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Dinantian conodont biostratigraphy of the Northumberland Trough

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ABSTRACT–Conodont faunas from Dinantian strata of the Northumberland Trough and Tweed Basin are described. Five zones are recognised. These zones are correlated with the standard British Stages and where possible with European and American sections. Chadian and Arundian faunas are dominated by *Taphrognathus, Cloghergnathus* and *Cavusgnathus* which typically occur in shallow intertidal and shallow subtidal environments. Holkerian and Asbian strata are barren of conodonts. In the Brigantian deeper-water genera including *Gnathodus* are represented. The shallow water nature of the lower faunas causes difficulty in correlation with goniatite-bearing sequences in the Craven Basin but reasonable correlations can be made to Ravenstonedale and the Avon Gorge.

INTRODUCTION

During the Carboniferous the Northumberland Trough developed as a half graben between the tectonically high Southern Uplands to the north and the fault-bounded Alston and Askrigg blocks to the south. Lower Carboniferous strata were deposited upon a surface of marked relief and lie either conformably on Old Red Sandstone "facies" (which may in part be Carboniferous in age) or unconformably on Lower Palaeozoic basement (Johnson, 1984). In the west lowermost Carboniferous sediments lie above the Birrenswark Lavas and traditionally the base of the Carboniferous system has been taken at the base of these (Robson, 1980).

The stratigraphy of the Northumberland Trough is of interest as it provides a link between the well known Midland Valley sequences to the north and the area of Ravenstonedale in Cumbria, Garwood's type (1913, p. 451) for the Carboniferous succession of northern England. In addition, the trough continues to be of interest in hydrocarbon exploration and a good biostratigraphy is required to produce basin development models. Here we present a conodont biozonation for the Dinantian rocks of the trough, the first comprehensive micropalaeontological zonation.

STRATIGRAPHY

Early lithological classification (Tate, 1867; Lebour, 1875; Miller, 1887) established the Cementstone, Fell Sandstone, Scremerston Coal and the Lower, Middle and Upper Limestone groups. This scheme was not applicable to the sequence in the west of the trough and Lumsden *et al.*, (1967) and Day (1970) revised this lithostratigraphy introducing the terms Lower, Middle and Upper Border groups with the Liddesdale Group forming the top of the succession (Fig. 1).

The top of the Dinantian Subsystem has been placed on goniatite evidence at the base of the Great Limestone. Ramsbottom (1973, p. 573) used patchily dolomitised, commonly algal, calcite mudstones, to mark the regressive upper boundaries of his mesothem cycles, documenting six for the Dinantian Subsystem. Each was supported by palaeontological evidence except for the basal Asbian event. More recent work (George, 1978) suggests these cycles may be suspect, the lack of definitive internal criteria often making their identification uncertain or wrong (Austin & Davies, 1984, for a review). This causes some difficulties in using the Dinantian stages of George *et al.* (1976).

Lower Border Group (LBG)

These are the oldest Carboniferous sediments in the west of the trough. The succession in the Bewcastle area (Fig. 2) was designated by Garwood (1931) as the type for the Group. Here it comprises 960m of alternating limestones, shales and sandstones deposited in a variety of environments associated with periodic delta progradation into a shallow marine gulf (Leeder, 1974a).

Until modern biostratigraphical methods were applied, much of the LBG was considered to be Courceyan in age. Day (1970) in his resurvey of the area noted the generally impoverished nature of the marine fauna, most of the molluscs, brachiopods, algae and serpulids common throughout the group are both long ranging and of limited diversity. Only the Cambeck Beds were reliably dated as C_2 (i.e. Chadian/Arundian-age) using the macrofauna (Day, *op. cit.*). Ostracods from the Lower Border Group including *Beyrichiopsis* c.f. *carinata* and *Lichvinia* sp. nov. were described as being of "essentially Tournaisian type" (Robinson, *in* Day, 1970, p. 166) though these persisted into the Viséan Series.

Miospore studies on the Bewcastle Formation (Butterworth & Spinner, 1967) and the Main Algal Formation (Gueinn, in Neves *et al.*, 1972) provided little further refinement. The miospores recovered are characteristic of the *Lycospora pusilla* or Pu Biozone (Neves *et al.*, 1972) then thought to range from the Courceyan to Viséan in age. Clayton (1984) revised the miospore zonation of the Dinantian Subsystem making the Pu zone lower Viséan in age.

Ramsbottom (1973) interpreted the Main Algal Formation as the regressive phase at the top of Dinantian Mesothem 1, which he correlated with the Tournaisian-Viséan boundary. George *et al.*, (1976) followed Ramsbottom (*op. cit.*) and equated the Courceyan-Chadian boundary of their new stages with the base of the Cambeck Beds. Leeder (1974a, b;

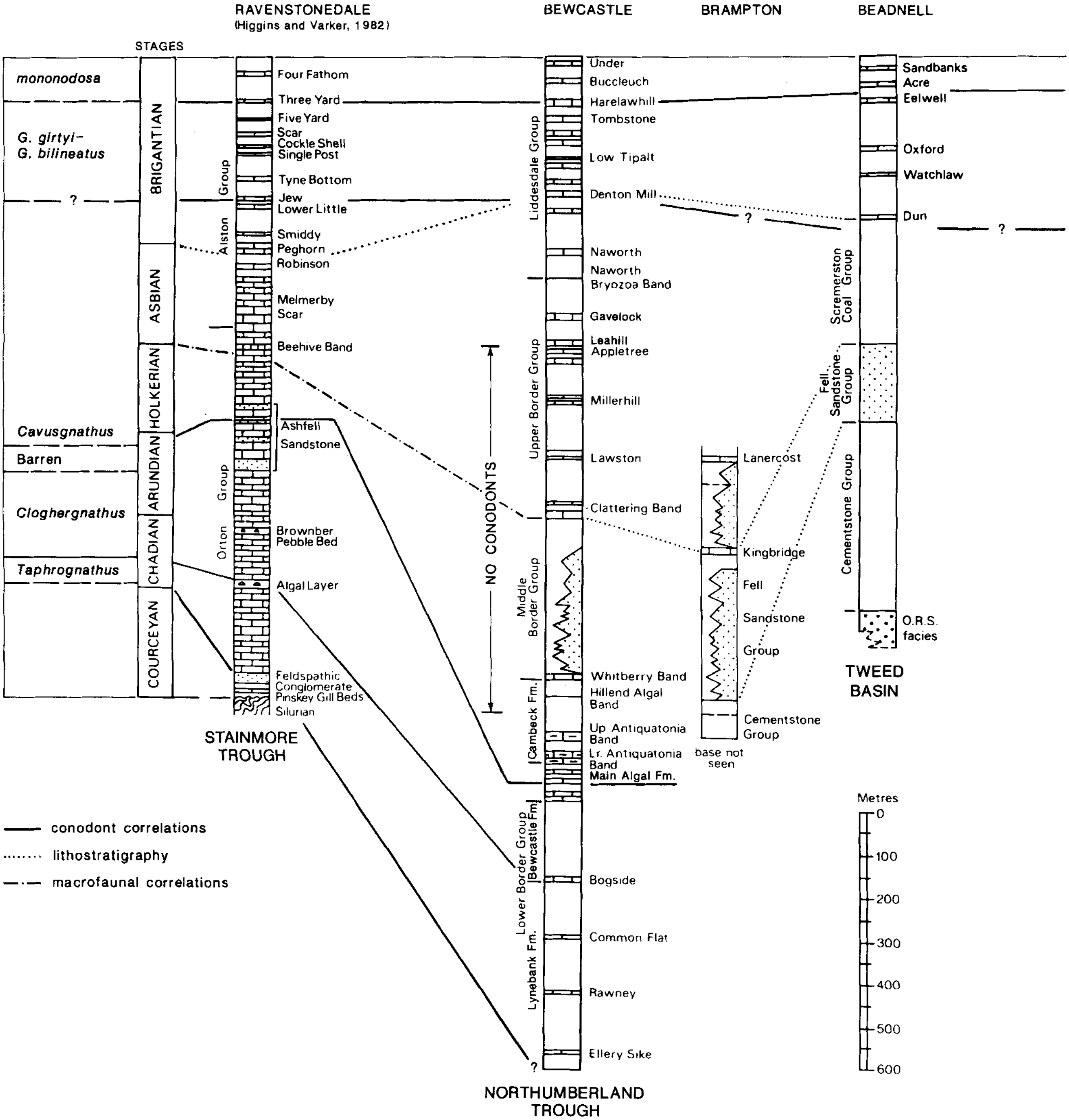


Fig. 1. Lithostratigraphy and conodont biostratigraphy of the Northumberland Trough and Ravenstonedale (after Robson, 1980).

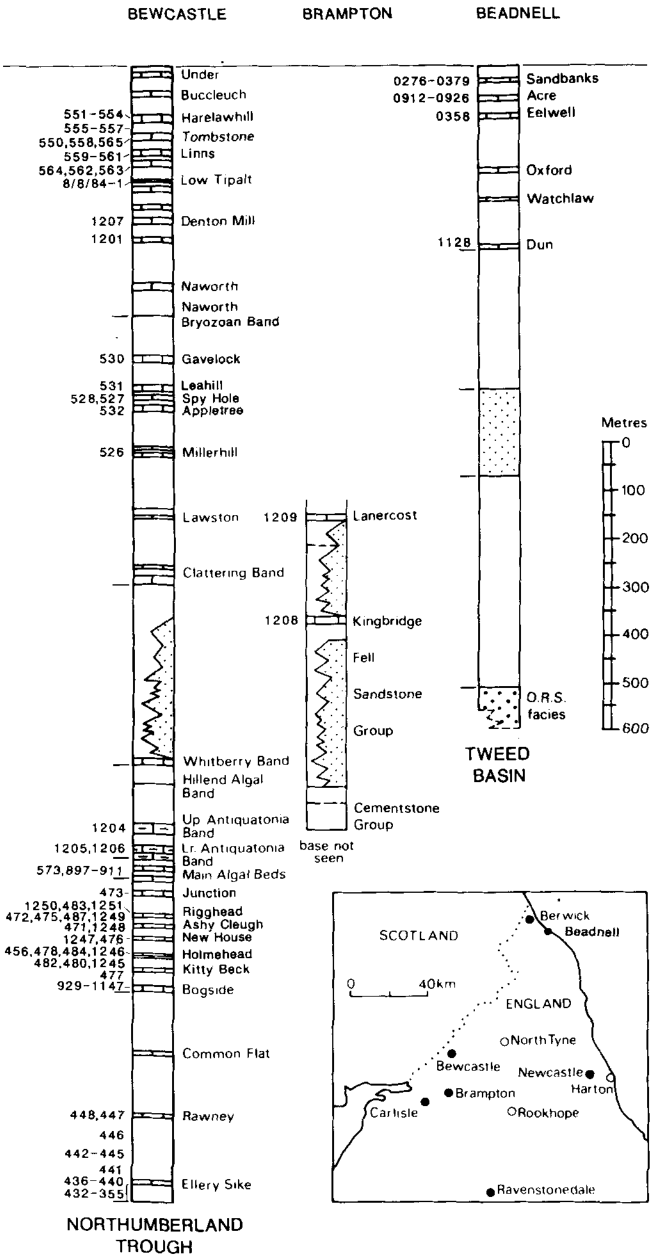


Fig. 2. Sample numbers and localities.

1975a, b; 1976) also considered the Lynebank, Bewcastle and Main Algal formations to be Tournaisian in age.

Ramsbottom (1977) reported the discovery in the lowermost Lynebank Formation of Chadian foraminifera and the conodont species *Mestognathus beckmanni* and *Polygnathus bischoffi*, elsewhere found together in strata of Chadian age. Subsequently the Lynebank, Bewcastle and Main Algal formations were considered to be Chadian in age and the Cambeck Formation Arundian in age (Robson, 1980, fig. 2).

Middle Border Group (MBG)

Most of the MBG has been referred to the Arundian and Holkerian Stages (Day, 1970; Robinson, *in* Day, 1970; George *et al.*, 1976; Robson, 1980). There are few diagnostic fossils in the sequence which is dominated by the Fell Sandstone and coeval Scremerston Coal Group in north Northumberland. The Fell sandstone has traditionally been correlated with the Ashfell Sandstone in the Stainmore Trough to the south (George *et al.*, 1976, fig. 11) the latter sandstone being confined to the upper Arundian Stage.

Upper Border Group (UBG)

The base of the Asbian Stage can be placed in the Archerbeck borehole using foraminifera, within the Glencartholm Volcanics at an horizon correlated with the Clattering Band of Bewcastle (Day, 1970, pl. V). This unit is defined as the base of the UBG and contains a macrofauna of *Lithostrotion martin, L. portlocki* and *Semiplanus* sp., a fauna which can be traced eastwards from Bewcastle into the North Tyne area (Fowler, 1966, p. 76; Westoll *et al.*, 1955, p. 81). In northern Northumberland George *et al.*, (1976) placed the base of the Asbian Stage some 600m beneath the Redesdale Ironstone, consequently much of the Scremerston Coal Group became Asbian rather than Holkerian in age as traditionally conceived (Taylor *et al.*, 1971, pl. V).

Robinson (*in* Day, 1970, p. 334) examined ostracods from the Spadeadam No. 3 (Camp) Bore and from the Clattering Band. Many of the species recorded are also known from the Middle Border Group. Neves & Williams (*in* Day, 1970, p. 1972, pl. X1) reported miospore assemblages from eight samples of coal and shale collected from the UBG of the River Irthing. They found a well preserved though low diversity microflora with few species of diagnostic age. They considered this reflected the poor state of knowledge of Viséan assemblages. Comparing their microfloras with the more recent range charts compiled by Clayton (1984) it appears they are typical of the upper Holkerian Stage (Tc Biozone) to Asbian Stage (Nm Biozone).

Liddesdale Group

The base of the Brigantian Stage has been placed at the base of the Peghorn Limestone, correlated by Trotter & Hollingworth (1932, p. 52) with the Low Tipalt Limestone of the Greenhead-Bewcastle area. This limestone lies midway through the group (Fig. 1).

The lower part of the Liddesdale Group contains many fossils typical of the Asbian Stage, including a *G. bilineatus* Biozone fauna in the Denton Mill Limestone. Higher in the Group (Penton Limestone and above) typical Brigantian fossils are found, such as *Lonsdaleia floriformis, Gigantoproductus striatosulcatus* and *G.*

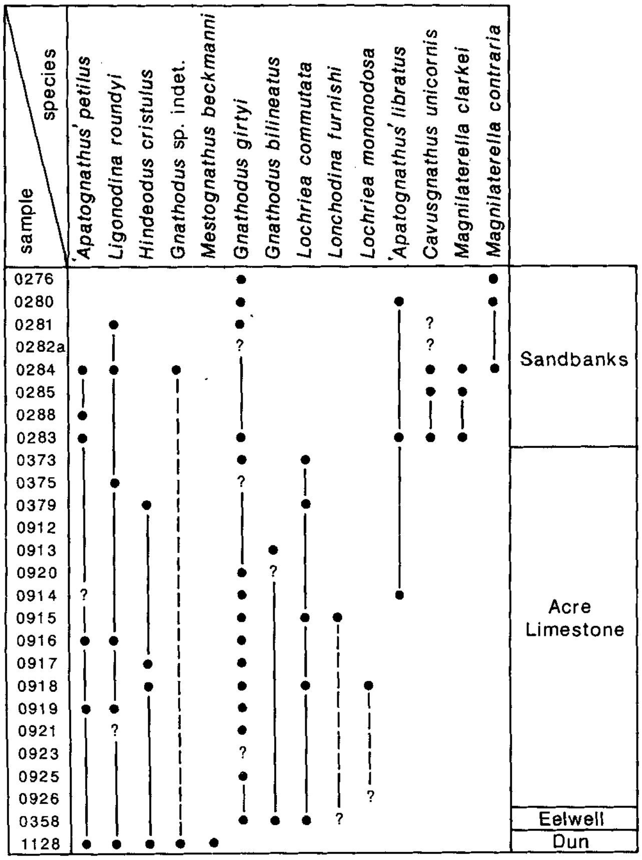


Fig. 3. Specimen abundances for the Lower Border Group. Dots represent present but not counted; ? represents questionable assignment.

giganteus. *Saccamminopsis floriformis* is recorded from the Buccleugh Limestone. The equivalence of part of the P_1 zone of the Brigantian Stage has been confirmed by the presence of *Posidonia becherii* and *Beyrichoceratoides truncatus* in the shales between the Gastropod and Tombstone limestones (Ramsbottom, *in* Day, 1970, p. 175). Above in the higher limestones of the group macrofaunas and a *L. monodosa* Biozone conodont fauna are indicative of the P_2 zone, this cannot be confirmed on goniatite evidence.

CONODONT FAUNAS

Generally conodonts throughout the sequence are low in abundance and diversity (Figs. 2, 3, 4, 5), reflecting the marginal marine, shallow-water nature of the sequence. Preservation is generally good with thermal maturity values only exceeding conodont colour alteration index (CAI) 2 in proximity to the Whin Sill and related late Carboniferous-Permian intrusions (Armstrong & Strens, 1987). It is noticeable particularly in the Lower Border Group sequence that many specimens are exceedingly small, particularly *Vogelgnathus* and *Taphrognathus* species. This may be a result of the euryhaline nature of the environment, evidenced in the upper part of the group where algal laminites and gypsum pseudomorphs are found (Leeder, 1975a, b).

A sequence of five conodont biozones is recognisable in the Northumberland sequence (Figs. 6, 8): the *Taphrognathus*, *Cloghergnathus*, *Cavusgnathus*, *G. bilineatus* and *L. mononodosa* biozones (c.f. the order of Austin & Davies, 1984, fig. 21). These are defined in the Bewcastle area where the sediments are thought to

Explanation of Plate 1

All specimen and sample numbers refer to the micropalaeontological collections held in the Geology Dept., University of Newcastle upon Tyne.

Fig. 1. *'Apatognathus' cuspidatus* (Varker): posterior (× 60); TG1/574, sample 285.

Fig. 2. *'Apatognathus' libratus* (Varker): posterior view (× 100); TG1/576, sample 914.

Fig. 3. *'Apatognathus' scandalensis* (Higgins & Varker): posterior view (× 60); TG1/479, sample 552.

Fig. 4. *'Apatognathus' aff 'A' libratus* (Varker); anterior view (× 60); TG1/414, sample 563.

Fig. 5. *Bispathodus stabilis* (Branson & Mehl): lateral view, Pa element (× 80); TG1/560, sample 1342.

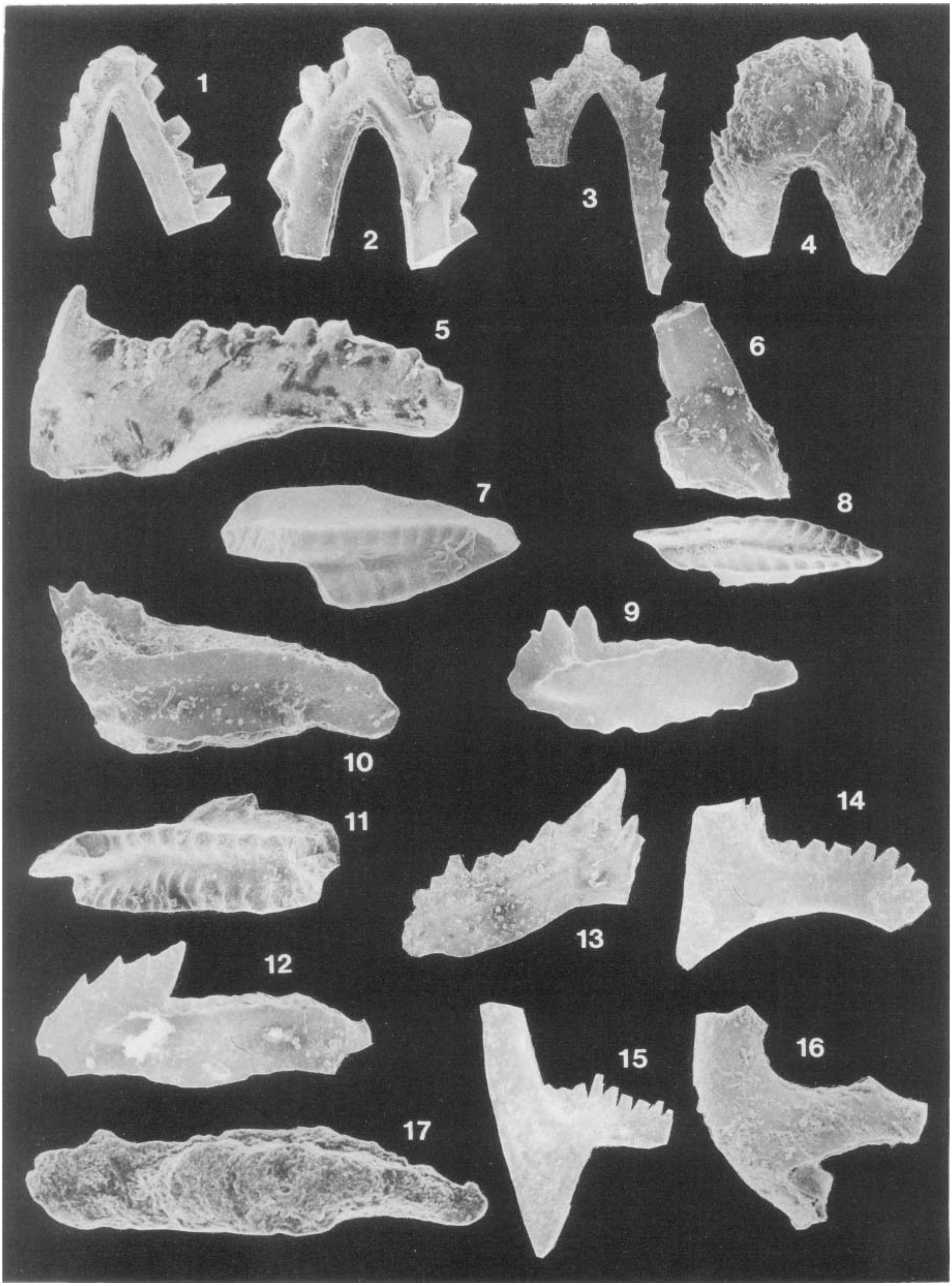
Figs. 6, 7. *Cavusgnathus* sp. idet.: fig. 6, lateral view, M element (× 70); TG1/421, sample 1204; fig. 7, upper view, Pa element (× 75); TG1/577, sample 1204.

Figs. 8, 9. *Cavusgnathus* c.f. *naviculus* (Hinde): fig. 8, upper view, Pa element (× 80); fig. 9 inner lateral view, Pa element (× 80); TG1/424, sample 902.

Fig. 10. *Cavusgnathus cristatus* Branson & Mehl: lateral view, Pa element (× 60); TG1/420, sample 1204.

Figs. 11–16. *Cavusgnathus unicornis* (Youngquist & Miller): fig. 11, upper view, Pa element (× 60); TG1/405, sample 558; fig. 12, inner lateral view, Pa element (× 60); TG1/416, sample 554; Fig. 13, inner lateral view, Pb element (× 35); TG1/407, sample 558; fig. 14, inner lateral view, M element (× 60); TG1/418, sample 554; fig. 15, inner lateral view, M element (× 35); TG1/411, sample 558; fig. 16, inner lateral view, ?Sc element (× 100); TG1/480.

Fig. 17. *Cloghergnathus carinatus* (Higgins & Varker): outer lateral view, Pa element (× 80); TG1/589, sample 487.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reflect more marine conditions and where a more complete and continuous sequence is exposed. The lower three zones can be traced to Ravenstonedale and the upper two zones correlate well with schemes proposed by Higgins (1975; not shown in Fig. 8) and Metcalfe (1981) for the Central Pennines and the Craven Basin respectively (Fig. 8).

Currently, no single conodont zonation for Lower Carboniferous strata is applicable throughout Britain (refer to Varker & Sevastopulo, 1984 for a review) though attempts have been made at a conflated scheme (Varker & Sevastopulo, *op. cit.*; Higgins, 1984). This problem is caused by the strong environmental controls on Lower Carboniferous conodonts, particularly the distinction between shallow and deeper-water environments. Direct correlations with the Stage stratotypes of the Dinantian Subsystem would be preferable but only limited conodont data is currently available for these (see Austin & Davies, 1984 for a review).

Whilst the Northumberland Trough represented a distinct depositional basin during Dinantian time, the conodont faunas recovered are similar to those reported from the Ravenstonedale shelf sequence. There are several advantages in correlating the Bewcastle succession with that of Ravenstonedale. The latter is the stratotype for the Lower Carboniferous succession of northern England and is demonstrably more complete than coeval shelf sections elsewhere in Britain. It is geographically close to Bewcastle and despite minor differences the depositional environments for both areas appear to be similar (Higgins & Varker, 1982; Leeder, 1975a, b).

The lowest conodont fauna in Ravenstonedale, 'Fauna A' (Varker & Higgins, 1979; Higgins & Varker, 1982), is mid-Courceyan in age and not present in the Bewcastle area.

species \ sample		0276	0277	0278	0279	0280	0281	0282a	0284	0285	0286	0288	0283	0287	0373	0374	0375	0376	0377	0379	0912	0913	0920	0922	0914	0915	0916	0917	0918	0919	0921	0923	0924	0925	0926	0358	1128
CAI		1		1		1	1	1	1+	1+	1	1	1+		1	1	1			1	1	1	1		1	1	1	1	1	1	1	1		1	1	1	2
wt. processed (kg)		1.2	1.3	1.0	1.5	1.4	1.2	1.4	1.4	1.3	1.3	1.4	0.6	1.5	0.6	0.6	0.7	0.6	0.7	0.8	1.5	1.6	1.6	1.5	1.1	1.1	1.1	1.2	1.1	0.9	0.6	0.9	1.0	0.9	1.0	0.8	1.2
FRAGMENTS		9	0	8	0	28	12	6	7	11	0	6	13	0	4	1	2	0	0	6	3	11	7	0	13	16	7	9	27	14	7	2	0	0	3	10	25
INDET. ELEMENTS																	1					1					1										
FISH		●				●	●	●	●	●	●				●	●	●			●							●	●								●	
'Apatognathus' petilus									1	2		1	2												2		1			1							?2
'Apatognathus' libratus													2												1												
'Apatognathus' scandalensis									1																?1												
Cavusgnathus unicornis	Pa								1	1			1																								
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Cavusgnathus sp. indet.	Pb						1																														
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	Sa				1		1																														
	Sb						?1	2																													
Gnathodus bilineatus	Pa							?1														1	?1													4	
Gnathodus girtyi	Pa					4	8						4		3		?1						3		7	4	6	3	1	4	1			1		6	
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	Sc_2						1	?2							3		1						F		2		1	1		5		?1		?1		13	
Hindeodus cristulus	Pa																			1								1	1								1
	Pb																																				1
	Sb																																				1
Hindeodus scitulus	Pa				2																																
Ligonodina roundyi		2				4	1		1								1											1		1	?1						4
Lochriea commutata	Pa														1					1						1			1							3	
Lochriea mononodosa	Pa																												1						?1		
Lonchodina furnishi																																				1	
Lonchodina sp. indet.						2																															
Magnilaterella clarkei									2	?1			?1																								
Magnilaterella contraria		1				2		?1	1																												
Mestognathus beckmanni	Pa																																				?1

Fig. 4. Specimen abundances for the Middle Border Group and Liddesdale Group of the Bewcastle area.

species \ sample		0551	0552	0553	0554	0555	0556	0557	0550	0558	0565	0559	0560	0561	0564	0562	0563	8/8/84–1	1207	1210	0530	0531	0528	0527	0533	0532	0526	1209	1208	1204	1205	1206
wt. processed (kg)		1.3	1.0	1.0	1.1	1.2	1.3	1.1	1.0	1.3	1.2	1.1	1.0	0.3	1.3	1.3	1.2	1.0	0.8	0.8	1.0	1.0	1.0	0.9	1.0	1.1	0.9	1.0	0.4	1.1	0.8	1.0
FRAGMENTS		23	35	8	15	20	33	33	12	75	0	6	13	4	17	7	11	0	2	19	0	6	8	3	1	0	0	2	0	53	2	1
INDET. ELEMENTS		4	3	3					2																							
FISH		●	●	●	●	●	●	●	●				●		●		●				●	●	●	●	●			●		●		
Draffania biloba				1																												
'Apatognathus' libratus			1		1	1				2		?1					1															
'Apatognathus' scandalensis			1																													
Cavusgnathus cristatus	Pa																													1		3
	M																													?1		
Cavusgnathus unicornis	Pa				3	?1	1			2			1																			
	Pb				1					1																						
	M				1		?2			1																						
	Sb						2																									
	Sc												?1																			
Gnathodus girtyi	Pa	3	5		?1	9		?1		2		1					4		1													
	Pb					1				1																						
	M	1	1	4	2	3																										
	Sb				1																											
	Sc_2	F	1							1							1															
Gnathodus sp. indet.	Pa									1																						
	M																							1								
Hindeodus cristulus	Pa	1						1					1																			
	Sa	?1																														
Hindeodus scitulus	Pa		1	?1						1																						
Ligonodina roundyi		2	1	2		2	5	3		6			?1		2		2			1												
Ligonodina sp. indet.			1																													
Lochriea commutata	Pa			?1		1	1						1				1															
	Sb						?1																									
Lochriea mononodosa	Pa	1	7																													
	Pb		?1																													
Lonchodina sp. indet.		1																														
Magnilaterella contraria									1																							
Mestognathus beckmanni	Pa							4	3																							
	Sc							?1																								

Fig. 5. Specimen abundances for the Upper Limestone Group of Beadnell (Tweed Basin).

***Taphrognathus* Biozone**

T. varians (Branson & Mehl), *Cloghergnathus carinatus* Higgins & Varker and *'Apatognathus' cuspidatus* Varker, characterise this partial range zone. In Ravenstonedale, the appearance of *C. carinatus* and the disappearance of *T. varians* mark the lower and upper boundaries respectively. *Hindeodus scitulus* (Hinde) was recorded in Ravenstonedale but is absent from the Northumberland sequence. *T. varians* and *C. carinatus* occur in the Lynebank Formation. The former disappears in the middle of the Bogside Limestone where we have a high sample density. Consequently we are confident in placing the top of this zone a few metres above the base of the Bewcastle Formation. *Taphrognathus varians* with affinities to *Cloghergnathus* continues above this zone into the Kitty Beck Limestone and may in future allow recognition of a local subbiozone within the *Cloghergnathus* Biozone. Within this biozone the fauna in Northumberland is much more diverse than that of Ravenstonedale which suggests a more favourable environment for conodonts, perhaps slightly deeper and less prone to salinity fluctuations. Of particular interest is the occurrence of *Vogelgnathus* sp. nov., which is considerably older than any other species reported in this genus (Norby & Rexroad, 1985).

T. varians has a wide distribution being recorded from Viséan strata in the Upper Mississipi Valley (Collinson, Rexroad & Thompson, 1971) and from Australia (Jenkins, 1974). In Britain *T. varians* was reported from the Main Algal Limestone of Roxburghshire (Rhodes *et al.*, 1969) where it is early Viséan in age. In Ravenstonedale it is associated with foraminifera in the Stone Gill Beds which are clearly referable to the Chadian Stage (Ramsbottom, 1977). In Europe this *Taphrognathus* fauna is uncommon, it occurs in Ireland (Austin & Mitchell, 1975) with the characteristic early Viséan conodonts *Mestognathus beckmanni* and *Cloghergnathus*. *Taphrognathus* is known from the Windsor Group of Novia Scotia (von Bitter, 1976) where it occurs with *Cavusgnathus* species and is likely to be Holkerian in age (Higgins & Varker, 1982, p. 154; Von Bitter & Austin, 1984, p. 100).

***Cloghergnathus* Biozone**

This assemblage zone ranges from the middle of the Bogside Limestone to the lower-Main Algal Formation. These beds yield an impoverished fauna and of the species recorded from similar levels in Ravenstonedale only *C. carinatus* is present in the Bewcastle area. Higgins & Varker (1982, p. 154) considered this zone to be an "interregnum between the disappearance of *Taphrognathus* and the appearance of *Cavusgnathus*". This appears to be the case in Bewcastle. *M. beckmanni, C. carinatus* and *Cloghergnathus* sp. nov. disappear synchronously before the appearance of *Cavusgnathus*. *M. beckmanni* reappears in the Asbian Dun Limestone of the Tweed Basin. The *Cloghergnathus* Biozone is poorly defined elsewhere (Higgins & Varker, 1982). It appears to correlate with the *T. varians-Apatognathus* interval in the Upper Mississippi Valley and corresponds to a broad *Cavusgnathus*-bearing zone in Ireland, between the top of the Lower Carboniferous Shale and the Upper Calp Limestone (Austin & Mitchell, 1975). In Ravenstonedale this zone occupies the Scandal Beck Limestone to mid Ashfell sandstone interval. George *et al.*, (1976) dated the former as Chadian and the latter as Arundian in age.

***Cavusgnathus* Biozone**

In Ravenstonedale the lower limit of this zone is marked by the first appearance of *Cavusgnathus regularis* and *C. unicornis*, the upper limit cannot be defined (Higgins & Varker, 1982). Correlation of the lower boundary in the Bewcastle area is problematical as the earliest *Cavusgnathus* are fragments and a single specimen of *C. cf. naviculus* from the Birky Cleugh Limestone in the Main Algal Formation.

Barren samples between the last *Cloghergnathus* Biozone Fauna in the Ashy Cleugh Limestone (Bewcastle Formation) and the *Cavusgnathus* Biozone Fauna in the Birky Cleugh Limestone leave approximately 77 m of section in which *Cavusgnathus* could make its first appearance. *C. charactus* has been recorded from the Liddel Formation of Harden Burn, Roxburgshire (Rhodes *et al.*, 1969), ten miles to the north of Bewcastle. The Liddel Formation has been traditionally correlated with the Main Algal Formation on lithostratigraphic, macrofaunal and miospore

Explanation of Plate 2

Fig. 1. *Cloghergnathus* c.f. *globenskii* (Austin & Mitchell): upper view, Pa element (× 80); TG1/563, sample 1138.

Figs. 2, 3. *Cloghergnathus-Taphrognathus* intermediate: fig. 2, upper view, Pa element (× 80); fig. 3, inner lateral view, Pa element (× 80); TG1/433, sample 1049.

Figs. 4, 5. *Cloghergnathus* sp. nov.: fig. 4, upper view, Pa element (× 80); TG1/33, sample 1140; fig. 5, inner lateral view, Pa element (× 80); TG1/466, sample 930.

Figs. 6–9. *Cloghergnathus* sp indet.: fig. 6, lateral view, M element (× 80); TG1/453, sample 939; fig. 7, lateral view, Pb element (× 80); TG1/35, sample 1141; fig. 8, posterior view, Sa element (× 80); TG1/36, sample 1142; fig. 9, lateral view, Sc element (× 80); TG1/23, sample 1048.

Fig. 10. *Gnathodus symmutatus* (Rhodes, Austin & Druce): lateral view, Pa element (× 80); TG1/40, sample 439.

Fig. 11. *Gnathodus bilineatus* (Roundy): upper view, Pa element (× 60); TG1/581, sample 358.

Figs. 12, 13. *Gnathodus girtyi* (Hass): fig. 12, upper view, Pa element (× 60); TG1/408, sample 558; fig. 13, posterior view, M element (× 80); TG1/046, sample 352.

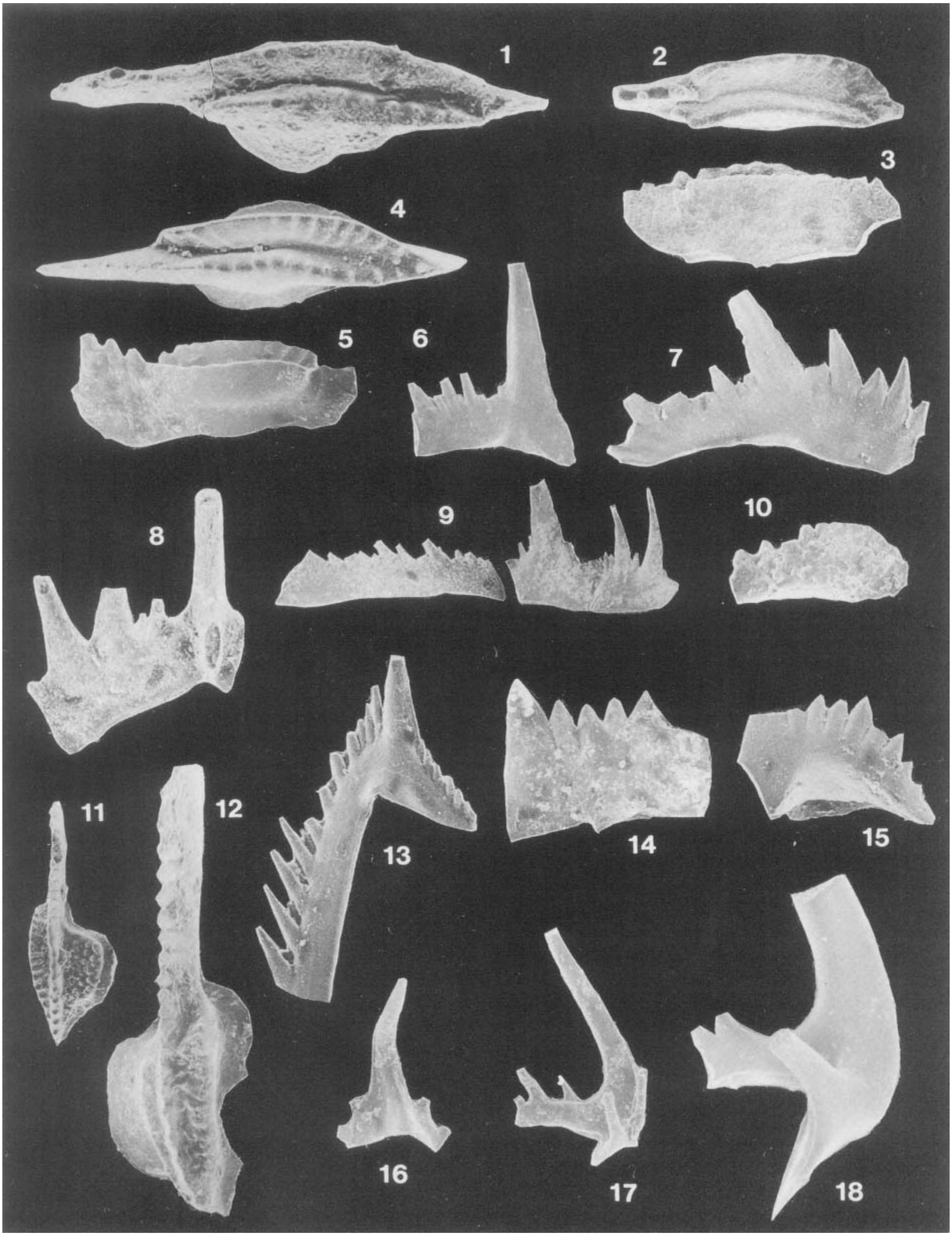
Fig. 14. *Hindeodus cristulus* (Youngquist & Miller): lateral view, Pa element (× 70); TG1/409, sample 558.

Fig. 15. *Hindeodus scitulus* (Hinde): lateral view, Pa element (× 80); TG1/574, sample 551.

Fig. 16. *?Lonchodina* sp.: posterior view, Sb element (×70); TG1/474, sample 551.

Fig. 17. *Ligonodina* sp.: inner lateral view, Sc element (× 70); TG1/477, sample 552.

Fig. 18. *Ligonodina roundyi* (Hass): inner lateral view, Sc element (*?Cavusgnathus* sp.) (× 70); TG1/473, sample 551.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grounds (Garwood, 1931; Gray, 1971; Leeder, 1974a). Gueinn (discussion in Leeder, 1974a, p. 177) questioned this on the basis of miospore data. The presence of *C. charactus* in the Liddel Formation lends support to the traditional correlation and suggests the base of the *Cavusgnathus* Biozone should fall within the lower Main Algal Formation. In Ravenstonedale this zone includes the upper beds of the Ashfell Sandstone and at least the lowest beds of the Ashfell Limestone and therefore according to George *et al.* (1976) spans the Arundian-Holkerian boundary.

***Gnathodus girtyi-Gnathodus bilineatus* Biozone**

Samples from the upper Cambeck Formation to the lower Liddesdale Group lack conodonts. The Denton Mill Limestone yields a low diversity fauna including *G. girtyi* and *G. bilineatus*. In Britain and Ireland the base of the *G. bilineatus* Biozone is marked by the first appearance of these two species, although *G. girtyi girtyi* is known to range down into the upper part of the *Lochriea commutata* Biozone (Varker & Sevastopulo, 1984). The base of this zone lies within the Asbian Stage (Metcalfe, 1981; Varker & Sevastopulo, 1984) and correlates well with the combined *Mestognathus beckmanni-G. bilineatus* and *L. mononodosa* zones of the Avon Gorge (Austin, 1973). In Britain the top of the zone is defined by the first appearance of *L. mononodosa* in the mid Brigantian Stage. In the Northumberland trough this lies within the Harelawhill Limestone and in the Tweed Basin between the Eelwell and Acre Limestones. Here the fauna includes *M. beckmanni* suggesting shallower-water depths.

***Lochriea mononodosa* Biozone**

As defined by Varker & Sevastopulo (1984) the base of this zone is marked by the first appearance of *L. mononodosa* (Rhodes *et al.*) and the top by the first appearance of *G. girtyi collinsoni* Rhodes *et al.* The latter subspecies has not been recovered from Northumberland and the *L. mononodosa* Biozone is taken to the top of the Brigantian Stage. The base of the synonomous *G. nodus* Zone (Metcalfe, 1981) occurs within P_{2b} of the Brigantian Stage and Higgins (1975) defined his *G. girtyi collinsoni* Zone as ranging through the P_2 subdivision of the Stage.

The appearance of a *L. mononodosa* Biozone fauna in the Acre and Sandbanks limestones of the Tweed Basin allows interbasinal correlation and our data therefore supports the correlations made by Holliday *et al.*, (1975), that the Harelawhill and Eelwell limestone are in part equivalent.

Facies Control of Carboniferous conodonts

Austin (1976) distinguished a shelf biofacies comprising *Cavusgnathus*, *Mestognathus* and *Taphrognathus* from a deeper-water biofacies dominated by *Gnathodus*. This work was later substantiated in northern England (Higgins & Varker, 1982) and to some degree refined (Varker & Sevastopulo, 1984; Austin & Davies, 1984). Without exception the Chadian and Arundian conodont faunas of Northumberland are of shallow-water type. Von Bitter (1976) placed *Taphrog-*

Explanation of Plate 3

Fig. 1. *Lochriea commutata* (Branson & Mehl): upper view, Pa element (× 60); TG1/412, sample 563.

Fig. 2. *Lochriea mononodosa* (Rhodes, Austin & Druce): upper view, Pa element (× 70); TG1/422, sample 552.

Fig. 3. *?Magnilaterella* sp.: inner lateral view (× 60); TG1/410, sample 558.

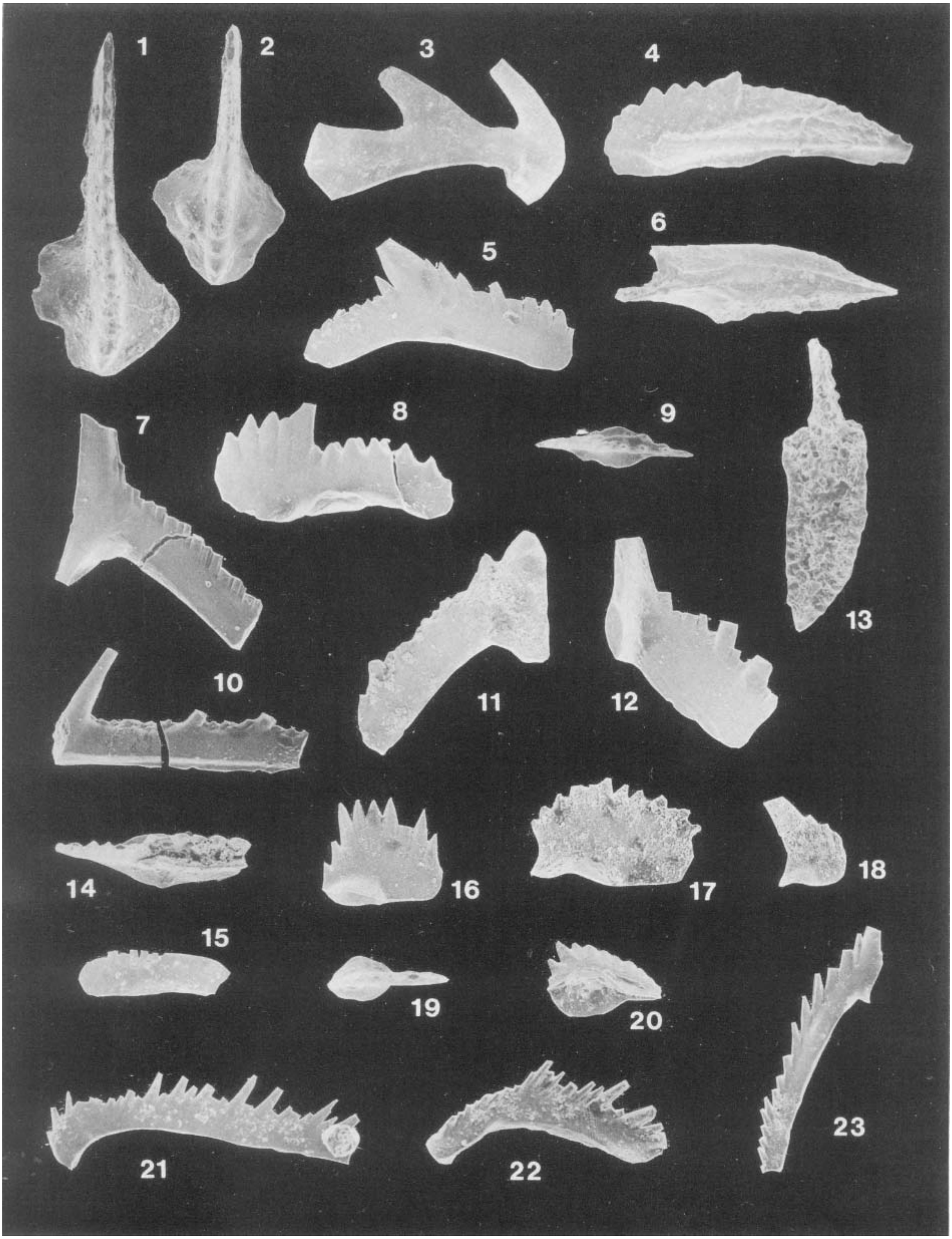
Figs. 4–7. *Mestognathus beckmanni* (Bischoff): fig. 4, inner lateral view, Pa element (juvenile) (× 60); TG1/425, sample 439; fig. 5, lateral view, Pb element (juvenile) (× 60); TG1/592, sample 1266; fig. 6, lower view, Pa element (juvenile) (× 60); TG1/423, sample 439; fig. 7, lateral view, M element (× 60); TG1/584, sample 1266.

Figs. 8–12. *Patrognathus variabilis* (Rhodes, Austin & Druce): fig. 8, inner lateral view, Pa element (× 100); TG1/570, sample 941; fig. 9, upper view Pa element (× 100); TG1/450, sample 941; fig. 10, lateral view, Sc element (× 100); TG1/591, sample 1266; fig. 11, lateral view, M element (× 100); TG1/572, sample 941; fig. 12, posterior view, Sa element (× 100); TG1/571, sample 941.

Fig. 13. *Polygnathus bischoffi* (Rhodes, Austin & Druce): upper view, Pa element (× 60); TG1/426, sample 433.

Figs. 14, 15. *Taphrognathus varians* (Branson & Mehl): fig. 14, upper view, Pa element (× 80); TG1/569, sample 1048; fig. 15, lateral view, Pa element (× 80); TG1/429, sample 1050.

Figs. 16–23. *Vogelgnathus* sp. nov.: fig. 16, lateral view, Pa element (× 100); TG1/428, sample 1052; fig. 17, lateral view, Pa element (× 100); TG1/38, sample 1143; fig. 18, lateral view, Pb element (× 100); TG1/37, sample 1142; fig. 19, upper view, Pa element (× 100); TG1/428, sample 1052; fig. 20, oblique lower view, Pa element (× 100); TG1/449, sample 944; fig. 21, lateral view Sc element (× 100); TG1/444, sample 944; fig. 22, lateral view, Sb element (× 100); TG1/34, sample 1141; fig. 23, lateral view, M element (× 100); TG1/590, sample 1271.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Stage	Varker and Sevastopulo 1984			Rhodes *et al.* modified Austin 1973b. Non-sequences George *et al.* 1976	Metcalfe 1981	Higgins and Varker 1982	This paper
Brigantian		*G. bilineatus*	*G. girtyi collinsoni*	*G. girtyi collinsoni*	*L. nodosa*	NO DATA	*L. mononodosa*
			L. mononodosa	*L. mononodosa*			
			G. bilineatus	*M. beckmanni–G. bilineatus*	*G. bilineatus*		*G. girtyi–G. bilineatus*
Asbian							?
Holkerian	*M. beckmanni*	*informal unit with taphrognathids*	*L. commutata*	*Cavusgnathus* *'Apatognathus'* *with non-sequences*	*L. commutata*	*Cavusgnathus*	*Cavusgnathus*
Arundian		*L. commutata*	*G. homopunctatus*	NO CONODONTS	*G. homopunctatus*	*Cloghergnathus* (B)	*Cloghergnathus*
Chadian		*G. homopunctatus*		*beckmanni–bischoffi*		*Cloghergnathus* (A)	
					beckmanni–bischoffi	*Taphrognathus*	*Taphrognathus*

Fig. 6. Conodont species ranges for the Dinantian strata of the Bewcastle area.

nathus, Apatognathus and *Hindeodus scitulus* in his Biofacies II association which occurred in inner shelf and reef environments. Higgins & Varker (1982) concluded that *Clydagnathus, Cloghergnathus, Taphrognathus, Cavusgnathus* and *'Apatognathus'* showed a high degree of facies control in Ravenstonedale, occurring typically in littoral and lagoonal facies but ranging into offshore infratidal facies.

The Holkerian and Asbian rocks of Northumberland have failed to yield conodonts – the Middle and Upper Border Groups represent a sequence laid down over a flat lower delta plain that allowed frequent inundation by marine conditions. Cyclothems were predominant with the marine argillaceous limestones containing faunas dominated by brachiopods. The reason for the absence of conodonts remains unclear.

The incoming of the Liddesdale Group over the Northumberland Basin marks a change in sedimentation and the conodont faunas. Thicker fully marine limestones can be traced across the whole area, the Denton Mill (or Dun Limestone) being the first to cross the Cheviot Block into the Tweed Basin. This marked the end of the separate identities of the basin and blocks and triggered the appearance of the deeper water *Gnathodus*-dominated fauna of the mid Brigantian Stage. Shallower water must have persisted in the Tweed Basin during the Denton Mill sedimentary cycle as *Mestognathus* reappears in the Dun Limestone. This distinction between the main trough and the Tweed Basin disappears as one passes up the sequence where thick Yoredale cycles continue to the top of the Dinantian succession. Limestones are generally thicker and contain a marine coral-brachiopod fauna. Conodonts are typically more abundant and represented by the genera *Gnathodus, Lochriea, Hindeodus* and *'Apatognathus'*.

CONCLUSIONS

It has been shown that, although environmentally controlled, conodonts are of biostratigraphic use within the shallow-water depositional environments of the Northumberland Trough. Five biozones have been established: the *Taphrognathus, Cloghergnathus, Cavusgnathus, G. bilineatus* and *L. mononodosa* biozones. The lower three allow good correlations to be made with the sequences in the Stainmore trough. The upper two zones can be traced throughout the trough into the Tweed Basin, and correlate with schemes proposed for the Central Pennines and Craven Basin.

The Lower Border group is recorrelated in terms of the Viséan Stages, the Lynebank and lower part of the Bewcastle Formation are Chadian in age, the upper part of the Bewcastle and Main Algal Formation are Arundian in age and the Cambeck Formation is in most part Holkerian in age. A Brigantian age is confirmed for the upper part of the Liddesdale Group. Our correlations support the lithostratigraphic correlations made by Holliday *et al.* (1975) between the Liddesdale Group and Upper Limestone Group of the Tweed Basin, in that the Harelawhill and Eelwell limestones are in part equivalent.

Conodont age data help to constrain the timing of tectono-stratigraphic events within the development history of the trough. Rapid sedimentation, associated with a rifted origin for the trough occurred until the mid Brigantian age. Depositional conditions on either side of the Alston Block varied through time. Two comparisons can be made. Firstly the base of the *Cloghergnathus* Biozone lies within algal laminities in Ravenstonedale and within the shallow marine Bogside

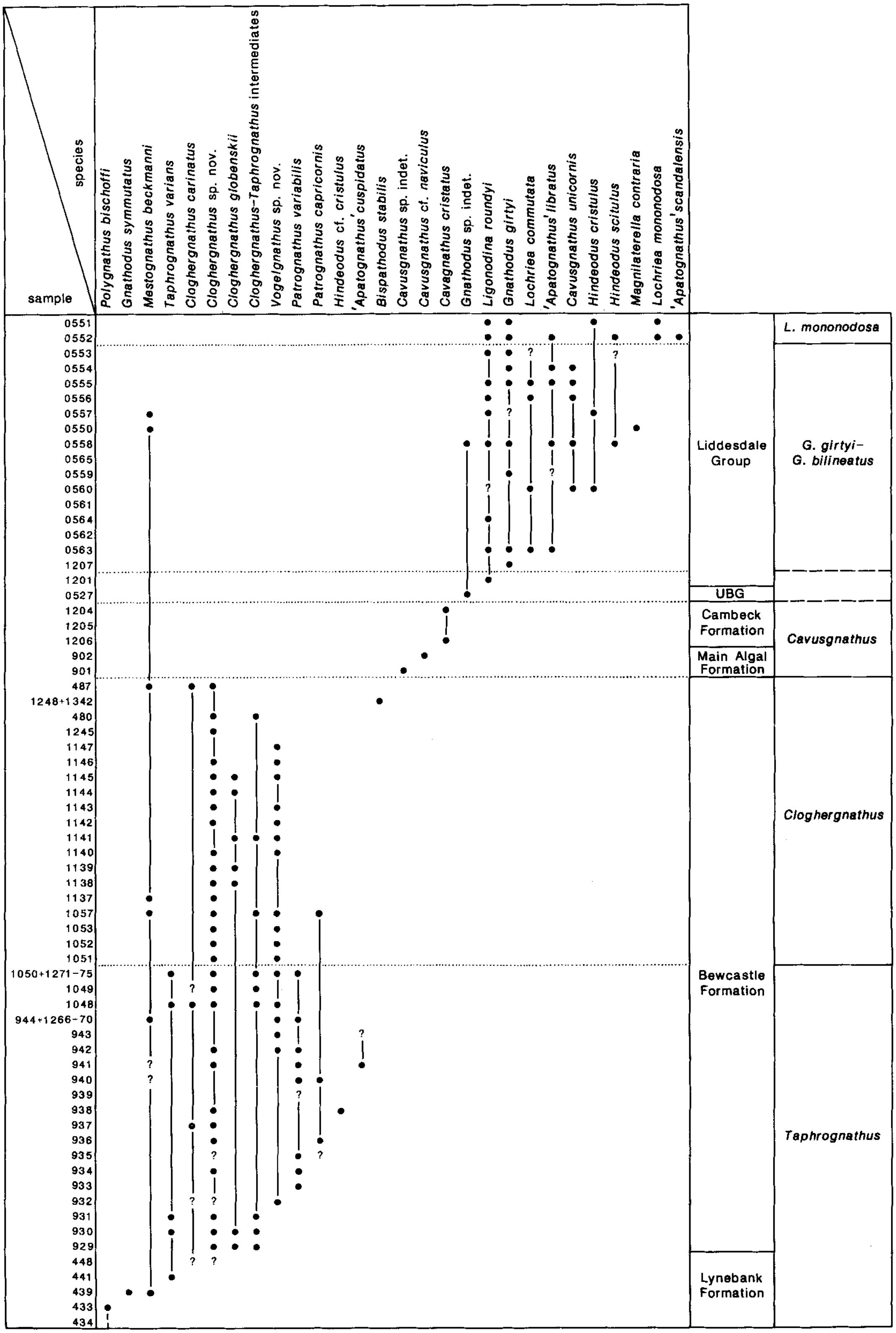

Fig. 7. Conodont species ranges for the Upper Limestone Group of the Tweed Basin.

Sample	wt. processed (kg)	FISH	OSTRACODS	GENUS INDET. FRAGMENTS	'Apatognathus' cuspidatus	Bispathodus stabilis	Bispathodus sp. indet.	Cavusgnathus cf. naviculus	Cavusgnathus sp. indet.	Cloghergnathus carinatus	Cloghergnathus globenskii	Cloghergnathus sp. nov.	Cloghergnathus–Taphrognathus intermediates	Cloghergnathus sp. indet. Pa	Cloghergnathus sp. indet. Pb	Cloghergnathus sp. indet. M	Cloghergnathus sp. indet. Sa	Cloghergnathus sp. indet. Sb	Cloghergnathus sp. indet. Sc	Gnathodus symmutatus	Hindeodus c.f. cristulus	Mestognathus beckmanni Pa	Mestognathus beckmanni Pb	Mestognathus beckmanni M	Mestognathus beckmanni Sa	Mestognathus beckmanni Sc	Mestognathus sp. indet.	Patrognathus capricornis	Patrognathus variabilis Pa	Patrognathus variabilis Pb	Patrognathus variabilis M	Patrognathus variabilis Sa	Patrognathus variabilis Sb	Patrognathus variabilis Sc	Patrognathus sp. indet. Pa	Patrognathus sp. indet. M	Patrognathus sp. indet. Sc	Polygnathus bischoffi	Taphrognathus varians	Vogelgnathus sp. nov. Pa	Vogelgnathus sp. nov. Pb	Vogelgnathus sp. nov. M	Vogelgnathus sp. nov. Sb	Vogelgnathus sp. nov. Sc	GENUS INDET. Pa	GENUS INDET. Pb	GENUS INDET. M	GENUS INDET. Sa	GENUS INDET. Sb	GENUS INDET. Sc
911	1.0																																																	
910	1.5																																																	
909	1.0																																																	
908	1.2																																																	
907	1.2																																																	
906	1.1																																																	2
905	1.1	●																																																
904	1.2	●																																											1					
903	1.5	●																																																
902	1.3	●		3				1																																										
901	1.2	●		4					1																																									
900	1.4	●		1																																														
899	1.3	●	●																																															2
898	1.5																																																	
897	1.4																																																	
573	1.0	●																																																
473	1.5																																																	
1251	1.3	●		1																																														
483	1.5	●	●																																															
1250	1.3	●																																																
487	1.2	●		1						1		2							?4			1																												
475	1.5																																																	
1249	1.3	●												1																																				1
475	1.5																																																	
471	1.6																																																	
1248+1342	2.3	●		10		1/?1	2																																						2					2/?1
476	1.5		●																																															
1247	1.4																																																	1
484	1.5	●	●																																															
1246	1.3																																																	
486	1.1																																																	
478	1.5	●	●																																															
480	1.5	●	●									2	1	1					?1																											1	1			12
1245	1.3		●	13								7		3		?1			?1																										2	1				
482	1.0																																																	
477	1.5	●																																																
1147	1.3	●																	?2																						3				?1						
1146	1.3	●		1								4		3		?2			?8																						11				?2						
1145	1.2	●									2/?1	1		1																											1						2				1
1144	1.2	●	●								1	4/?1				?1			?1																																
1143	1.2	●		4								3/?2		2		?4	?1		?7																						3				?1						4
1142	1.4	●	●									3				?1	?1																								3	?1	?1		?3						9
1141	1.3	●									1		2		?2				?4																						1			?1							
1140	1.3	●										4		2	?1	?1																									1							1			8
1139	1.4	●		4							4	5		2	?2				?2																											4					
1138	1.4	●		4							2	8		1		?2			?7																											1					
1137	1.4	●		4								2				?3						2			?1																						3			1	4
1057	1.3	●		3								4	1				?1		?10			1	?1			?5		1								?1	?1			1				?1	1	1/?2	1			
1056	1.1																																																	
1055	1.1	●																																											?1						
1054	1.2	●																	?1																											1					
1053	1.3	●	●	1								3			?1	?1			?3																						10				?1						
1052	1.4	●		7								2			?1																										4				?4	6					2
1051	1.4	●										1																													5				?7						
1050+1271-75	3.2	●		6								1/?1	1	2															1										2	64	?2	?6	?1	?16	2	1				3
1049	1.2	●		12						?2		16	10	8																															15	1				16
1048	1.3	●		14						1/?1		14	1		?7	?4			?18																				3/?1	1			?1		10		1			26
947	0.3	●																																																
945	0.4		●																																															
944+1266-70	3.1	●		2										1		?3						7/?1	?2	?2		?2	2		1								?7			11	?1			?7		1				26
943	1.1	●		1	?1											?1											1													1						2				2
942	1.3	●										1				?1													2					?2						1										3
946	0.3	●	●																																															
941	1.2	●	●	11	1							1		1								?1							12	?2	?2	?1	?1	?8														2		21
940	1.2	●	●	8										?1					?1			?1						1	2						1	?2	?3								1	1		1		18
939	1.2	●		3												?3													?1	?1				?2																1
938	1.2	●		7								3				?2			?1		1																													3
937	1.2	●		3						1		4					?1	?1	?2																										3		1			7
936	1.2	●	●	7								4																1/?1																	2	1				2
935	1.2	●	●	3								?1				?1												?1	1/?1	?2															2			1		1
934	1.2	●		8								1				?4													4	?1	?1			?4												1	1	1		4
933	1.2	●																											2	?1			?1												1	3				12
932	1.2	●		1						?1		?1			?1																									2				?4						2
931	1.3	●	●	14								5	1	2/?2	?1	?1			?4																				1						2					12
930	1.2	●	●	6							2	15/?1	3	3	?3				?6																				2/?1						4			1		12
929	1.2	●	●	7							1	4	1	1	?2	?2		?2	?1																										3					11
448	1.4		●	4						?1		?2				?1																													1					1
447	1.2	●		1																																									1	1				
446	0.9																																																	
445	1.3																																																	
444	1.3	●																																																
443	0.9																																																	
442	1.1			2																																														1
441	1.5	●		1																																			2							1				3
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Fig. 8. Dinantian conodont biozonations of Great Britain (in part after Varker, & Sevastopulo, 1984).

Limestone in Northumberland. Secondly and more importantly the Ashfell Sandstone in Ravenstonedale is in part older than the Fell Sandstone of Northumberland.

The Northumberland Trough sequence reflects the continuation of shallow-marine sedimentation throughout Dinantian time and is thus ideal for the study of the palaeontology and palaeoecology of the somewhat unusual and restricted Dinantian conodont faunas which could obviously tolerate fluctuating salinities.

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APPENDIX – SECTION LOCALITIES

Penton Bridge to Harelawhill Limestones: Liddel Water, NY 433 470; Day (1970, p. 161, figs. 28, 29).
Low Tipalt Limestone: Tipalt Burn, NY 665 671; Johnson (1959).
Denton Mill Limestone: Toddle Burn, NY 662 676; Johnson (1959).
Un-named Limestone (between Denton Mill and Naworth Limestones). Toddle Burn, NY 663 682; Johnson (1959).
Upper Millerhill Limestone: R. Irthing, NY 685 752; Day (1970, p. 128).
Lower Millerhill Limestone: R. Irthing, NY 685 752; Day (1970, p. 128).
Leahill Limestone: R. Irthing, NY 689 726; Day (1970, p. 128).
Appletree Limestone: R. Irthing, NY 689 726; Day (1970, p. 128).
Lanercost Limestone: R. Lyne, NY 495 722; Day (1970, p. 115).
Kingsbridge Limestone: R. King Water, NY 580 650; Day (1970, p. 96, fig. 20).
Upper Antiquatonia Band: R. White Lyne, NY 5114 7309; Day (1970, p. 73, fig. 17).
Lower Antiquatonia Band: R. White Lyne, NY 5114 7309; Day (1970, p. 73, fig. 17).
Main Algal Limestones 1 to 13: Birky Cleugh, Bewcastle, NY 5883 7540 to NY 5926 7539; Day (1970, p. 61, fig. 15).
Junction Limestone: Ashy Cleugh, Bewcastle, NY 5790 7674; Day (1970, p. 39, fig. 9).
Rigghead Limestone: Ashy Cleugh, Bewcastle, NY 7533 7680; Day (1970, p. 39, fig. 9).
Ashy Cleugh Limestone: Ashy Cleugh, Bewcastle, NY 5727 7676; Day (1970, p. 39, fig. 9).
Serpula Band: Ashy Cleugh, Bewcastle, NY 5715 7676; Day (1970, p. 39, fig. 9).
New House Limestone: Ashy Cleugh, Bewcastle, NY 5704 7676; Day (1970, p. 39, fig. 9).
Holmehead Limestone: Ashy Cleugh, Bewcastle, NY 5690 7685; Day (1970, p. 39, fig. 9).
Kitty Beck Limestone: Ashy Cleugh, Bewcastle, NY 5676 7688; Day (1970, p. 39, fig. 9).
Un-named Limestone (between Bogside and Kitty Beck Limestones): Ashy Cleugh, Bewcastle; NY 5665 7694; Day (1970, p. 39, fig. 9).
Bogside Limestone: Ashy Cleugh, Bewcastle, NY 5649 7700 to NY 5654 7695; Day (1970, p. 39, fig. 9).
Rawney Limestone: River White Lyne, Bewcastle, NY 5475 7554; Day (1970, p. 286).
Un-named Limestones (between Rawney and Ellery Sike Limestones): River White Lyne and Ellery Sike Bewcastle.
Ellery Sike Limestone: Ellery Sike, Bewcastle, NY 5446 7583; Day (1970, p. 286).
Un-named Limestones (below Ellery Sike Limestone), Ny 5441 7580 and NY 5439 7582; Day (1970, p. 286).