Palaeoecology of the late Visean (Dinantian) coral-chaetetid biostrome at Little Asby Scar (Cumbria, Great Britain)

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Abstract: An Upper Visean (Dinantian) coral-chaetetid sponge biostrome is described from the basal bed of the Potts Beck Limestone at Little Asby Scar, northern England. The biostrome most probably represents the shallowest phase of a shallow-water succession. Chaetetid-dominated facies alternate with coral-dominated facies both horizontally and vertically. The number of organisms *in situ* is highest in the chaetetid-dominated facies (~30%), whereas the coral-dominated facies consists mainly of *Siphonodendron* debris (~95%). These *Siphonodendron* debris layers provided the hard substrate for chaetetid sponge growth. Considerable vertical variations also include the distribution of syringoporid corals and heterocorals. The biostrome is classified as a polyspecific parabiostrome according to its composition and the abundance of intact organisms.

It displays a complex development with autochthonous growth of chaetetid sponges and few *Siphonodendron* colonies, and imported *Siphonodendron* debris. The biostrome lacks rigidity because the absence of encrusting organisms prevented development of a framework; superstratal growth seems not to be developed.

Key words: Dinantian, Visean, *Siphonodendron*, chaetetid sponges, biostrome, Cumbria

Contents

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1. INTRODUCTION

Detailed analyses of biostromes are relatively scarce (JOHNSON, 1958; KERSHAW, 1994; ARETZ, 2001, 2002), despite their abundance in shallow-water environments of the Southern Laurussian shelf during Dinantian time. This lack of attention might be due to the common idea that corals were not successful reef-builders during the Carboniferous, and thus only formed structures of low height and undifferentiated coral beds and biostromes. However, corals did contribute significantly to reef-formation during the Visean, and coral-rich reefs are relatively common during that time (e.g., WEBB, 2001; ARETZ, 2002). At least some biostromes can be interpreted as pioneer phases that failed to develop into larger, well-differentiated reefal bioconstructions (KERSHAW, 1994; ARETZ, 2002).

It is the aim of this paper to demonstrate the contribution of rugose corals and chaetetid sponges to the formation of a Late Visean biostrome and to evaluate their potential for the development of rigid bioconstructions.

2. SETTING AND SUCCESSION

The biostrome in question forms the lowest bed of the Potts Beck Limestone in the stratotype of the Holkerian/Asbian boundary at Little Asby Scar, near Ravenstonedale, Cumbria (northern England). The boundary was defined and the stratotype located by

land

topographic
height (block)

● stratotype: Little Asby Scar
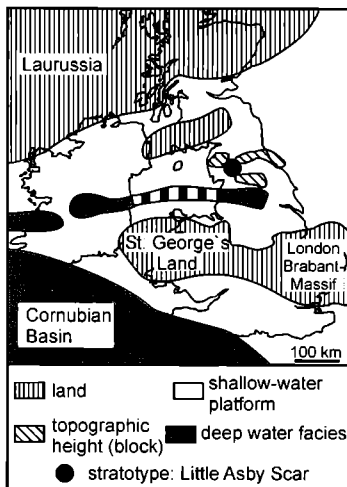
shallow-water
platform

deep water facies

Fig. 1:
Simplified palaeogeographic map of the British Isles during the Visean and location of Little Asby Scar (modified from COPE et al., 1999; RAMSBOTTOM, 1981).

George et al. (1976). Little Asby Scar is situated in the Stainmore Trough, a small intra-platform "basin" between the Alston and Askrigg Blocks (Fig. 1). The topographic location of the outcrop is on a hillside north of Potts Beck and east of Mazon Waths Farm (NY 6988 0827). The biostrome crops out laterally more or less continuously over at least one thousand metres.

The succession at Little Asby Scar is shown in Fig. 2. The boundary between the Ashfell Limestone and the overlying Potts Beck Limestone is a thin siltstone bed (bed e of George et al., 1976), which is discontinuous (1–15 cm thick) and could not be traced over all of the outcrop interval (Aretz & Nudds, 2005). The Potts Beck Limestone is overlain by the Knipe Scar Limestone.

The general structure is best seen from the opposite hillside on the southern bank of the Potts Beck (Fig. 3). The beds west of the stratotype (S in Fig. 3) are sub-horizontal, whereas immediately east of the stratotype they bend steeply down (30–40°). Farther east, the beds are again sub-horizontal. This arrangement is also seen in the morphology of the hillside. At the bottom of the hillside (~50 m below the stratotype), an exposure of limestone, yielding highly silicified rugose corals and gastropods, reveals an explanation of the structure observed above. These beds (AA, Fig. 3) are in the form of an asymmetrical anticline with a smooth western flank and a steeper eastern flank. Higher up, a fault immediately east of the stratotype separates the steep dipping part of the succession from the sub-horizontal beds farther east. This fault separates the Potts Beck and Knipe Scar limestones as suggested by White (1992).

The biostratigraphy of the stratotype area is somewhat complicated (Aretz & Nudds, 2005). The original definition of the Asbian (George et al., 1976) is ambiguous. The boundary seems to be based on the appearance of the rugose coral genus *Dibunophyllum*. However, the single record of *Dibunophyllum* (see George et al., 1976; Ramsbottom, 1981) has never been repeated in the basal beds of the Potts Beck Limestone, either by Riley (1993) or in this study. The genus first appears east of the fault in younger beds of the Knipe Scar Limestone (KS 1 in Fig. 3). Foraminifers are important index fossils in

Stage	VISEAN (part)						
Sub-Stage	**Holkerian**	**Asbian**		**Brigantian**			
foram's	*Kosinkotextularia Pojarkovella nibelis* Cf5	*Neoarchaediscus* Cf6					
		α–β	γ	δ			
corals	E	F	G	H	I	J	K
		Alston Group					
	Stainmore Trough	Ashfell Limestone	Potts Beck Limestone	Knipe Scar Limestone	Robinson Lst	limestones and shales	

Fig. 2:
Overview of different stratigraphic zonations (after Riley, 1993) and lithostratigraphy of the Stainmore Trough (George et al., 1976).
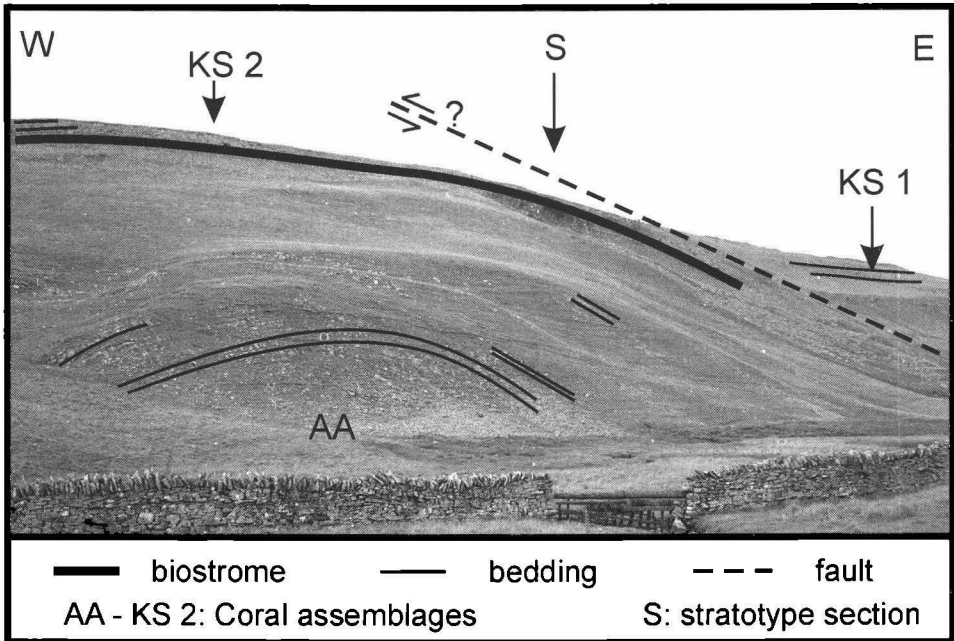
Fig. 3: Geological structure of the stratotype area as seen from Potts Beck with location of the stratotype, sample localities for the coral assemblages, and the position of the biostrome (dark line). The dip of the beds at the base of the hillside clearly indicates an anticline, and higher up a fault next to the stratotype.

the shallow-water environments of the Dinantian (e.g. Conil et al., 1990), but their record at the Holkerian/Asbian boundary is controversial. Strank (in Ramsbottom, 1981) suggested that the first Asbian taxa did not appear until 19.6 m above the boundary. In contrast White (1992) reported *Vissariotaxis* only two meters above the boundary. Additional problems arise from the faunal list given by Strank (in Ramsbottom, 1981), wherein taxa that are considered elsewhere to be Asbian are listed as occurring in the highest beds of the Ashfell Limestone.

The coral fauna of the studied biostrome in the basal bed of the Potts Beck Limestone does not imply a biozonal boundary at this level (Aretz & Nudds, 2005). It does not contain any coral taxa that first appear in the Asbian; instead all taxa reported are known from both the Holkerian and the Asbian. The first diagnostic Asbian coral taxa appear in the higher beds east of the fault. Therefore, the age of the basal beds of the Potts Beck Limestone is questionable. According to the coral data recovered during our study and the foraminiferal data of White (1992), a late Holkerian age may be suggested, but further investigations on the foraminifers are needed.

The lithostratigraphic succession of the stratotype area is characterised by rapidly changing shallow-marine facies conditions. According to earlier workers crinoidal limestones of various composition and texture dominate the succession. Various lithotypes (e.g. bioclastic limestone, shales, dolomites) are intercalated into this dominant lithotype.

Each lithotype does not represent a distinctive unit; the units of George et al. (1976) and Ramsbottom (1981) are commonly composite. The macrofauna is mostly fragmented, and cross-stratification occurs throughout the succession.

3. BIOSTROME

3.1. Description

The lowest bed of the Potts Beck Limestone (bed f in George et al., 1976) is rich in chert-nodules and corals and is described in the following text as the biostrome. This bed is the best exposed of the entire succession.

From the stratotype, it can easily be traced about 900 m towards the west, but only 50 m towards the east, where it bends downwards, follows a ridge and disappears under large blocks of scree. Farther east, beyond the fault, it is not exposed. The quality of the exposure changes over this distance, but is mostly very good. It is this bed from which Ramsbottom (1981) reported *Dibunophyllum bourtonense*. Kershaw (1994) interpreted the coral bed as a heterogeneous autoparabiostrome.

The coral fauna of the biostrome (Pl. 1, Figs. 1–6) is relatively diverse, consisting of *Siphonodendron* sp., *S. martini*, *Siphonophyllia siblyi*, *Axophyllum vaughani*, *Caninophyllum archiaci*, *Hexaphyllia mirabilis*, *Syringopora* sp., and Auloporidae indet. Large chaetetid sponges are common in some parts of the biostrome.

3.1.1. Microfacies

At the top of the Ashfell Limestone, the succession is dominated by medium-bedded, fine-grained limestone (Fig. 4). Some shaley, grey-coloured intercalations occur in varying thickness and are of discontinuous horizontal extent; macrofauna is rare. Carbonate petrography reveals that most bioclasts are small fragments of microflora (calcareous algae) or microfauna (foraminifers, ostracods). The identification of various tubes is partly hampered by the micritisation of the components. The tubes can be calcispheres as well as smaller algal tubuli fragments. Other bioclasts are small fragments of brachiopods, gastropods, pelmatozoans, bryozoans, and very rarely corals and chaetetids.

Three dominating microfacies types can be differentiated according to the texture and bioclasts: foraminifer-*Koninckopora*-pelmatozoan grainstones (MF I in Fig. 4), foraminifer-ostracod-*Koninckopora* packstones (MF IIa), and foraminifer-tubule-*Koninckopora* pack/grainstones (MF IIb). Lamination and in some cases cross-stratification are abundant in all three microfacies types and can be distinguished by the orientation of elongated bioclasts and millimetre-thick coarser stringers. Somewhat thicker coarse-grained intercalations of bioclastic pack/grainstone (MF IV) occur rarely. Their bioclast spectrum is comparable, but fragments of macrofauna become more abundant.

Coarse-grained bioclastic pelmatozoan-foraminifer grainstone (MF III) dominates the lowest part of the basal bed (bed f in George et al., 1976) of the Potts Beck Limestone (Fig. 4). Higher, coral-chaetetid rudstones dominate. The composition of the rudstones varies considerably, both vertically and horizontally. Therefore coral rudstones (MF V) can be differentiated from coral-chaetetid rudstones (MF VI) and chaetetid rudstones

(MF VII). Besides this main facies type, coarse-grained bioclastic grainstones still occur. Petrographic observations show varying textures. Grain-supported pelmatozoan-foraminifer grain/rudstones are intercalated with bioclastic packstones. The latter are in some cases remarkably rich in gastropods.

This basal bed is overlain by fine-grained, medium-bedded limestones. Petrographic analysis shows the dominance of microfacies types (MF IIa, b) already known from the underlying Ashfell Limestone, but packstone texture and bioturbation may be more common in these levels.

However, the Potts Beck Limestone as a whole consists of bedded limestone of various grain-sizes (mud- to rudstone textures), mostly rich in crinoids. Most parts of the succession might be bioclastic, commonly fine- to medium-grained grainstones and packstones. Micrite-dominated textures, weathered to a brownish colour, are rare, but some of them are very rich in fish remains (pers. comm. Dr. H.M. Weber, Bergisch-Gladbach). Vertical and horizontal variation of the grain size occurs over short distances. Small-scaled cycles might be indicated by the variation of grain-sizes and textures (see also WHITE, 1992, Fig. 8.29). A diverse macrofauna (brachiopods, gastropods, pel-
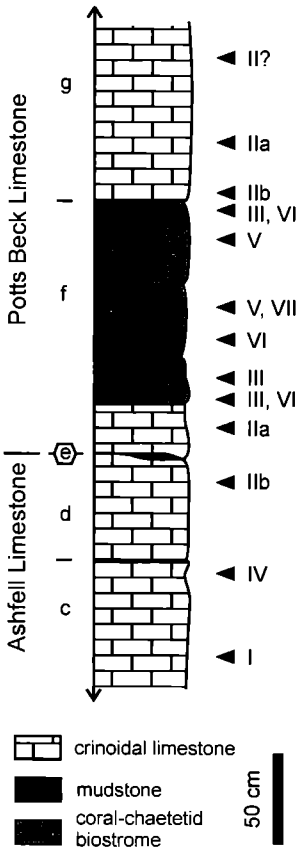

Fig. 4:
Stratotype section: Succession at the boundary level, lithotypes, identification of the samples, and distribution of microfacies types (MF I–VII) as described in the text (modified after RAMSBOTTOM, 1981).

matozoans, and corals restricted to the basal part) is observed and seems to be more common in coarser textures.

3.1.2. Facies variation within the biostrome

Considerable variation in composition and thickness have been observed for the biostrome. Four sections (A–D in Fig. 5) have been chosen as representative of the compositional changes within the biostrome.
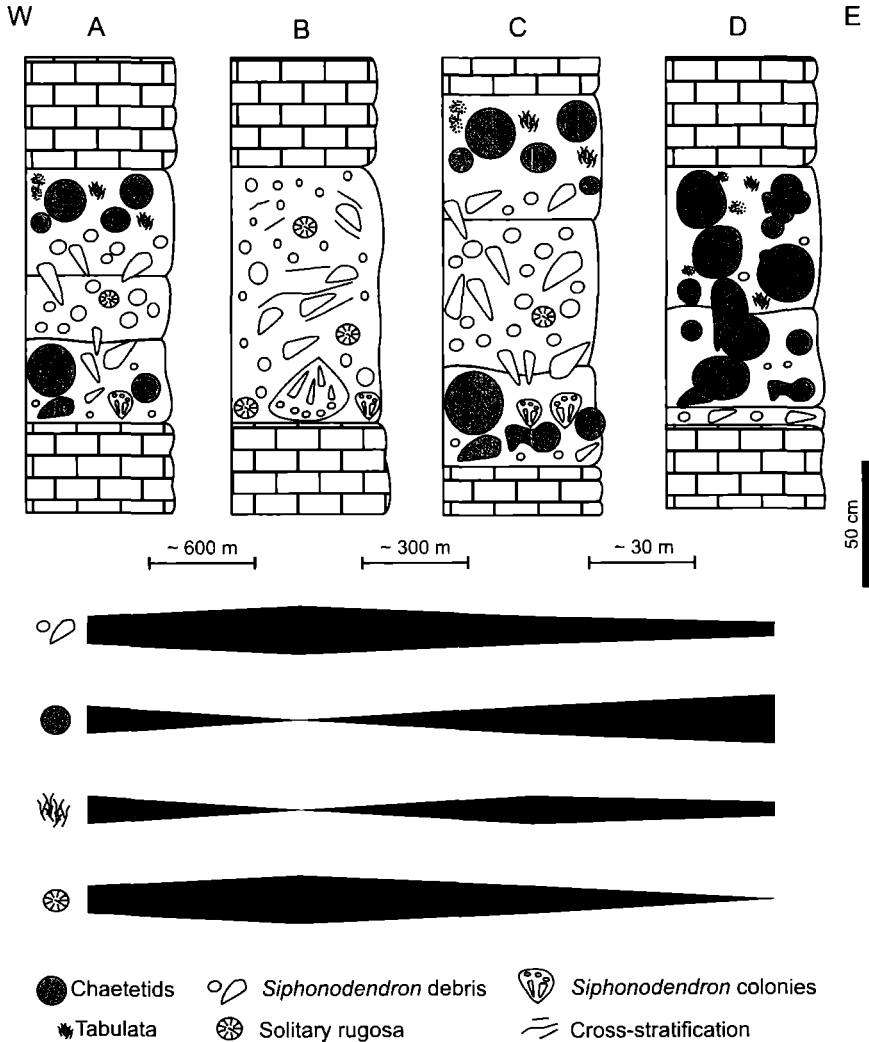

Fig. 5: Sketches of four distinctive sections of the biostrome which show differences in thickness and vertical and horizontal variations in fauna. The bars below the sections indicate the relative abundance of the main biota.

The biostrome is thickest (1.4 m) in the stratotype area (Section C in Fig. 5, S in Fig. 3), and consists mainly of fragments of *Siphonodendron* spp. and chaetetid sponges. Silification is common and occurs in numerous chert-nodules, silicified macrofauna, and some layered chert-concentrations. The grain-size varies throughout the bed, but is generally coarse. Cross-stratification occurs.

At section C the biostrome can be subdivided into three horizons. The lower horizon (35–55 cm thick) is dominated by multi-layered chaetetid sponges up to 30 cm in diameter and laminated chert-concentrations, in some cases showing relict structure of the chaetetid sponge skeleton. Rugose corals are less abundant and mostly preserved as debris; only a few *Siphonodendron* colonies occur (Pl. 2, Fig. 3). This horizon is overlain by a 45–65 cm-thick layer of *Siphonodendron* debris (Pl. 2, Fig. 2). The top of the biostrome is formed by a horizon of syringoporid corals (most colonies only slightly reworked and presumably dislocated), chaetetid sponges, which have maximum diameters of up to 20 cm, and in the lower part of this horizon some *Siphonodendron* hash.

Section B, 300 m west of the stratotype (Fig. 5), is 1.0 m thick. This section consists mainly of coral debris and a few inverted *Siphonodendron* colonies at the base. Cross-stratification is common in the middle and upper parts of the section. The section represents an end-member of a compositional change. From the stratotype section westwards, the abundance of chaetetid sponges (Pl. 2, Fig. 4) and syringoporid colonies decreases, as does the thickness of the biostrome. About 50 m west of the stratotype, the last syringoporids occur (Pl. 2, Fig. 5); chaetetid sponges persist farther west, but finally also disappear. In this transition unit unbroken *Siphonodendron* colonies are in some cases concentrated in the basal part (Pl. 2, Fig. 5), but they are never common. Finally, at section B, the entire biostrome consists only of coral clasts.

Section A (Fig. 5), about 600 m west of section B, shows a similar composition to section C (at the stratotype) represents the most westerly 150 m of the exposure. Here, the biostrome is about 1 m thick, and can again be divided into three horizons. A basal horizon of chaetetid sponges and few intact *Siphonodendron* colonies is succeeded by a *Siphonodendron* debris horizon. The top is formed by a horizon of chaetetid sponges and syringoporid corals. The succession differs from that at section C in the smaller dimensions of the chaetetid sponges and in the overall reduced thickness.

Although section D is only 30 m east of section C (Fig. 5), the composition is completely different, and the thickness is reduced to 1 m. The entire section D is dominated by multi-layered, columnar and tabular chaetetid sponges (= ragged domical shape of KERSHAW & WEST, 1991) (Pl. 2, Figs. 6, 7). Their dimensions are variable, from a few centimetres to about 20 cm in diameter. They commonly form large patches, when they overgrew each other. Some syringoporid colonies and bioclastic debris occur between the patches. *Siphonodendron* is relatively rare apart from a 10 cm-thick basal debris layer and a few small debris patches in the middle part of the biostrome.

3.1.3. Faunal variation within the biostrome

Several changes in the biotic composition of the biostrome were observed in the four sections described above. The distribution of the biota shows significant lateral and vertical differences within the four sections (A-D, Fig. 5). Solitary rugose corals (*Axophyllum vaughani, Siphonophyllia siblyi, Canoinophyllum archiaci*) are most abundant in

the *Siphonodendron* debris facies. Therefore, they are most common in section B, rare in sections A and C, and have not been reported from section D. A similar trend is seen in the distribution of colonial rugosans (*Siphonodendron* spp.), but their abundance is invariably much higher. They are most abundant in section B, still numerous in sections A and C, and only become rare in section D, where they are restricted to the basal level and a few small patches. In contrast to the pattern for rugose corals is the distribution and frequency of tabulate corals (mainly syringoporids) and chaetetid sponges. Chaetetids dominate section D; they are quite common in sections A and C, mostly restricted to the bottom and the top of the biostrome, and are absent for the greatest lateral extent of the biostrome (section B). The size of the chaetetids mirrors that trend. Although the individual size of the chaetetids in section D is generally smaller than in section C, the size of the chaetetid patches is significantly greater. Syringoporid corals show a similar distribution as the chaetetids, but their frequency is less high.

Vertical trends occur in the position of intact colonies of *Siphonodendron* (*in situ* or inverted), which are only known from the lower part of the biostrome, and in the concentration of tabulate corals in the upper part. The diameter of heterocorals also seems to increase towards the top of the biostrome. Specimens with diameters of more than 1.2 mm have only been found at the top of the biostrome, with the smallest diameters (0.6–0.7 mm) in the lower and middle part. Finally the largest multi-laminated chaetetids are concentrated in the lowest part of sections C and D.

Fasciculate rugose corals (*Siphonodendron* spp.) are mostly fragmented, and single fragments rarely have more than five corallites. Aggregates of randomly orientated corallites of different sizes are common. Intact colonies have maximum diameters of 25 cm, but are very rare (fewer than 5%), and more than 50% of them are inverted. Therefore, only ~2.5% of the *Siphonodendron* material is in growth position or over-turned. It is difficult to estimate the number of chaetetid sponges in growth position, but it is probably closer to 30%. Different growth generations are observed in larger chaetetids (Pl. 2, Figs. 3, 5). Most of the solitary corals (at least 95%) have been abraded so that the dissepimentarium is partly or totally missing.

Extensive areas of the biostrome are dominated by 1.0 m-thick accumulations of *Siphonodendron* fragments (section B). These are cross-stratified in the middle part of the bed. The rare occurrences of *Siphonodendron* in growth position are restricted to the base of the biostrome (Pl. 2, Fig. 5). Solitary corals are quite common in the *Siphonodendron*-dominated part of the biostrome. Towards the east (section D), the biostrome is also 1.0 m thick, but differs fundamentally from section B to west. Large, columnar, spherical and tabular chaetetids, partly growing upon each other, are dominant. *Siphonodendron* debris is restricted to the base, whereas the number of tabulates increases towards the top. These sections (B and D) are two end members of a spectrum and mixing of these end members is seen in sections A and C. The stratotype reveals the best section for a mixed member (Fig. 5).

3.2. Interpretation

The coral-chaetetid sponge bed is classified as a biostrome due to its wide lateral extent, its low thickness and the high number of potential bioconstructors. KERSHAW (1994) point-

ed out that most of the dendroid rugose corals (*Siphonodendron* spp.) were *in situ*. In combination with the chaetetids in the coral bed, he classified it as heterogeneous auto-parabiostrome. The observations of this study imply modification of that classification.

The proportion of intact *Siphonodendron* colonies is significantly lower than KERSHAW estimated and in addition more than half of them are overturned. Therefore, following the classification of KERSHAW (1994) the coral bed should be re-classified as a parabios-trome. A higher percentage of fauna in growth position is estimated in the parts in which chaetetids become more dominant; these parts can be classified as autoparabiostromes. In both cases the biostrome is composed of a varied biota, and is therefore heterogene-ous (KERSHAW, 1994) or polyspecific (ARETZ, 2002).

The varied classification of different parts of the biostrome is an effect of its complex formation. Section D suggests that a chaetetid-dominated biostrome formed on a basal layer of small-sized *Siphonodendron* fragments (Fig. 5). Chaetetid sponges become rare immediately west of section C, and quickly disappear such that a chaetetid biostrome is not developed at all in section B. Section A, at the western end of the exposure, is similar to section C and a chaetetid biostrome is again developed. Section B thus rep-resents the coral dominated part of the biostrome. The common occurrence of coral debris and cross-stratification suggests an allochthonous origin of the coral material. However, such material has not been transported far as some colonies are still intact. The well-agitated environment seems to have hampered the development/preservation of an autochthonous biostrome.

The sections A and C represent the mixed area in which the chaetetid facies inter-calates with the *Siphonodendron* debris facies. Phases of more suitable living conditions with little incoming debris (lower horizon) alternated with phases with much incoming debris (middle horizon). However, the growth form of the chaetetids reflects changing sediment/debris input during the formation of chaetetid-dominated facies (KERSHAW & WEST, 1991). Chaetetids with smooth edges, representing low sediment input, coexist with forms characterising high sediment input and/or high turbulence (e.g. multi-lay-ered, laminated forms and forms with changes in growth direction). Therefore, the sediment input changed frequently and eventually some smooth shaped forms devel-oped in protected positions (possibly surrounded by larger chaetetids?).

The concentration of a few intact *Siphonodendron* colonies at the base of the bios-trome indicates that energy levels were initially low. The preservation of *Syringopora* colonies and chaetetids in growth position at the top of the biostrome again indicates low energy levels. However, the absence of any micritic matrix in the biostrome, the abundant cross-stratification and the large number of transported and re-worked bio-clasts indicate the continuous presence of well-agitated shallow water.

It is difficult to decide whether optimal conditions for the development of a chaetetid-dominated biostrome existed in the middle part of the exposure (section B) and that this biostrome was destroyed through the incoming debris, or if the mass of incoming debris directly hampered any development, or if a *Siphonodendron*-dominated part of the biostrome was more easily destroyed. However, the most western part of the bios-trome, where chaetetids reappear and contribute to its formation, indicates that this chaetetid-dominated part was not a single, isolated occurrence.

Several scenarios are possible. First, the biostrome was differentiated into chaetetid- and coral-dominated parts, and periodically affected by storm events. *Siphonodendron*,

a fragile organism, was easily destroyed whereas the more massive chaetetids persisted, and resulted in a debris-dominated coral facies and a chaetetid facies in growth position. This scenario is also supported by dislocated chaetetid sponges. Secondly, it is possible that section B lies within a rim/channel through which continuous transport took place, while biostrome formation occurred on its protected flanks. This scenario, however, lacks the support of the outcrop geometry, because such a channel cannot be seen in the field, because the shift between the dominating facies types seems to be gradual, and because of the occurrence of the basal *Siphonodendron* debris layer in section D. However, the formation of the chaetetid-dominated facies without any change in composition and growth orientation throughout section D supports some differentiation of the biostrome. Finally, it is possible that a former chaetetid biostrome of some size was partly removed in its central parts, which were later covered by *Siphonodendron* debris.

In the first scenario formation and destruction occur in the same place. In the latter two scenarios the provenance of *Siphonodendron* is somewhat questionable. The high number of fragmented and re-oriented corals combined with cross-stratification and the absence of micritic matrix, indicates a high-energy system. A local source is likely for the coral debris; perhaps major storm events periodically destroyed nearby *Siphonodendron* meadows and transported the debris into the Little Asby Scar region.

Perhaps this complicated structure is best explained by a shoal scenario which combines growth and destruction in place, together with some minor import of external debris. The Little Asby Scar biostrome shows a cross section through a marginal part of a shoal and its edges. Section B represents the part that is closest to its centre. *Siphonodendron* thickets formed on the shoal and the delicate colonies were repeatedly destroyed during storm events. The partly autochthonous nature of the *Siphonodendron* debris is seen in the intact colonies, which do not support transport over long distances, and in the accumulation of larger fragments, which seem to be the result of para-autochthonous disintegration of colonies. However, the high number of single corallite fragments (in some cases 100% of the bioclasts), the loss of the dissepimentarium of almost all solitary taxa, and the abundant cross-stratification indicate somewhat longer transport (allochtonous *Siphonodendron* debris). The chaetetid-dominated facies represents the deeper and calmer facies around the edges of the shoal (section D), while sections A and C represent the transitional area between the chaetetid-dominated off-shoal facies and the *Siphonodendron* debris facies. However, the absence of any micritic sediment throughout the biostrome indicates its entire formation in higher energy levels.

The precise centre of the shoal cannot be located. The outcrop geometry does not reveal any swell-like structure and therefore the centre is probably some distance to the north, since in some areas near to section B the *Siphonodendron* debris seems to show layers inclined towards the south. However, the concentration of single *Siphonodendron* corallites suggests that the source of that debris was not distant.

The development of the biostrome was eventually stopped by the deposition of fine-grained, algal rich limestones. The appearance of packstone textures and the reduced grain size in the overlying beds probably indicates a trend towards deepening in this area. This deepening enabled the formation of the flourishing chaetetid-*Syringopora* facies on top of the biostrome in sections A, C, and D, and supports the interpretation of the depositional area of the chaetetid-dominated facies as being somewhat deeper.

The biostrome as a whole was not a rigid bioconstruction. Rigidity may have been established in the chaetetid-dominated facies in section D, where relatively few organisms are dislocated, and framework structures may only be developed locally by overgrowing sponges. However, other bioconstructions show that chaetetid sponges and *Siphonodendron* were capable of being frame builders in the Carboniferous (e.g. MINWEGEN, 2001; ARETZ, 2002), but due to the absence of encrustors, such as calcimicrobes or bryozoans, a rigid framework with substantial relief did not develop at Little Asby Scar. Also the formation of multi-layered chaetetids does not support the development of superstratal growth, which is necessary for the development of substantial relief.

4. COMPARISON

JOHNSON (1958) described three biostromes from Northern England (the *Chaetetes* Band, the Brunton Band, and the Frosterley Band) from slightly younger (Namurian) strata. This widespread occurrence is a major contrast to the Little Asby Scar biostrome (LAS). The *Chaetetes* Band is generally ~ 1 m thick, and is therefore of similar thickness to the LAS biostrome. JOHNSON (1958) described the heterogeneous nature of the bed and emphasised the lens-like occurrence of piles of tabular chaetetids and isolated occurrences of *Chaetetes* on a single bedding-plane. Both types of occurrence are also observed at Little Asby Scar, but the variations occur within a single outcrop. The Brunton Band (an "algal biostrome" comprising the genus *Calcifolium*) does not share any similarity with the LAS biostrome, except in its horizontal geometry. The same is true for the Frosterley Band, which is of remarkable horizontal extent and contains medium to widely spaced *Dibunophyllum bipartitum*, *Diphyphyllum fasciculatum* and *Actinocyathus floriformis*.

The "biostromal reefs" of CALDWELL & CHARLESWORTH (1962) of the Asbian of the Ballymote Syncline (County Sligo, Ireland) are in some cases similarly rich in *Siphonodendron* debris, but chaetetids are almost absent. They are also of a much wider horizontal extent (~ 40 km) than the LAS biostrome. Although ARETZ & HERBIG (2003) postulated very different depositional environments for the single "biostromal reef", no overlap with the LAS biostrome is known.

The coexistance of *Siphonodendron* and chaetetids has been described from the upper Royseux biostrome in Belgian (ARETZ, 2001). The biostromes are comparable in thickness, but chaetetid sponges occur in Belgium only very locally and were only accessory faunal elements in the biostrome. The biostrome formation formed due to colonial rugose corals, mainly *Siphonodendron*. The number of colonies in growth position in Belgium (~70%) is much higher than at Little Asby Scar (~2.5%). The lower biostrome from the same Belgian locality (ARETZ, 2001) differs in the development of evolutionary stages and faunal replacements within the biostrome, the absence of chaetetids, and the low amount of coral debris. Additionally, both biostromes were only traced for 80 m.

ARETZ (2002) described *Siphonodendron martini* biostromes from the Belgian Lives Formation. These biostromes are slightly older than the LAS biostrome, and normally do not exceed a height of more than two *Siphonodendron* colonies (~ 50 cm). *Siphonodendron* debris is abundant in these biostromes, but is almost exclusively autochthonous. The biostromes formed in the transition bed from matrix-supported to grain-supported textures. Biostromal development ceased when energy levels became too high

and resulted in destruction of the colonies. The *Siphonodendron* growth-form with large diameters and low height, in combination with a virtual horizontal growth mode for most of the corallites, supports the formation in quieter water for the Belgian biostromes. Although, the energy setting also controlled the LAS biostrome, it was much more pronounced, as the grainstone texture of the LAS biostrome shows.

The *Siphonodendron* limestone in Southern Spain (RODRIGUEZ et al., 1994) is very different to the LAS biostrome. Main differences are its higher number of colonies in growth position, the absence of chaetetid sponges, the importance of gigantoproductid brachiopods as hard substrate for initial coral growth, its cyclic development, and its depositional setting as a reef flat.

5. CONCLUSIONS

(1) The Little Asby Scar biostrome is of considerable horizontal extent and shows significant vertical and horizontal compositional changes. However, an internal subdivision could not be generalised, although distinctive horizons can be traced in various parts of the biostrome.

(2) Two facies dominate the biostrome; a chaetetid sponge facies and a *Siphonodendron* debris facies.

(3) The number of *Siphonodendron* colonies in place is much lower (< 2.5%) than previously thought, such that the biostrome is now classified as a parabiostrome (KERSHAW, 1994).

(4) The formation of the biostrome took place in a shallow, well-agitated environment (shoal). The highest water energy may have been reached in the middle horizon of the biostrome.

(5) The carbonate petrography around the Holkerian/Asbian boundary interval indicates a dominance of fine-grained, algal rich grainstones textures. The biostrome may be the most shallow facies at this interval.

(6) Despite the abundance of potential framework builders in the biostrome, framework development occurred only very locally. Its development was hampered by the lack of encrusting organisms and the high-energy setting of the biostrome.

(7) A comparable Dinantian biostrome has not previously been reported from the Laurussian shelf.

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Plate 1

Fig. 1:   *Siphonophyllia siblyi* SEMENOFF-TIAN-CHANSKY, 1974, transverse section, biostrome; x 1

Fig. 2:   *Dibunophyllum bipartitum* (McCOY, 1849), transverse section, Knipe Scar assemblage 1; x 1

Fig. 3:   *Caninophyllum archiaci* (MILNE EDWARDS & HAIME, 1852), transverse section, biostrome; x 1

Fig. 4:   *Siphonodendron* sp., transverse section, biostrome; scale bar = 5 mm.

Fig. 5:   *Siphonodendron martini* (MILNE EDWARDS & HAIME, 1851), transverse sections, biostrome; x 2

Fig. 6:   *Syringopora* sp. (PHILLIPS, 1836), small colony fragment from the biostrome; x 1

Fig. 7:   *Axophyllum vaughani* (SALÉE, 1913), transverse section, biostrome; x 1

Fig. 8:   Heterocorals (H) in coral rudstones (MF V), F: foraminifers, P: pelmatozoan fragments. Scale bar = 2 mm.

Fig. 9:   Chaetetid rudstones (MF VII): chaetetid sponge (C) bottom right, inbedded into grain-supported matrix, F: foraminifers, P: pelmatozoan fragments. Scale bar = 2 mm.

Fig. 10: Coral rudstones: *Axophyllum vaughani* (A) fragment in the left, inbedded into coarse bioclasts (brachiopods, B and pelmatozoans, P), note the partly micrite filled gastropod shell (G). Scale bar = 2 mm.

Fig. 11: Foraminifer-*Koninckopora*-pelmatozoan grainstones (MF I): lamination due to the orientation of elongated bioclasts (mainly *Koninckopora,* K) and a coarser bioclastic layer. Scale bar = 2 mm.
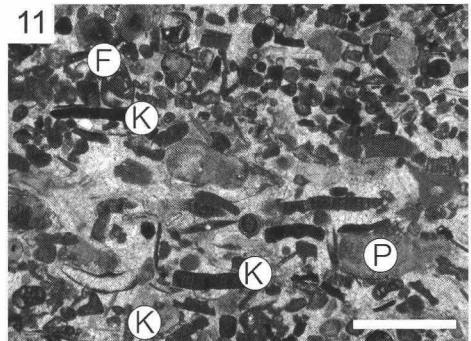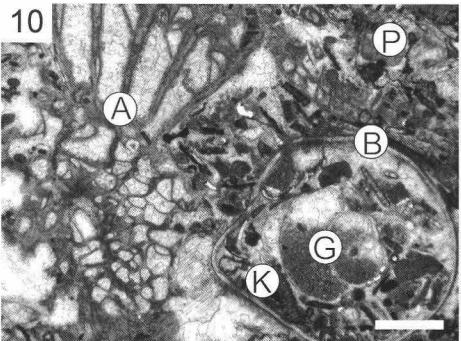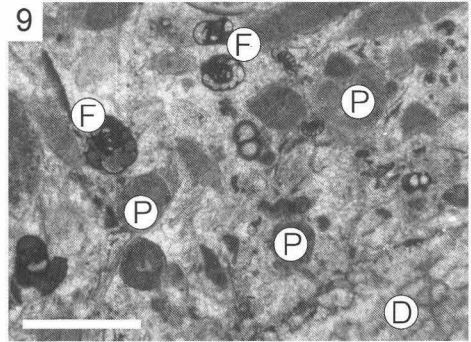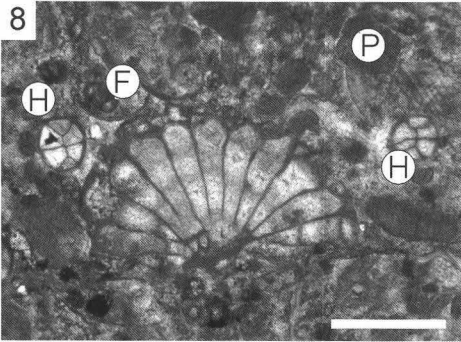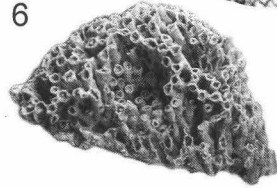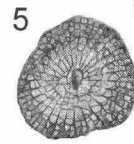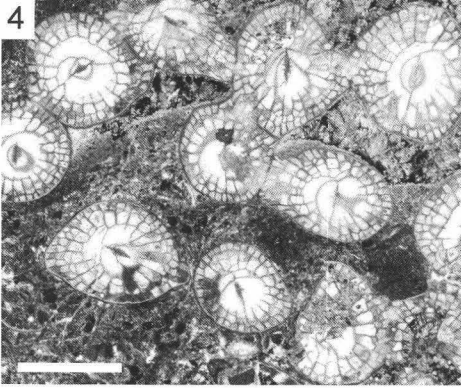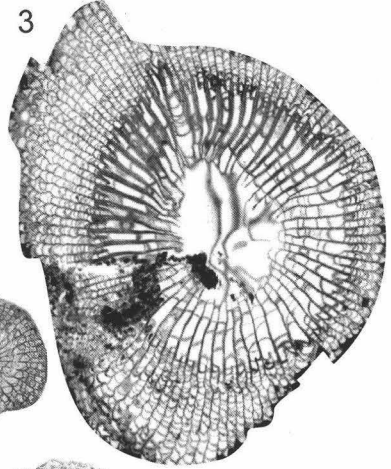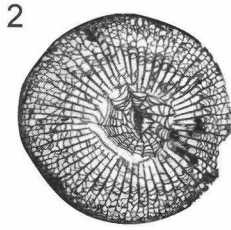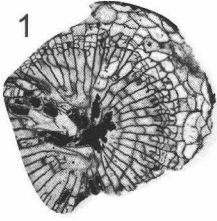
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Plate 2

Fig. 1: The section C at the stratotype is composed of three horizons. The lower and upper horizons are dominated by chaetetid sponges, the middle part by *Siphonodendron* debris.

Fig. 2: Close up of the *Siphonodendron* debris from the middle horizon of section C.

Fig. 3: Close up of the lower horizon of section C: Chaetetid sponges, layered chert-nodules and some intact *Siphonodendron* colonies are surrounded and covered by coarse sediment often rich in *Siphonodendron* debris. The large chaetetid sponge is dislocated as indicated by the lamination and growth direction. The initial growth centre is top left and eventually a *Siphonodendron martini* fragment provided a hard substrate for growth initiation.

Fig. 4: Tabular chaetetid sponge covered by *Siphonodendron* debris, ~ 80 west of section C.

Fig. 5: Intact *Siphonodendron* colonies at the base of the biostrome, ~ 40 west of section C.

Fig. 6: Numerous chaetetids, sometimes in patches, and few syringoporoid corals, from middle part of section D.

Fig. 7: Chaetetids (encircled in white), and few syringoporid corals packed slightly looser than in Fig. 6; from the middle part of section D.

The white scale bars in Figs. 2, 3, 6 and 7 are 10 cm long.