

Apparently, faunal-bands are rare in the SE part of the Askrigg Block, for example Pen-y-ghent (Dunham & Wilson, 1985, p. 51), but which localities in this list (if any) occur at Mallerstang where the *Chaetetes* Biostrome occurs, and is the *Chaetetes*-Band present at any of the remaining localities?

Settle district (Sheet 60)

Arthurton et al. (1988) made no mention of the *Chaetetes*-Band in the Settle district, but on pp. 70 - 71 they referred to the Great (Main) Limestone in the Darnbrook Beck headwaters [SD 8725 7173 – SD 8742 7171] and [SD 8727 7132 – SD 8739 7138]. Is the *Chaetetes*-Band present at this locality?

For the sake of completeness, the following list is part of that compiled by P J Brand (originally submitted on 08 September 2004) of fossiliferous exposures (including boreholes) collected from the Namurian of Northern England. Those referring at least in part to the Great Limestone include

Exposure or borehole	BGS Reg. No.	National Grid Reference
Quarry N of West Layton		NZ 1433 1047
R Tees at Abbey Bridge		NZ 0663 1496
Old Quarry, Lamb Hill		NZ 0229 1339
Sleightholm Beck		NY 965 114
River Greta 1070m E37S of Bowes Moor Hotel		NY 9365 1174
River Greta 275m S9W of Old Spital		NY 9105 1185
Huggill Sike 870m E of East Millwaters		NY 9769 1267
Quarry 805m S10E of church at Mickleton		NY971 230
Tarn Gill 730m at 108° from Tarn House		NY 8155 1879
Augill Beck 430m upstream from Augill Bridge		NY 8180 1498
Dowgill Beck at waterfall 260m N of Light Trees Farm		NY 8487 1460
Crowdundle Beck		NY 6915 3315
Hartside House Quarry (Dowhill Quarry)		NY 6898 4346
Weasel Beck		NY 6309 4704
Knar Burn		NY 6505 4783
New Water		NY 590 511
New Water 1050m above River Gelt		NY 591 516
Great Dun Fell		NY 706 326
Scars on N side of Mickle Fell		NY 8132 2501
Maldon Fell, scar W of Maldon Hall		NY7752 2891
Rive Nent, at Nenthead		NY 786 430
Sunnyside 1 Bore	NZ 03NE/11	NZ 052 350
Woodland Bore	NZ 02NE/4	NZ 0910 2769
Roddymoor Bore	NZ 13NE/146	NZ 1513 3634
Mount Pleasant Quarry		NZ 0328 1508
Easter Beck near spring		NY 8989 2521
Stable Green Quarry		NY 9191 2812
Stoneygill Beck		NY 9318 2653
Shears Quarry, E side of Hindeshope Beck		NY 9486 2726
Brockesgill		NY 9242 2739
Parson Byers Quarry		NZ 0042 3670
New Frosterly Quarry		[NZ 0113 3715]
Dead Friars, Edmondbyers Bore	NY 94SE/1	NY 968 448
Rookhope Bore	NY 94SW/1	NY 9375 4278
Barrock Park Bore	NY 44NE/28	NY 4613 4660

BGS Internal Report IR/07/023R

Wood Close Bore?	NY 43NW/2	NY 4098 3794
Throckley Bore	NZ 16NW/45	NZ 1456 6762
Brunton Bank Quarry		NY 9284 6994
Angerton Quarry 740m S of Greenhead		NY 659 646
Quarry 550m S of Tindale Tarn		NY 601 580
Clowskill Quarry 1210m ESE of Haltonleagate		NY 591 592
Forest Head Quarry		NY 584 574
Quarry 550m S of White House		NZ 016 786
Scarp at Wellhouse		NZ 026 837
Mootlaw Quarry		NZ 020 763
Greenleighton Quarry		NZ 0345 9214
Wards Hill Quarry		NZ 0798 9648
Acklington Station Bore	NU 20SW/53	NU 2210 0153
Acklington Colliery 10/3 Bore	NU 20SW/48	NU 2044 0257
Hazonlea 2 water Bore	NU 10SE/9	NU 187 043
Hazon Ford Bore	NU 10SE/10	NU 194 042
Guyzance Bore	NU 20SW/55	NU 2201 0269
Warkworth Bore	NU 20NW/17	NU 2402 0554
Boulmer Bore	NU 21SE/3	NU 2609 1315
Liddel Water 460m S24E of Shiellingmoss		NY 4362 7727
Liddel Water 915m N26E of Crookholm		NY 4303 7723
Staffler Bore	NY 37SW/1	NY 3297 7227
Cranberry Bore	NY 36NW/3	NY 3072 6949
Knottyholm Bore	NY 37NE/6	NY 3948 7713
Archerbeck Bore	NY 47NW/14	NY 4157 7815
Bigrigg 6 Bore	NX 91SE/99	NX 9945 1280
Bigrigg 5 Bore	NX 91SE/104	NX 9936 1290
High Walton Bore	NX 91SE/209	NX 9853 1270
Winder Gate 2 Bore	NY 01NW/36	NY 0413 1779
North Lonsdale 3 Bore	NY 02SE/31	NY 0752 2125
Ulloch 1 Bore	NY 02SE/137	NY 0652 2418
Ulloch 4 Bore	NY 02SE/140	NY 0572 2422
Gatra 4 Bore	NY 02SE/38	NY 0691 2085
Branthwaite Outgang Bore	NY 02NW/47	NY 0484 2509
Rowhall Farm Bore (see Brand, 2003b)	NY 03NE/49	NY 0851 3664
Lowling 5 Bore	NY 34NW/7	NY 3143 4646
North quarry 915m E30N of Daleside		NY 2706 3941
Quarry 640m ESE of Barnatrig		NY 3417 4714
Brocklebank Quarry 1140m E25N of Hilltop		NY 3054 4292
Quarry 320m S of Parkhead		NY 3371 4037
Quarry 320m S of Close		NY 2343 4160
Quarry 400m SW of Wellrash		NY 2402 4132
Quarry 45m S of Angerton Bank		NY 252 411
Headend Quarry, 1205m SSW of Angerton Bank		NY 250 408
Quarry in swallow hole, 1005m ENE of Trig. point 1129' on seat		NY 2908 4048
Overend Quarry		NX 9897 1645
Townthwaite Beck 640m W35S of Hilltop		NY 2898 4210

Knock Ore Gill between Great Dun Fell and Knock Fell		NY 7162 3126
Fourstones Quarry		NY 8869 6872
Chestergarth Quarry, Rookhope		NY 9431 4189
Stream at Clargillhead		NY 729 499
R. West Allen at Carrshield		NY 8032 4646
Barneycraig Quarry, Carrshield		NY 8033 4663
Roadside at Killhope		NY 822 434
Shore at Beadnell		NU 239 287
New Dryburn Quarry 1610m N of Lowick		NU 008 410
Swinhope No 1 Bore	NY 84SW/1	NY 8332 4478
Swinhope No 2 Bore	NY 84SW/2	NY 8379 4512
Swinhope No 3 Bore	NY 84SW/3	NY 8315 4587
Swinhope No 4 Bore	NY 84SW/4	NY 8217 4547

References

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