The coral fauna of the Holkerian/Asbian boundary stratotype section (Carboniferous) at Little Asby Scar (Cumbria, England) and implications for the boundary

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ABSTRACT: Five coral assemblages from the Holkerian-Asbian succession at the stratotype section at Little Asby Scar, Cumbria (England) have been studied. The stratotype section is located near a fault zone, and contact of the Potts Beck Limestone (earlier Asbian) and the Knipe Scar Limestones (later Asbian) is tectonically controlled.

The coral fauna of the limestone bed which defines the base of the Asbian consists of a coral assemblage which does not contain any coral taxa appearing in the Asbian. The first *Dibunophyllum*, the traditional coral genus for the Asbian-Brigantian, is not known until the overlying Knipe Scar Limestone. However, other coral taxa from the Knipe Scar Limestone are typical of the later Asbian. No coral assemblages can be doubtless assigned to the earlier Asbian. The coral assemblages of Little Asby Scar proved that the first appearance of *Siphonodendron junceum* is in the upper Asbian.

The distribution of other important biostratigraphic groups, the foraminiferans and brachiopods, supports a relocation of the originally defined Holkerian-Asbian boundary. However, the bases of the biozones of the two most abundant groups, corals and foraminiferans, do not coincide; Asbian foraminiferans appear earlier than Asbian corals.

The attempt to correlate the Little Asby Scar succession to the Belgian Namur-Dinant basin and its standardized sedimentary sequences based on a simple presence-absence comparison of corals and foraminiferans does not result in a definite correlation.

It is evident that the Holkerian-Asbian boundary as originally defined is lithostratigraphic, and that the absence of any biostratigraphic support prevents the use of that level in a chronostratigraphic context. Therefore, after a consensus on the criterion for the base of the Asbian, the stratotype section should be relocated to a better exposed section.

INTRODUCTION

Stratotype sections form the basis for regional and/or global correlation and thus are important spikes in the stratigraphical column. They are often linked to significant changes within the geological record (e.g. fauna or lithofacies) and the concept of stratotype sections is widely accepted.

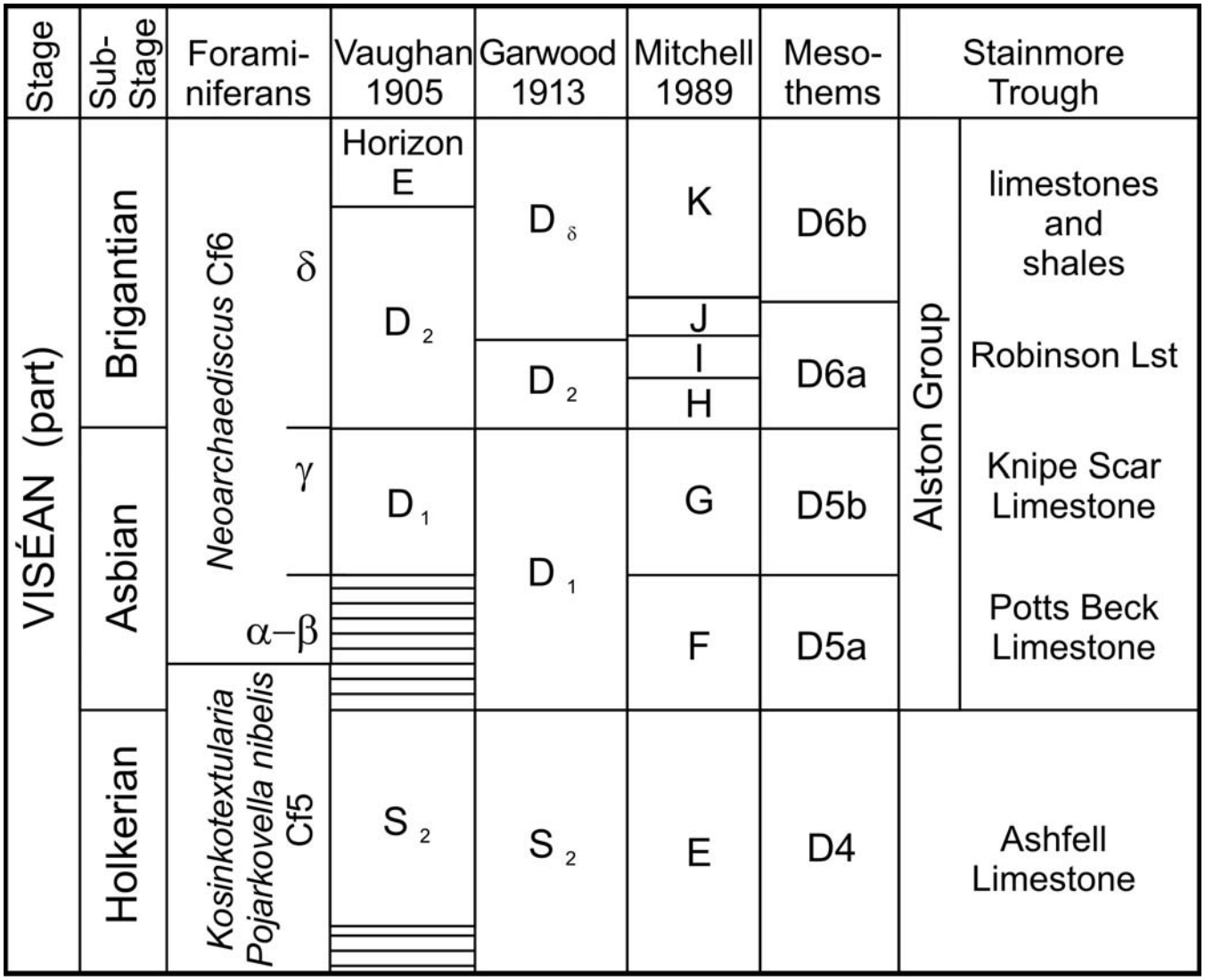
The first modern biostratigraphic framework for the Lower Carboniferous succession of southern England was introduced by Vaughan (1905) who used a combination of lithology and "biozones" of brachiopods and corals (text-fig. 1). Since this pioneer work in the Bristol area, various attempts have been made to establish a general correlation for the whole of the British Isles. Facies shifts and biogeographical provincialism hampered this approach for many years. Important correlations were proposed by Garwood (1913) and Bisat (1928), but were limited to a particular region or facies. Hill (1938-41) described the distribution of rugose corals within the British Lower Carboniferous succession, and added some remarks on the existing stratigraphical framework.

It is important in the context of this study that two of Vaughan's "zones" of the upper Viséan were named after the rugose coral genus *Dibunophyllum* (text-fig. 1) and that this genus has been used as the marker for the interval now referred to the Asbian and Brigantian substages.

Based on what was then a new stratotype concept George et al. (1976) established a chronostratigraphical framework for the Lower Carboniferous succession of the British Isles, dividing it into six regional stages: Courceyan, Chadian, Arundian, Holkerian, Asbian and Brigantian (text-fig. 1). To be consistent with the internationally recognized stratigraphic chart (Gradstein et al. 2004) these regional stages now become substages.

This subdivision was a combination of the older systems with two new approaches, first, the eustatically-controlled sea-level fluctuations (Ramsbottom 1973, 1979), and secondly, a biostratigraphy based on microfossils (Hallet 1970, Butler 1973, Conil et al. 1980). A stratotype section was established for the lower boundary of each substage. Thanks to this attempt many major problems of British Lower Carboniferous stratigraphy have been solved. As a consequence of its modern chronostratigraphical approach with defined boundaries, it was used for international correlation and was adapted in many other countries (e.g. Portugal: Herbig et al. 1999, Germany: Herbig 1998, Weyer 2001, France: Poty et al. 2002, Brazil: Melo and Lobosziak 2000, Eastern Canada: Giles and Boutilier 2003).

Notwithstanding its international recognition, further work on successions of different ages and different parts of Britain have highlighted problems in precise recognition of substage boundaries, e.g. in indicating the transitional character of the fauna considered to be significant for a stage (e.g. Somerville and



TEXT-FIGURE 1
Overview of different British stratigraphical zonations for the Holkerian – Brigantian time interval (after Riley 1993). Foraminiferans (after White 1992, Riley 1993), mesothems (Ramsbottom 1979), lithostratigraphy of Stainmore Trough (George et al. 1976).

Strank 1984, Cozar and Somerville 2004). Riley (1993) reviewed the Lower Carboniferous biostratigraphy and chronostratigraphy, and evaluated the stratotype sections and the problems linked to them.

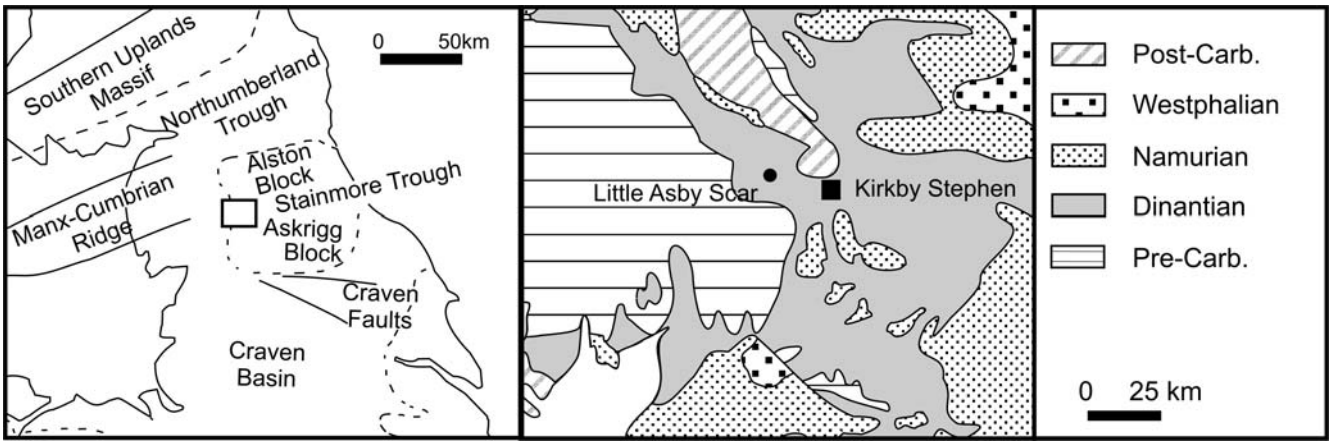
The use of rugose corals in Lower Carboniferous biostratigraphy is still valuable, especially in shallow-water or reefal facies. Poty (1985, and in Conil et al. 1991) proposed a biozonation based on Belgian coral assemblages applicable for regional as well as long-distance correlation. Its application is consistent in Spain, France (Boulonnais, Montagne Noire), western Germany, and most likely in Britain. Mitchell (1989) proposed a coral biostratigraphy for Britain and Jones and Somerville (1996) highlighted that rugose corals are a useful tool in Irish biostratigraphy.

It is the aim of this study (1) to describe the diverse coral fauna of the section at Little Asby Scar, (2) to place the taxa into their biostratigraphic context, and (3) to discuss the position of the Holkerian/Asbian boundary.

SETTING AND SUCCESSION

The Holkerian/Asbian boundary was defined at Little Asby Scar, near Ravenstonedale (Cumbria, northern England) by George et al. (1976). Little Asby Scar is situated in the Stainmore Trough, a small intraplatform "basin" between the Alston and Askrigg Blocks (text-fig. 2).

The exact location of the stratotype section is in a hillside north of Potts Beck and east of Mazon Waths farm (NY 6988 0827). The boundary interval crops out discontinuously for at least one hundred metres. The precise boundary is a thin mudstone/shale bed (bed e of George et al. 1976) between the Ashfell Limestone (Holkerian) and the Potts Beck Limestone (Asbian), which could not be traced horizontally for the entire exposed boundary interval by the authors, and which shows significant



TEXT-FIGURE 2
Location of the stratotype section at Little Asby Scar (after Ramsbottom 1981).

variations in thickness throughout its exposures (0-15cm) (text-fig. 3).

The original published log of the section comprised only the boundary interval of the succession (George et al. 1976). More complete and detailed logs can be found in Ramsbottom (1981), Strank (1981) and White (1992). The boundary interval is well exposed and well documented, but in the younger part the logs show some inconsistencies due to poor outcrop. One problem is the continuity between the lower and upper benches of the scarp (so-called in Ramsbottom 1981), which are equivalent to the Potts Beck Limestone and overlying Knipe Scar Limestone, respectively (White 1992; See also text-fig. 3 herein.) The contact is not exposed; Ramsbottom estimated a 1.4 m thick black mudstone, whereas White (1992) found no evidence for this and speculated on a fault-bounded contact (for a discussion of this problem see below).

The succession of the stratotype area is characterized by fast 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 often composite. The macrofauna is mostly fragmented, and cross-bedding is seen on various surfaces throughout the succession.

At the top of the Ashfell Limestone, the succession is dominated by medium bedded, fine-grained limestone. Some shaley, grey-coloured intercalations occur in varying thickness, and are of discontinuous horizontal extension.

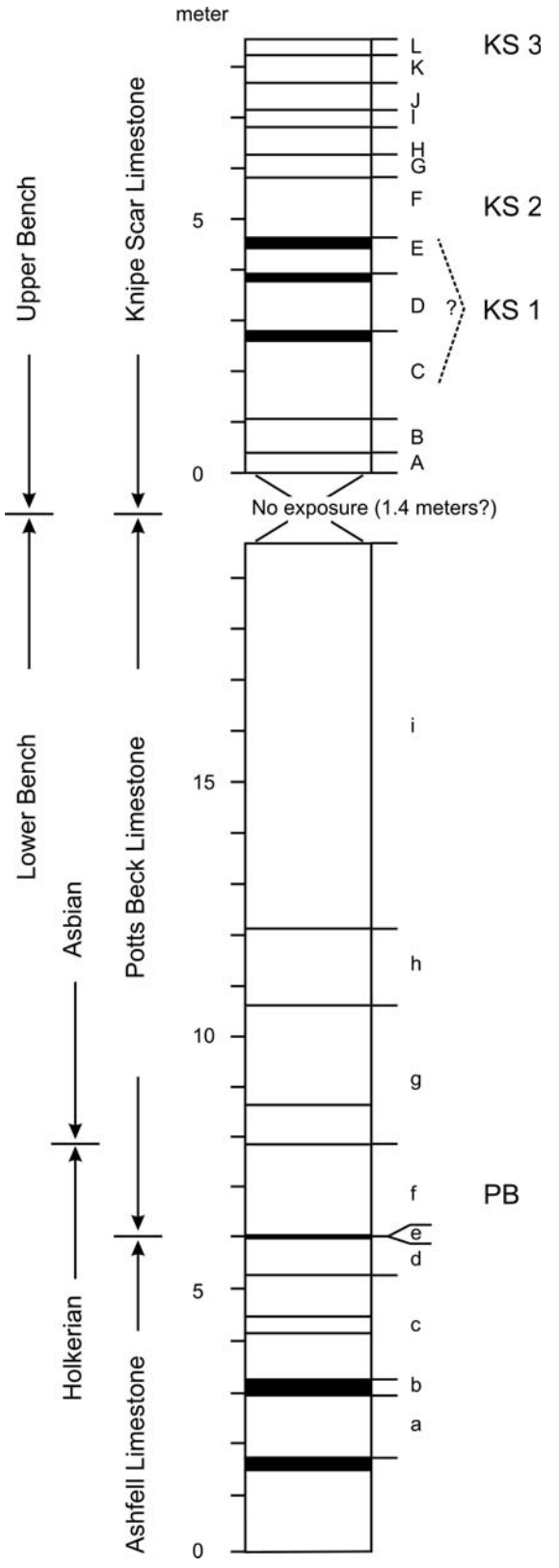
The lowest bed of the Potts Beck Limestone (bed f of George et al. 1976; text-fig 3 herein) is rich in chert and corals, and is referred to herein as the 'biostrome'. Aretz and Nudds (in press) provide detailed analyses of the biotic composition and facies, and an interpretation of its formation. This bed is the best exposed of the entire succession. From the stratotype section, it can easily be traced along strike for about 900 m towards the west, but only 50 m towards the east, where it bends downwards, follows a ridge and disappears under huge blocks of scree. Further east it is not exposed.

The biostrome is 1.4 m thick in the stratotype area and consists mainly of fragments of *Siphonodendron* and chaetetid sponges. The bed is highly silicified, seen in numerous chert-nodules, but also in the silicified macrofauna and some layered chert-concentrations. The grain-sizes vary throughout the bed, but are generally coarse. Cross-stratification, upside-down orientations, and numerous fragmented bioclasts are seen on various surfaces of the exposure and indicate shallow water environments at the boundary interval.

Above the biostrome the Potts Beck Limestone consists of bedded limestone of various grain-sizes, mostly rich in crinoids. Most parts of the succession might be bioclastic, often grainstones. Micrite-dominated textures, weathered to a brownish colour, are rare, but some of them are very rich in vertebrate remains (pers. com. Dr. H. M. Weber, Bergisch-Gladbach). Vertical and horizontal variations of the grain sizes occur over short distances and the different textures given by White (1992) are common. Small-scale cycles might be indicated by the variation of grain-sizes and textures (see also White 1992, text-fig. 8.29). A diverse macrofauna (brachiopods, corals, gastropods, and pelmatozoans) is observed and seems to be more common in coarser textures.

Aretz and Nudds (in press) showed the dominance of three facies types at the boundary interval: (1) fine-grained foraminiferan-*Koninckopora* grainstone, (2) coarse-grained bioclastic grainstone, and (3) coral-chaetetid rudstones. Facies type 3 is restricted to the biostrome, while facies types 1 and 2 are found below and above it. Occasionally facies type 2 is also found within the biostrome. Facies type 1 dominates the units well below the biostrome, but directly below it facies type 2 is dominant. Above the biostrome, the distribution is less obvious. A clear vertical zonation of facies types is not seen, but within the first metre, facies type 2 again is dominant.

The biostrome indicates a general phenomenon of the geological structure observed in this area. The view from the opposite hillside, on the southern bank of Potts Beck, reveals that west of the stratotype the beds are sub-horizontal, whereas immediately east of the stratotype the beds turn steeply down (30-40°). Further east, the exposure is again sub-horizontal. This arrangement is also seen in the morphology of the hillside (text-fig. 4).



TEXT-FIGURE 3
Stratigraphic log of the stratotype section at Little Asby Scar Scar (redrawn from Ramsbottom 1981). Bed numbers of Ramsbottom (1981), The positions of the coral associations PB and KS 1-3 are indicated. The log shows the proposed position of the Holkerian/Asbian boundary based on the coral fauna

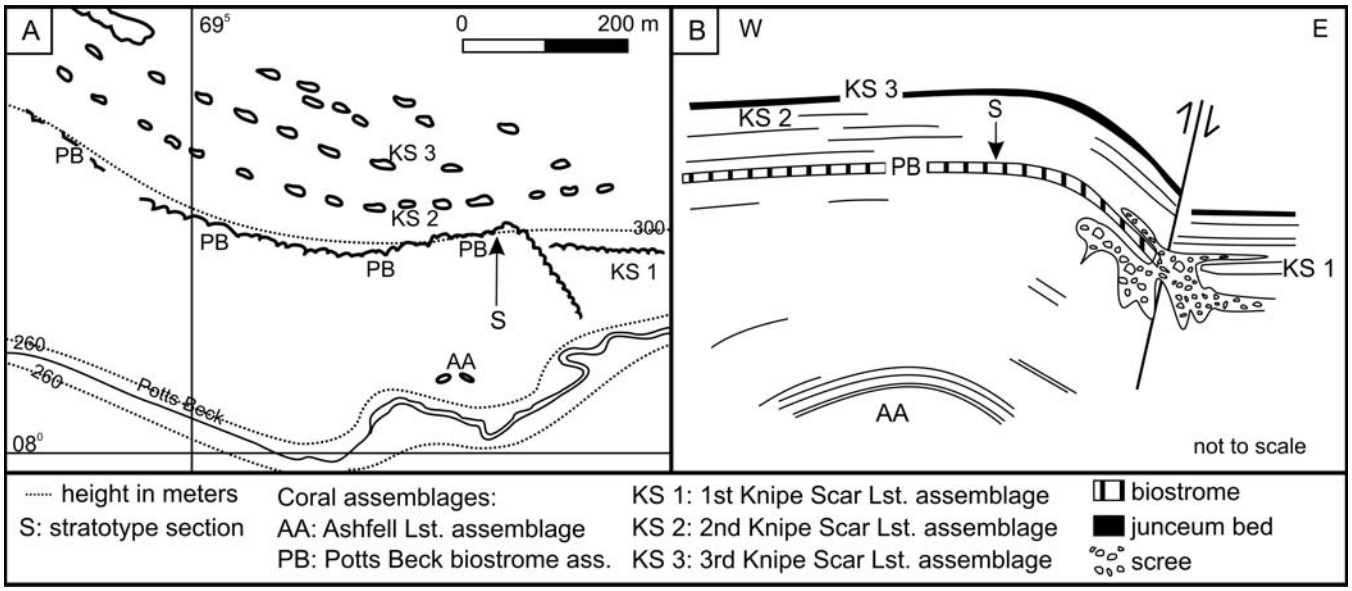
At the bottom of the hillside (50m below the stratotype), an exposure of limestones beds, containing highly silicified rugose corals and gastropods, reveals an explanation of the structure observed higher up. These beds (AA, text-fig. 4) show an anticline, with a smooth western flank and a somewhat steeper eastern flank.

Higher up the hill this anticline is seen in its wider extent. The eastern flank is disturbed by a fault which downthrows to the east and separates the lower and upper benches of Ramsbottom (1981). Therefore, at least on the eastern flank up to the area of the stratotype section the contact of the Potts Beck Limestone and Knipe Scar Limestone is due to tectonic movements. The exact orientation and position of the fault could not be deduced from the outcrop due to the poor exposures, but it is important since the completeness of the succession and the contact of Potts Beck and Knipe Scar limestones depend on its geometry. The biostrome (PB in text-fig. 4) follows the anticlinal structure perfectly, but it could not be traced to the east of the fault zone where it is possibly hidden by scree and grass. However, the fault zone does not disturb the succession in the immediate stratotype section, and therefore it does not affect the defined Holkerian/Asbian boundary.

CORAL FAUNA

Rugose coral assemblages (more than 150 specimens) have been collected at five localities on Little Asby Scar (text-fig. 4). A few samples came from the bottom of the hillside (AA), from the small exposure of the Ashfell Limestone referred to above. Numerous corallites have been collected from the biostrome (PB), and also in a slightly higher coral bed which outcrops east of the fault (KS 1). Two further assemblages were found approximately 21m and 24m above the biostrome in the vertical prolongation of the stratotype section, in the ridge which forms the crest of Little Asby Scar (KS 2 and KS 3).

The composition of these five coral assemblages differs significantly (text-fig. 5). Besides a few undeterminable fragments of solitary corals, only highly silicified colonies of *Lithostrotion vorticale* (Parkinson 1808) have been recovered from assemblage AA. The coral fauna of the biostrome (PB) is relatively diverse. It comprises *Siphonodendron* sp, *Siphonodendron martini* (Milne-Edwards and Haime 1851), *Siphonophyllia siblyi* Semenoff-Tian-Chansky 1974, *Axophyllum vaughani* (Salée 1913), *Caninophyllum archiaci* (Milne-Edwards and Haime 1852), numerous heterocorals, and syringoporoid tabulate corals. Assemblage KS 1, east of the fault zone, comprises *Siphonodendron martini*, *Caninophyllum archiaci* (Milne-Edwards and Haime 1852), *Dibunophyllum bipartitum* (McCoy 1849), *Koninckophyllum* sp., *Haplolasma* sp., undeterminable axophyllids, and syringoporid corals. Assemblage KS 2, high on the western scarp, contains *Lithostrotion maccoyanum* Milne-Edwards and Haime 1851, *Siphonodendron junceum* (Fleming 1828), *Siphonodendron pauciradiale* (McCoy 1844), *Siphonodendron martini* (Milne-Edwards and Haime 1851), *Siphonodendron* cf. *scaleberense* Nudds and Somerville 1987, *Palaeosmilia murchisoni* Milne-Edwards and Haime 1848, and rare heterocorals. Finally at the top of both the western and eastern scarps is a bed packed with *Siphonodendron junceum* (KS 3), which is an excellent marker horizon and which allows interpretation of the folding and faulting in this area (text-fig. 4). This bed probably equates with bed L of Ramsbottom (1981), the uppermost bed of the Knipe Scar Limestone in his measured section (see text-fig. 3).



TEXT-FIGURE 4
The stratotype section at Little Asby Scar. A, topographic map (modified from Ramsbottom 1981); B, sketch of the structure of the hillside from the southern bank of the Potts Beck (not to scale).

Heterocorals occur in greater abundance in assemblage PB, especially in the upper part of the biostrome, but occur scattered throughout the entire succession. Tabulate corals are common in parts of the biostrome (see Aretz and Nudds, in press), but only single corallite fragments have been recovered elsewhere.

TAXONOMY

The detailed descriptions of the Little Asby Scar specimens allow some precisions on the variability of the taxa, especially for some rare taxa as *Siphonophyllia siblyi*.

Class ANTHOZOA Ehrenberg 1834
Subclass RUGOSA Milne-Edwards and Haime 1850
Order STAURIIDA Verrill 1865
Suborder CANINIINA Wang 1950
Family CYATHOPSIDAE Dybowski 1873
Genus *Siphonophyllia* Scouler in McCoy 1844

Siphonophyllia siblyi Semenoff-Tian-Chansky 1974
Plate 1, figures 1-3

"A Campophyllid" Sibly 1906 , p.369, pl. 31, fig. 3.
**Siphonophyllia siblyi* SEMENOFF-TIAN-CHANSKY 1974, p. 184, fig. 68, pl. 47, fig. 1-3, pl. 50, fig. 1. — KHOA 1977, p. 371, pl. 19, fig. 1a-e. — POTY 1981 p. 53, pl. 26, fig. 5. — RODRIGUEZ and FALCES 1992, p. 191, pl. 16, fig. 3. — SOMERVILLE 1997, pl. 2, fig. 6.

Diagnosis. Emended from Semenoff-Tian-Chansky (1974) and Poty (1981). Medium-sized *Siphonophyllia* of up to 4cm in diameter. Thin and sinuous major septa often slightly thickened at the base of the tabularium. Length of the major septa 2/3 of the corallite-radius. Short minor septa eventually developed in the tabularium, mostly reduced to spines in the inner dissepimentarium. Dissepimentarium consists of an inner zone of simple and lonsdaloid dissepiments, and an outer zone of large lonsdaloid dissepiments. Marked cardinal fossula, alar fossulae may be developed. Wall and septa mostly laminar.

Material. Fragments of four corallites from the biostrome (PB). LAS 104, 110, 148, 150.

Description. (i) external characters. The abraded corallites are up to 2.8cm in diameter; original maximum diameter are of about 3.5cm. The corallites are ceratoid to sub-cylindrical. The outer surface shows transversal growth rings and longitudinal furrows and ribs. Furrows and ribs are not connected to the insertion of the septa. Rejuvenescence might occur.

(ii) internal characters. 40-50 septa in two orders. The major septa are thin and sinuous, but might be slightly thickened at the base of the tabularium. Lonsdaleoid dissepiments interrupt the major septa in the outer dissepimentarium, where they might persist as septal crests. The major septa extend up to 2/3 of the corallite-radius. The cardinal septum is shortened and a distinctive fossula developed. Alar fossulae might be developed. The minor septa are short and mostly reduced to spines within the inner dissepimentarium and the base of the tabularium.

The dissepimentarium is narrow (4–6mm) and consists of an outer, often slightly thicker zone of lonsdaleoid dissepiments and an inner zone of simple and lonsdaleoid dissepiments. The tabularium comprises 2/3 of the corallite diameter.

The dissepiments are elongated and subvertical declined. The tabulae are complete, flat, and slope down at the margins. There are 8-10 tabulae per centimetre.

Discussion. The larger size of the Little Asby Scar specimens is the only differences to those described from Algeria (Semenoff-Tian-Chansky 1974) and Belgium (Poty 1981). This confirms the observation by Semenoff-Tian-Chansky when comparing his Algerian specimens to a "campophyllid" described by Sibly (1906) from the Mendips. The Polish specimen described by Khoa (1977) is very close to some Little Asby Scar specimens, especially in the development of alar fossulae. However, because the descriptions are based on very few specimens,

there is not much known about the variability of this rare species. The development of an alar fossulae may be a significant difference, but Khoa (1977) reported it not from all sections of his single specimen, thus indicating some important intra-specific variability. The Belgian and Algerian specimens do not show the phenomenon at all.

Age and occurrence. The Algerian type material is probably Brigantian in age. The British specimen of Sibly is D1 (=Asbian) in age. Poty (1981) reported *S. siblyi* from the Calcaire de Seilles (now Seilles Member of the Grands Malades Formation, Poty et al. 2002). This correlates to the Holkerian substage in Britain. The Spanish material (Rodriguez and Falces 1992) is from the Asbian, the Irish from the Brigantian (Somerville 1997).

Genus *Caninophyllum* Lewis 1929

Caninophyllum archiaci (Milne-Edwards and Haime 1852)
Plate 1, figures 4, 6

**Cyathophyllum archiaci* MILNE-EDWARDS and HAIME 1852, p. 183, pl. 34, fig. 7. — POTY 1981, p. 50, fig., 46, 47, pl. 23, fig. 6, pl. 24, fig. 1. [cum syn.]
Material. Three large fragments: two from KS 1 (LAS 71, 182), one from PB (LAS 135).

Description. (i) external characters. The fragments lack their outer walls and parts of their dissepimentarium. They are up to 10.4cm long and up to 4.5-6.4cm in width assuming a cylindrical corallite.

(ii) internal characters. There are two series of up to 60 septa. The long major septa (up to 30mm) are sinuous in the dissepimentarium and become straight to slightly sinuous in the tabularium. They do not reach the centre and leave an open central area of 1-1.5cm in diameter. Major septa are thin (0.1mm) within the dissepimentarium, become thick at the base of the tabularium (0.8mm) and thin towards the centre. The dilation is weaker in the counter than in the cardinal quadrants of the tabularium. The cardinal septum shortens (at least 4.3mm) in a prominent fossula. The length of the minor septa varies. In specimen LAS 71 they are continuous throughout the dissepimentarium and end after a few millimeters in the tabularium. Near the fossula minor septa are dilated at the proximal end and might be connected to the neighbouring major septum. The minor septa are thickened when entering the tabularium. This thickening is more prominent in the cardinal areas. In specimen LAS 182, they are shorter and do not persist within the tabularium.

The dissepiments are mostly simple, but they become very irregular when minor septa are short, are sometimes arranged in a herringbone pattern, sometimes discontinuous. The structure of the dissepimentarium is highly variable.

In longitudinal section, the dissepimentarium consists of numerous rows of steeply declined globose to elongated dissepiments (0.7-1.5mm long, 0.7-0.9mm high). The wide tabularium comprises up to 2/3 of the corallite. The complete tabulae with slightly downturned edges are wide and horizontally arranged. There are about 8 tabulae per centimetre.

Discussion. These specimens fit well into the description of Lewis (1929) who observed modifications in the thickness of the septa, the arrangement of the dissepimentarium and the length of the cardinal septum throughout the stratigraphic record of this species (from S1-D3= Upper Arundian – Brigantian). Lewis distinguished three distinctive types for the S1, S2-D1 and D2-D3 intervals. The specimens recovered at Little Asby Scar probably belong to the "*halkynense*" type (=S2-D1).

Age and occurrence. Reported in the British Isles from the late Arundian to Brigantian (Lewis 1929), in Belgium from the Lives-Formation, Livian, Middle Visean. (Poty 1981).

Suborder AULOPHYLLINA Hill 1981
Family PALAEOSMILIIDAE Hill 1940
Genus *Palaeosmilia* Milne-Edwards and Haime 1848

Palaeosmilia murchisoni Milne-Edwards and Haime 1848
Plate 1, figure 5

**Palaeosmilia murchisoni* MILNE-EDWARDS AND HAIME 1848, p. 261. SEMENOFF-TIAN-CHANSKY 1974, p. 160, fig. 60-62, 64, pl. 39, fig. 1-5, pl. 40, fig. 1, 2, pl. 41, fig. 1-5, pl. 42, fig. 1-3, pl. 71, fig. 4. [cum syn.]. — POTY in KIMPE et al. 1978, pl. 5, fig. 6, 7. — POTY 1981 , p. 46, fig. 43, pl. 20, fig. 7, 8, pl. 21, fig. 2. — POTY and HANNAY 1994 , p. 60, pl. 3, fig. 1.

Material. Three fragments recovered from assemblage KS 2 (LAS 50-52)

Description. The recovered fragments fit well into the variability of this species (Semenoff-Tian-Chansky 1974). The LAS specimens are up to 5.9cm in diameter. There are two series of 50-81 septa. The major septa always reach to the axis. The minor septa are up to 2/3 as long as the major septa. Septa are thin and for the most part slightly sinuous. The dissepimentarium consists of numerous rows of often elongated, regular dissepiments. The dissepiments are often arranged sub-horizontally in the outer part of the dissepimentarium; towards the axis they become inclined. Sometimes lonsdaleoid dissepiments might be developed at the outer edge of the corallite. The tabularium consists of domed tabulae, sagging in its central part.

Age and occurrence. This species is common throughout the entire Viséan (entry in Cf4α2 biozone) and early Namurian (Serpukhovian) successions of Europe and Northern Africa (see Mitchell 1989, Perret and Semenoff-Tian-Chansky 1971, Semenoff-Tian-Chansky 1974).

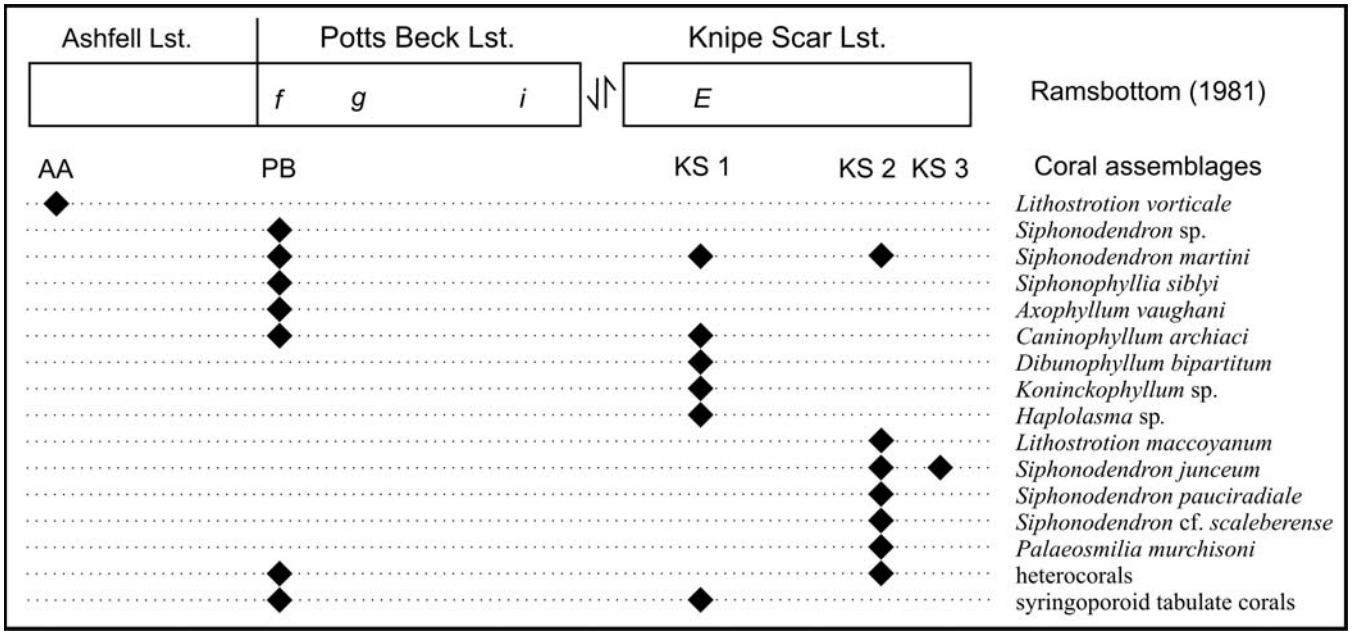
Family AULOPHYLLIDAE Dybowski 1873

Genus ***Dibunophyllum*** Thomson and Nicholson 1876

Remarks. Following the definition of Hill (1938-1941), later amended by Semenoff-Tian-Chansky (1974), the main characteristics of this genus are highly variable. The genus was derived from many rapidly evolving phylogenetic branches and its separation from related genera, such as *Clisiophyllum*, *Koninckophyllum* and *Arachnolasma*, maybe sometimes highly questionable (Fedorowski 1971). Therefore, many species in different genera are synonymous (see Hill 1938-41).

Dibunophyllum bipartitum (McCoy 1849)
Plate 2, figures 1-6

**Clisiophyllum bipartitum* MCCOY 1849, p. 2. — FEDOROWSKI 1971, p. 57, text-fig. 18, 19, 20, 21, pl. 3, fig. 6-9, pl. 4, fig. 1-8, pl. 5, fig. 1-8, pl. 15, fig. 1-8.
Dibunophyllum bipartitum (McCoy). — POTY 1981 , p. 41, text-fig. 40, pl. 18, fig. 1-3. [cun syn.]. — HERBIG 1986, p. 195, Fig. 3, fig. 6.— POTY and HANNAY 1994 , p. 60, pl. 3, fig. 1. — SOMERVILLE 1997, pl. 1, fig. 3.



TEXT-FIGURE 5
Distribution of the corals in the Little Asby Scar section showing the bed numbers of Ramsbottom (1981) and the coral assemblages (this paper).

? *Dibunophyllum burhennei* (Brüning 1923). — Weyer 2001, pl. 4, fig. 2. — Rodriguez 2002 et al. p. 67, pl. 3, 1-9.

Material. Ten corallites, mostly fragments, from assemblage KS 1, LAS 70, 72, 73, 170, 173, 174, 176, 178, 179, 185.

Description. (i) external characters. The corallites are trochoid to cylindrical. The maximum diameter is 2.8cm and the maximum height 4.5cm. The outer surface shows horizontal growth lines. The calice is not preserved.

(ii) internal characters. Septa are arranged in two series, each series comprises up to 53 septa. The major septa are straight near the wall, sometimes curved. Thickenings are observed at the base of the tabularium. The cardinal septum is shorter than the other major septa. The counter septum is often linked to the prominent axial structure. The minor septa are short (< 2.5mm) or sometimes developed just spines and are restricted to the outer dissepimentarium.

The axial structure is large and comprises about 1/3 of the corallite diameter. It consists of a thicker medial plate (up to 0.4mm thick) and is surrounded by some septal laminae (4-8 on each side) and numerous axial tabellae. The organization of the axial structure is variable, the prominence of the medial plate might be reduced, the number of axial lamellae and axial tabellae (highly variable) changes.

The dissepimentarium is wide (1/3 of the corallite) and consists of regular dissepiments; herringbone dissepiments are partly observed. The dissepiments are often elongated (up to 3.2mm long and 1.0mm high; mean 0.6mm high and 1.6mm wide), rarely globose. There are 3 to 6 rows of dissepiments, steeply declined (45-75°). Tabulae are incomplete, generally inclined (20°) and convex. The axial tabellae are numerous, either convex, and domed or steeply inclined (70°).

Discussion. The Little Asby Scar material is typical for this well-known species. Differentiation into subspecies according to Hill (1938-41) is not made, since Semenoff-Tian-Chansky (1974) showed the existence of form groups within this species.

Age and occurrence. *D. bipartitum* is widely distributed in late Viséan and early Namurian European successions. Mitchell (1989) concluded that *D. bipartitum* appears in the Asbian, but did not record it from the lower part of the Asbian. This observation is confirmed by the Belgian and French datasets (Poty 1981, Poty and Hannay 1994) where this species appears in foraminiferan biozone Cf6β = middle part of RC7α.

Genus ***Koninckophyllum*** Thomson and Nicholson 1876

***Koninckophyllum* sp.**
Plate 2, figure 7

Material. One transverse section in a fragment from assemblage KS 1. LAS 181

Description. (i) external characters. The fragment is 2.3cm in diameter and several mm long. The calice and outer surface are not preserved.

(ii) internal characters. There are two series of 54 septa. The major septa are thin, mostly straight and become somewhat sinuous towards their end. They end free in the tabularium and are not longer than 1.0cm. Only the counter septum (?) reaches the axis and is connected to the columella. Minor septa are short and mostly restricted to the dissepimentarium, sometimes entering the tabularium as short spines.

The columella is distinct (3.7mm long) and thickened in its centre (0.5mm).

The dissepimentarium is narrow (2–4mm) and consists of some irregular rows of regular dissepiments. Herringbone structures might develop where minor septa are very short.

Discussion. The genus *Koninckophyllum* is fairly common in the British Carboniferous. Numerous species have been described, but they might be partly synonymous (see Hill 1938). The characteristic variability in this genus could not be deduced from only one transverse section. Therefore, a specific assignement of the single specimen found at Little Asby Scar is not possible.

Sudorder LITHOSTROTIONINA Spasskiy and Kachanov 1971
Family LITHOSTROTIONIDAE D'Orbigny 1852
Subfamily LITHOSTROTIONINAE D'Orbigny 1852
Genus *Lithostrotion* Fleming 1828

Lithostrotion maccoyanum Milne-Edwards and Haime 1851

**Lithostrotion macoyanum* MILNE-EDWARDS and HAIME 1851, p. 444.— NUDDS 1980, p. 388, fig. 3a.— POTY 1981 , p. 24, fig. 14-16, pl. 7, fig. 3. [cum syn.]. — ARETZ 2001, fig. 3/5. — ARETZ 2002, p. 109, pl. 9, fig. 4, 5.

Material. Fragment from assemblages KS 2, LL.12667.

Description. (i) external characters. The corallum is massive and cerioid with polygonal corallites, sometimes slightly cylindrical. Their diameter varies from 2-4mm. The calices are shallow with a prominent columella. Increase has not been observed.

(ii) internal characters. Corallites are polygonal, sometimes pentagonal, hexagonal or heptagonal. The septa are in two orders, major and minor which are usually easily distinguishable. The number of septa varies between 12-14 of both orders and the major septa usually extend to the columella or abut onto neighbouring septa. Minor septa are variable in length; they just extend into the tabularium so that their length is proportional to the width of the dissepimentarium which itself is very variable. Both orders of septa are dilated in the dissepimentarium and thinner at their axial ends. All septa normally extend to the epitheca and there is usually a prominent columella. The narrow tabularium of this species is characteristic; it has an overall mean of 1.5mm. The width of the dissepimentarium is less characteristic showing considerable variation. In some corallites there is only one row of dissepiments; in others there may be three or four rows. The inner row of dissepiments is dilated and regular, whereas outer dissepiments are thinner and more irregular. All sections of dissepiments are concave towards the axis. The overall tabularium-diameter is very variable due to variation in the width of the dissepimentarium. It ranges from 2.0mm to 4.0mm. Tabulae are usually complete and tent-shaped. Occasionally they are incomplete when a periaxial series is developed at the periphery of the tabularium.

Discussion. This is the smallest known cerioid species of *Lithostrotion*. The specimen recovered at Little Asby Scar fits well into the descriptions of Semenoff-Tian-Chansky and Nudds (1979).

Age and occurrence. *L. maccoyanum* is fairly common in Europe (Mitchell 1989, Poty 1981, Rodriguez et al. 2002, Jones and Somerville 1996). Its short stratigraphic range (late Asbian – early Brigantian) is important for stratigraphic correlations.

Lithostrotion vorticale (Parkinson 1808)
Plate 2, figure 8

**Madrepora vorticalis* Parkinson 1808, p. 45, pl. 5, fig. 3, 6.
Lithostrotion vorticale (Parkinson). — NUDDS 1980, p. 388, fig. 3c. — POTY 1981, pl. 22, fig. 12, 13, 15, 16, pl. 6 fig. 1-3, pl. 7, fig. 1,2. [cun syn.]. — RODRIGUEZ and FALCES 1992, p. 200, pl. 18, fig. 4. — POTY and HANNAY 1994, p. 63, pl. 4, fig. 3. — RODRIGUEZ et al. 2002, p. 20, fig. 6a-i. — ARETZ 2002, p. 111, pl. 10, fig. 3.

Material. Two strongly silicified fragments from assemblage AA, LAS 54, 55.

Description. (i) external characters. Hemispherical, massive corallum with a maximum height of 15cm and a diameter of 25cm. Corallites are polygonal, often pentagonal or hexagonal. Their width varies from 5 to 12mm. Increase is by non-parricidal lateral budding. The calice has not been observed.

(ii) internal characters. The corallite wall is often only 0.1mm thick. The septa are straight to slightly sinuous. They are in two series, 20-23 of each. The length of the major septa is variable (2.2 – 3.2mm). Septa are often connected to the styliform columella, blind-ending septa occur. Cardinal and counter septum are recognized by the orientation of the columella and are connected to it, otherwise they are not differentiable from the other major septa. The columella itself, consists of a single lenticular plate of varying thickness within one corallite. The minor septa cross the dissepimentarium and end after about 0.2-

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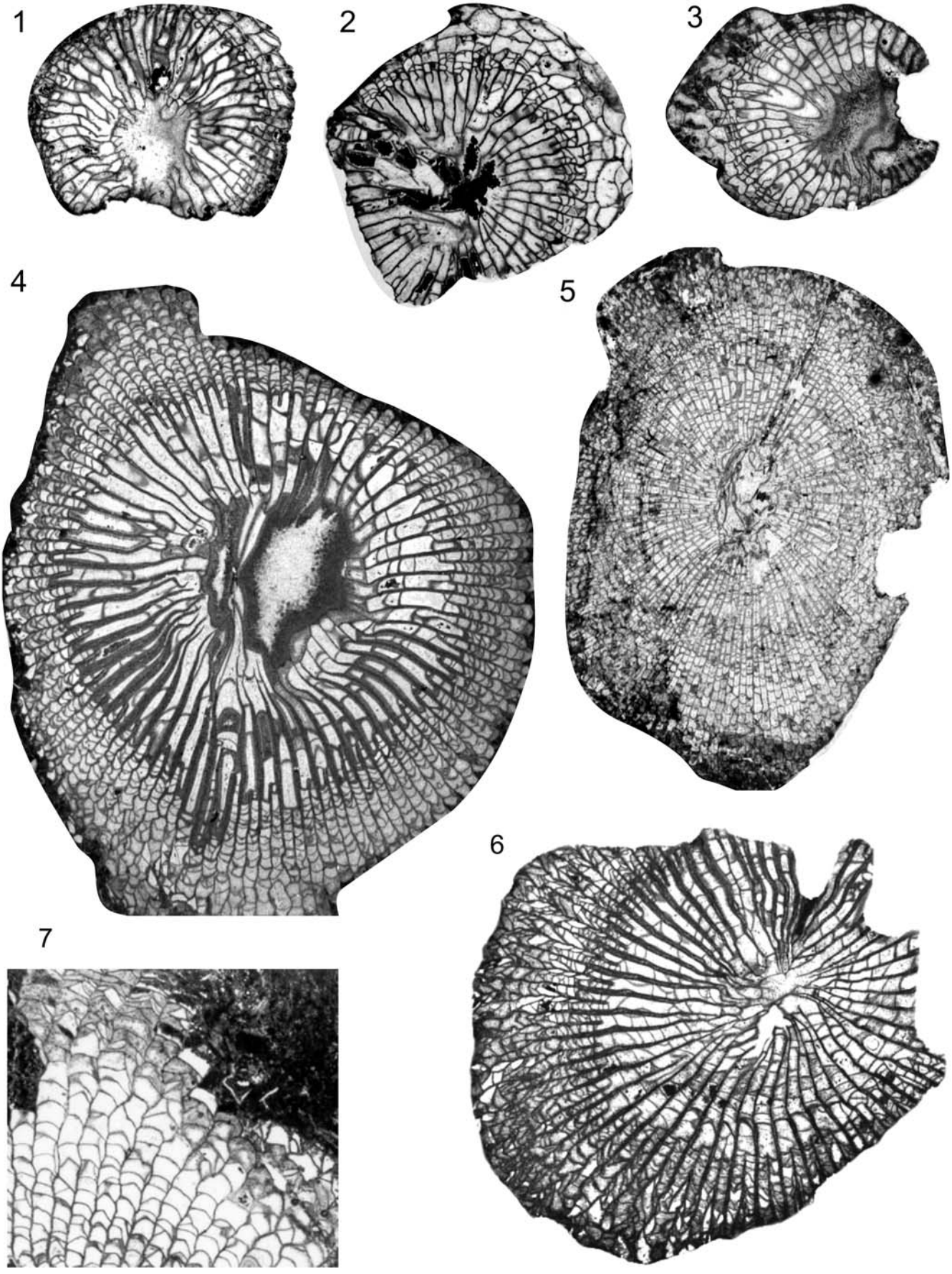
PLATE 1

All specimens ×2, except number 7, ×5.

1-3 transverse sections of *Siphonophyllia siblyi* Semenoff-Tian-Chansky 1974, LAS 148 (2), LAS 150 (1, 3), Potts Beck Biostrome assemblage, Holkerian?

4,6,7 *Caninophyllum archiaci* (Milne-Edwards and Haime 1852), transverse sections; 4, from the biostrome, LAS 135, Holkerian; 6, Knipe Scar assemblage 2, later Asbian, LAS 71; 7, detail of the irregular organized dissepimentarium of LAS 71.

5 *Palaeosmilia murchisoni* Milne-Edwards and Haime 1848, transverse section LAS 50, Knipe Sacr assemblage 2, later Asbian.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0.4mm within the tabularium. The diameter of the tabularium is 3.0 – 4.5mm in width (mean 3.6mm). Dissepiments are globose to elongated (0.17–0.7mm long). The structure of the dissepimentarium in a single corallite is very variable: the inclination of the dissepiments varies from 0 to 60° and the number of dissepimental rows from 1 to 4. Some lonsdaleoid dissepiments might be developed often connected to future offsets. The tabulae are incomplete and increasingly convex towards the axis.

Discussion. The two specimens recovered at Little Asby Scar fit well into the species-descriptions of Hill (1940) and Poty (1981).

Age and occurrence. In Britain, *L. vorticale* appears in the Holkerian and continues to the Late Brigantian (Mitchell 1989). Similar observations are made from western Europe by Poty and Hannay (1994) and Rodriguez et al. (2002).

Genus ***Siphonodendron*** McCoy 1849

Siphonodendron junceum (Fleming 1828)
Plate 2, figures 9-10

**Caryophyllia juncea* FLEMING 1828, p. 508.
Lithostrotion junceum (Fleming). — CALDWELL and CHARLESWORTH, 1962 p. 374, pl. 14, fig. 1. — NUDDS 1980 , p. 387, fig. 1a.
Siphonodendron junceum (Fleming). — POTY 1981, p. 32, fig. 26, pl. 13, fig. 1. [cun syn.]. — FONTAINE et al. 1991, p.46. — POTY and HANNAY 1994, p. 65, pl. 5, fig. 4. — SOMERVILLE 1997, pl. 1, fig. 6.— ARETZ 2001, fig. 3/7. — RODRIGUEZ et al. 2002, p. 24, fig. 10a-f. — ARETZ 2002, p. 111, pl. 3, fig. 1, 2; pl. 10, fig. 4-6.

Material: 3 specimens from assemblages KS 2 and KS 3, LAS 51, GIK 1771, LL. 12668.

Description. (i) external characters. Phaceloid, sometimes dendroid colonies with a spreading corallum ranging up to a metre in diameter and 35cm in height. The cylindrical corallites are 2.4 to 3.2mm in diameter. The increase is lateral. The surface and calice have not been observed.

(ii) internal characters. There are 14-18 septa in mature stages. The major septa are thin and slightly sinuous. Their length is variable, sometimes they are connected to the columella, sometimes they leave a central space. The columella is often a thin axial plate (lanceolate), but thickenings in its middle part are also common and a simple spider-web structure might be developed by connection to the major septa. Less commonly it is absent; such a diphymorphic state is usually restricted to single corallites, but sometimes affects large parts of the corallum. Minor septa are mostly developed as short spines. A dissepimentarium is not observed. The morphology of the tabularium depends on the organization of the columella. The incomplete tabulae (6-8 per 0.5cm length) generally rise convex (20-50°) towards the columella. A depression of the tabulae might be developed near the wall. The tabulae are complete in diphymorphic corallites and arranged horizontally in the centre of the corallite.

Age and occurrence. This species is common in Asbian and Brigantian successions of northwestern Europe and Spain. Its biostratigraphical occurrence is somewhat unclear. Mitchell (1989) reported *S. junceum* from the beginning of the Asbian (Fauna F) to the Late Brigantian (Fauna K) based on British coral assemblages. Mainly based on coral associations of Belgium, the Boulonnais and southern Britain, Poty (1981, 1985, 1991 in Conil *et al.*) considered the entry of this species to be somewhat later in the foraminiferan biozone (Cf6γ), equivalent to the Late Asbian. In his coral biozonation, the appearance of *S. junceum*, *L. maccoyanum* and *Aulophyllum fungites* marks the biozone RC7β. In north-western Ireland, *S. junceum* first appers in the foraminiferan biozone (Cf6γ) as in Belgium (Cozar et al., in press). In Spain, *S. junceum* occurs in the Asbian and continues through the Brigantian (Rodriguez et al. 2002, fig. 2).

Siphonodendron pauciradiale (McCoy 1844)

**Lithodendron pauciradialis* MCCOY 1844, p. 189, pl. 27, fig. 7.
Lithostrotion pauciradiale (McCoy). — CALDWELL and CHARLESWORTH 1962 , p. 376, pl. 14, fig. 2.
Siphonodendron pauciradiale (McCoy). — NUDDS 1980, p. 387, fig. 1e. — POTY 1981, p. 31, fig. 25, pl. 12, fig. 5, 6. [cun syn.]. — FONTAINE et al. 1991, p.47. — SOMERVILLE 1997 p.45, pl. 1, fig. 1.— RODRIGUEZ et al. 2002 p. 26, tab. 4, fig. 12 a-d. — ARETZ 2002, p. 11, fig. 1-3.

Material. A single fragment from assemblage KS 2. LL.12669.

Description. (i) external characters. The corallum is fasciculate and phaceloid with sub-parallel cylindrical corallites which often temporarily coalesce in a partly cerioid habit. Calices and epithecal surfaces have not been observed.

(ii) internal characters. The number of major septa ranges from 18-22. Some of the major septa are long, extending to the columella; this is usually the case with the cardinal and counter cardinal septa and some of the other primary septa. Other major septa extend only halfway to the axis or abut onto the adjacent major septa. Minor septa are short, only just penetrating the tabularium. Both orders of septa may be slightly dilated in the dissepimentarium although this is not marked. A columella is usually present which may also be dilated.

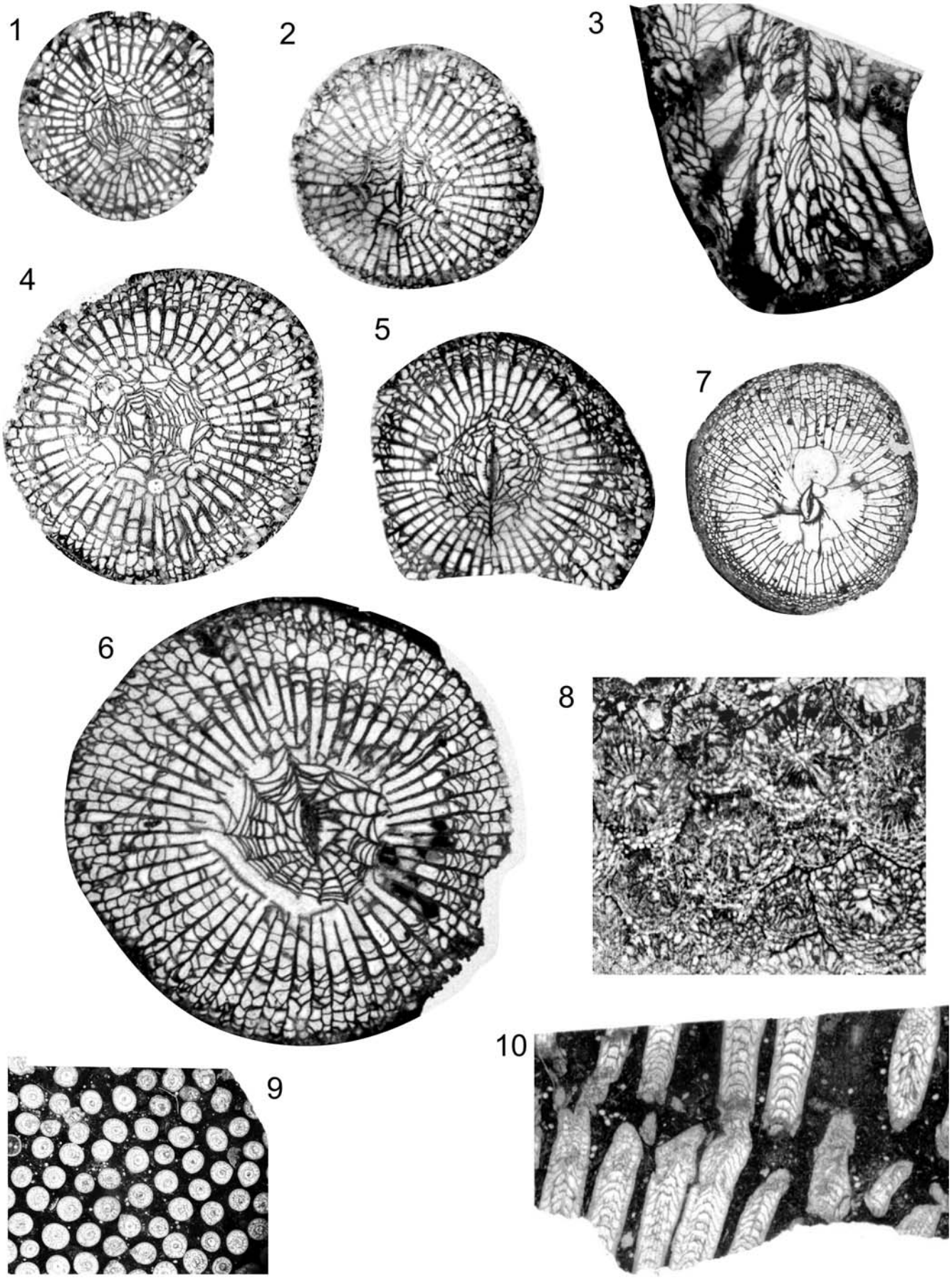
PLATE 2

1-6 *Dibunophyllum bipartitum* (McCoy 1849), transverse sections and longitudinal section [LAS 174a(1), LAS 73 (2,4), LAS 176 (3), LAS 185 (5), LAS 72 (6)], Knipe Scar assemblage 1, later Asbian, all ×3.

7 *Koninckophyllum* sp., transverse section LAS 181, Knipe Scar assemblage 1, later Asbian, ×2.

8 *Lithostrotion vorticale* (Parkinson 1808), transverse section LAS 55, Ashfell assemblage, Holkerian, ×3.

9,10 *Siphonodendron junceum* (Fleming 1828), transverse and longitudinal section, Knipe Scar assemblage 3, late Asbian. LAS 58, ×3.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There is never more than one complete row of dissepiments, although 2-3 dissepiments may be developed in those parts of a corallite which coalesce with adjacent corallites. The single row of dissepiments is usually dilated and forms a regular inner circle. Because the dissepimentarium is so constant, the overall diameter of this species is less variable than in most fasciculate species. Moreover, as the dissepimentarium is so narrow, tabularium diameter is only slightly smaller than the overall diameter. Tabulae are tent-shaped and usually complete.

Discussion. This species is easily recognisable by its single row of dissepiments.

Age and occurrence. *S. pauciradiale* appears in the early Asbian (Fauna F, Mitchell 1989) and persists into the Brigantian.

***Siphonodendron* sp.**
Plate 3, figure 1

Lithostrotion sp.n. A, NUDDS 1980 , p. 387, fig. 1d.
Siphonodendron irregulare (Phillips). — ARETZ 2002 , p. 112, pl. 5, fig. 4, pl. 11, fig. 4.

Material. Very abundant in the biostrome (PB) on the western scarp, mostly fragments. LAS 5, 7a, 9, 112, 114, 143.

Description. (i) external characters. Large, fasciculate, sometimes dendroid corallum. The corallites, 4.5 to 6.2mm in diameter (mean about 5.3mm), are cylindrical and sometimes in contact with each other, forming a pseudo-cerioid habit. Increase is non-parricidal and lateral. Calices and surface are not observed; the latter due to silicification.

(ii) internal characters. The number of major septa ranges from 19-23. The major septa are thin and either straight or sinuous in the tabularium. They end in an open central area. In most corallites a simple axial plate forms an axial structure (lanceolate); rarely this structure is missing and the corallites become diphymorphic. The orientation of this axial structure distinguishes the cardinal and counter septum, which otherwise cannot be differentiated. The minor septa cross the dissepimentarium and end as septal spines in the tabularium, reaching a length of up to 1/3 of the major septa.

The dissepimentarium consists of two or three rows of globose to elongated dissepiments. The tabulae are incomplete. They rise convex towards the axial structure and are curved peripherally downwards. There are approximately 24 tabulae and 28 dissepiments per centimetre.

Discussion. The correct specific assignment of *Siphonodendron* specimens between the two well-defined species *S. pauciradiale* (McCoy 1844) and *S. martini* (Milne-Edwards and Haime 1851) has been the cause of much confusion. The main problems are firstly the validity of *S. irregulare* (Phillips 1836), which was based on an inadequate description and the type specimens of which are now lost, and secondly the intra-colonial variability of the taxa, which have been described in recent studies under *S. irregulare* and *S. intermedium* (Poty 1981).

One of us (M.A.) favours an assignment to *S. irregualre,* the other (J.N.) to *S. intermedium*.

The Little Asby Scar specimens differ from *S. irregulare* (sensu Nudds 1980;) in the constant development of a second row of dissepiments, and its slightly larger dimensions. Compared to *S. intermedium* Poty 1981, the major septa of the Little Asby Scar specimens are longer and the number of septa smaller.

Age and occurrence. Due to the confusion concerning the correct specific assignments, the occurrence of these species in Britain is somewhat uncertain.

Siphonodendron martini (Milne-Edwards and Haime 1851)
Plate 3, figure 2

**Lithostrotion martini* MILNE-EDWARDS and HAIME, 1851 , p. 436. — CALDWELL and CHARLESWORTH 1962 , p. 377, pl. 14, fig. 5, 5a.— SEMENOFF-TIAN-CHANSKY and NUDDS 1979, p. 258, fig. 3, pl. 5, fig. 1-4, pl. 6, fig. 6,7. [cun syn.]. — NUDDS 1980, p. 387, fig. 1e.
*Siphonodendron martini (*Milne-Edwards and Haime). — POTY 1981, p. 24, fig. 14-16, pl. 7, fig. 3. — RODRIGUEZ and FALCES 1992, p. 205, pl. 19, fig. 4, 5, 6. — POTY and HANNAY 1994 p. 64, pl. 4, fig.

PLATE 3

1 *Siphonodendron* sp., transverse section, biostrome, Holkerian, LAS 9, ×3.

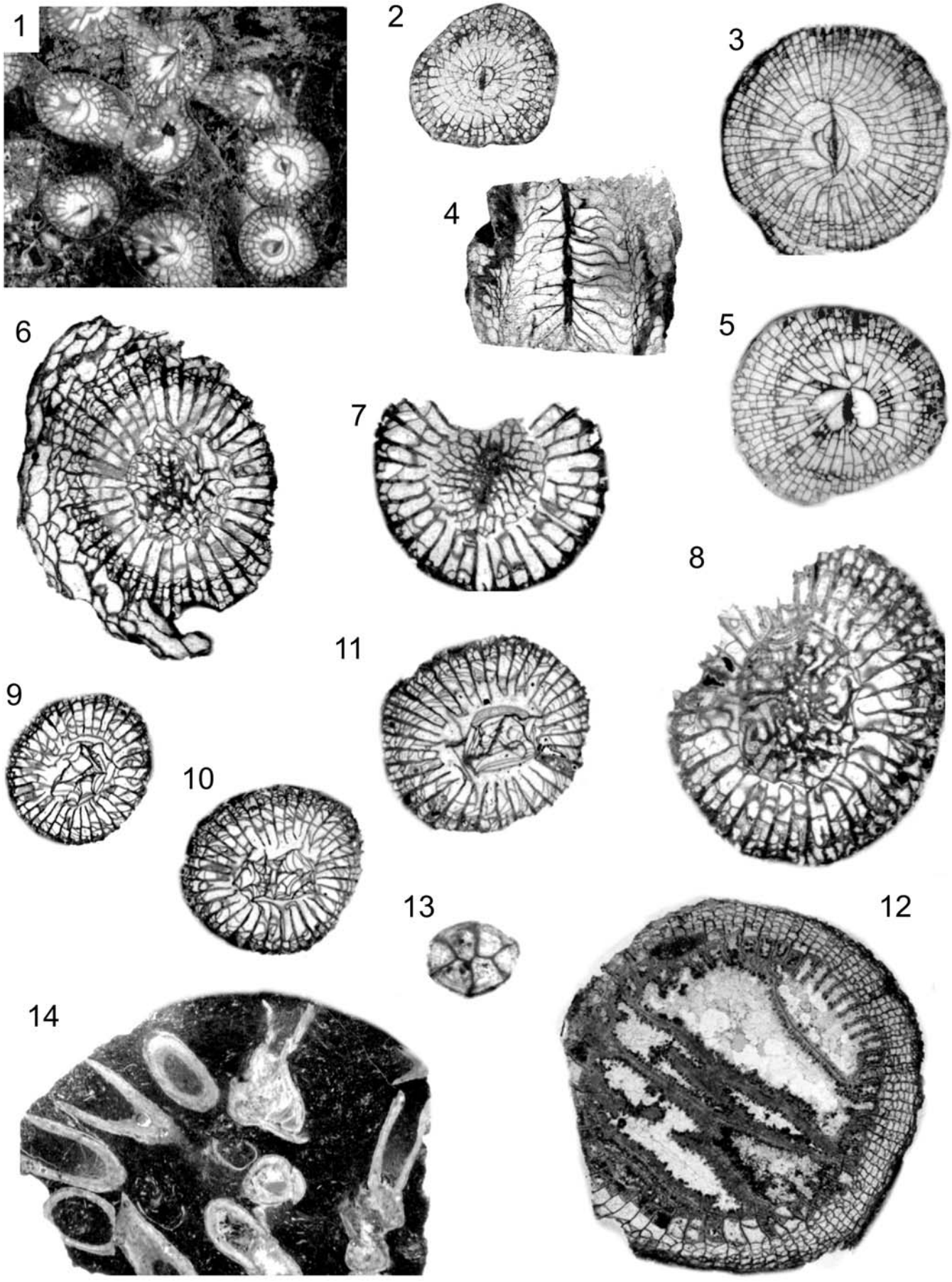
2 *Siphonodendron martini* (Milne-Edwards and Haime 1851), transverse section, biostrome, Holkerian, LAS 155, ×3.

3-5 *Siphonodendron* cf. *scalaberense* (Nudds and Somerville 1987), transverse and longitudinal sections LAS 53 (3) and LAS 172 (4-5), KS 2, later Asbian, ×3.

6-11 *Axophyllum vaughani* (Salée 1913), transverse sections showing the high variability of the axial structure, all from the biostrome, Holkerian, LAS 101 (6), LAS 139 (7), LAS 102 (8), all ×3, LAS 146 (9-11) ×2.

12-14 *Haplolasma*, transverse section, KS 1, later Asbian, LAS 171; 13, transverse section of heterocoral LAS 103, biostrome, Holkerian, *Hexaphyllia mirabilis* (Duncan 1867) or *Hexaphyllia marginata* (Fleming 1828) depending on the species concept, discussion in the text.

14 Syringoporid coral, LAS 57, biostrome, Holkerian. Due to incomplete silification tabulae were preserved only in few corallites.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2. — ARETZ 2001, fig. 3/7. — RODRIGUEZ et al. 2002, p. 30, fig. 14a-f, 15. — ARETZ 2002, p. 113, pl. 12, fig. 1-3.

Material. Numerous specimens from the biostrome (PB) on the western scarp, mostly fragments. LAS 59, 142, 155, LL. 10793, 10794, 10810.

Description. (i) external characters. The corallum is fasciculate and phaceloid, with cylindrical corallites, but many coralla are partly cerioid and have adjacent corallites growing in periodic coalescence. The corallites are bound by a thickened outer wall showing longitudinal inter-septal ridges. The calice is conical and deep with a prominent columella.

(ii) internal characters. The number of septa varies from 24-28 of both orders. Major septa are of variable length, but cardinal and counter septa extend to the columella in most colonies. Sometimes the other major septa continue to the axis, but more often they reach only half way to the axis. Minor septa are about half the length of the major septa, just entering the tabularium. Both major and minor septa are more dilated in the dissepimentarium than in the tabularium. A columella is usually present elongated in the cardinal plane. It may be strongly dilated or just a thin plate. Dissepiments vary from 2-4 rows and are generally regular and concentric. The innermost row is often strongly dilated and the dilation fuses with the dilation of the septa in the dissepimentarium. All dissepiments are quite steeply inclined. The width of the dissepimentarium is variable depending on the number of dissepiments present and accordingly the diameter of the corallite is variable in a similar way. The mean diameter is 7.8mm, with a total range from 6-10mm. Tabularium diameter is a more constant feature and reaching a mean diameter of 5.8mm. Tabulae are tent-shaped, incomplete and in two series.

Discussion. This is perhaps the most common species of *Siphonodendron*. All specimens recovered at Little Asby Scar fit well in the description of Semenoff-Tian-Chansky and Nudds (1979).

Siphonodendron* cf. *S. scaleberense Nudds and Somerville 1987
Plate 3, figures 3-5

cf. *Lithostrotion* sp. B NUDDS 1980 , p. 387, fig. 1g.
cf. *Siphonodendron scaleberense* NUDDS and SOMERVILLE 1987, p. 295, fig. 2 A-E, fig. 5 A, B.

Material. Two fragments from assemblage KS 2. LAS 53, 172.

Description. The corallites are 11.5-14mm in diameter. There are two series of 35-38 septa. The major septa are thin and straight to slightly sinuous, reaching a length of 3.5 to 5.2mm. The minor septa are 1/3-1/2 as long as the major septa. The counter septum is elongated and connected to the lanceolate columella. The cardinal septum is shortened and a fossula is developed.

The dissepimentarium consists of up to 2-5 rows of dissepiments, which are globular to elongated. There are 14-16 incomplete tabulae per centimetre. The tabulae rise convex towards the columella. Towards the periphery, tabulae are depressed, but rise towards the wall. The wall is simple and relatively thin (0.1mm).

Discussion. A full description of *S. scaleberense* was given by Nudds and Somerville (1987), but definite placement in this species is not possible due to the paucity of material.

Age and occurrence. *S. scaleberense* is known from Holkerian and Asbian succession of the British Isles (Nudds and Somerville 1987; Cozar et al., in press) and from the Asbian of Spain (Rodriguez et al. 2002).

Suborder LONSDALEIINA Spassky 1974
Family AXOPHYLLIDAE Milne-Edwards and Haime 1851

Genus *Axophyllum* Milne-Edwards and Haime 1850

Axophyllum vaughani (Salée 1913)
Plate 3, figures 6-11

*"*Clisiophyllum*" (*Carcinophyllum*) σ VAUGHAN 1905, p. 285, pl. 24, fig.3-3b.
Axophyllum vaughani (Salée). — POTY 1981, p. 59, text-fig. 52, pl. 28, fig. 3, 4. [cun syn.]. — FONTAINE et al. 1991 , p. 54, pl. 26, fig. 1-3. — POTY and HANNAY 1994, p. 66, pl. 2, fig. 11. — SOMERVILLE 1997, p. 41, pl. 2, fig. 3.
?*Axophyllum* cf. *vaughani* (Salée). — RODRIGUEZ and FALCES 1992, p. 210, pl. 21, fig. 2.

Diagnosis. A ceratoid to sub-cylindrical *Axophyllum* of up to 2.5cm in diameter. Relatively deep calyx. Prominent axial structure rising significantly from calice floor. Transversal rugae and longitudinal furrows and ribs on outer surface. Up to 39 septa for each cycle. Major septa straight to sinuous, interrupted in marginal dissepimentarium, thickened at base. Minor septa short to absent. Axial structure comprises 1/3 of the tabularium, highly variable, sometimes gangamophyllid. Dissepimentarium of large lonsdaleoid dissepiments, comprises 1/3 of the corallite. Tabulae flat or concave.

Material. Numerous corallite fragments from the biostrome (PB). The dissepimentarium is rarely preserved. 50 specimens sampled and cut; thin sections of the better preserved specimens: LAS 74, 100, 101, 102, 103, 105, 106, 107, 108, 112, 113, 136, 137, 138, 139, 140, 141, 144, 145, 146, 147, 149, 151, 152, 153, 156, 157, 175, 177, 180, 183, 184.

Description. (i) external characters. One corallite, almost completely preserved, allows a detailed description of the external characters. The corallite is ceratoid to sub-cylindrical. Its diameter is 0.4cm at its apex and 2.3cm at the calice. The calice is relatively deep (0.9cm). The axial structure consists of numerous curving axial lamellae (?) revolved on a thicker median plate and rises at least 0.6cm from the calice floor. The outer surface shows rugae and longitudinal furrows and ribs.

(ii) internal characters. The number of major septa ranges from 30-39. They are straight to sinuous and at least 6.3mm long. Major septa are interrupted at the marginal part of the dissepimentarium by lonsdaleoid dissepiments, but sometimes they persist as septal crests. Their thickness decreases from a maximum of 0.4mm at their thickened base to 0.05-0.1 at their proximal end within the tabularium. Sometimes they are connected to the axial structure.

Minor septa are short or absent.

The axial structure comprises 1/5 to 1/4 of the corallite and about 1/3 of the tabularium. In general, the axial structure consists of a straight to sinuous, thick medial plate, surrounded by curved axial lamellae and irregular axial tabellae. In some corallites, the axial structure becomes gangamophylloid (medial plate not differentiated from the axial lamellae). The variability within one corallite is high especially regarding thickness and arrangements of median plate and axial lamellae.

The dissepimentarium comprises up to 1/3 of the corallite and is often dominated by large lonsdaleoid dissepiments. The dissepiments are elongated and declined. The tabulae are flat or concave. The axial tabellae are slightly convex or concave and inclined at 30-65°.

Discussion. The Little Asby Scar specimens are very similar to the Belgian material described by Poty (1981) although the latter are of smaller dimensions. There is more variability in the axial structure in the Asby specimens, but Poty's description was based on much less material.

Age and occurrence. The stratigraphical record of *A. vaughani* ranges in Britain from the Holkerian to the early Brigantian (Fauna E-H, Mitchell 1989). In Belgium and northern France, this species is limited to the Livian (=Holkerian). Rodriguez and Falces (1992) reported this species from the lowest unit of the succession in the Los Santos de Maimona Basin, which, according to the coral fauna, is Asbian in age.

In addition to the rugose corals described above, a transverse section of specimen LAS 171 is figured (pl. 3, fig. 12). This section is made in a thin fragment (2-3mm) and with some doubt it could be assigned to *Haplolasma*.

?Order HETEROCORALLIA Schindewolf 1941

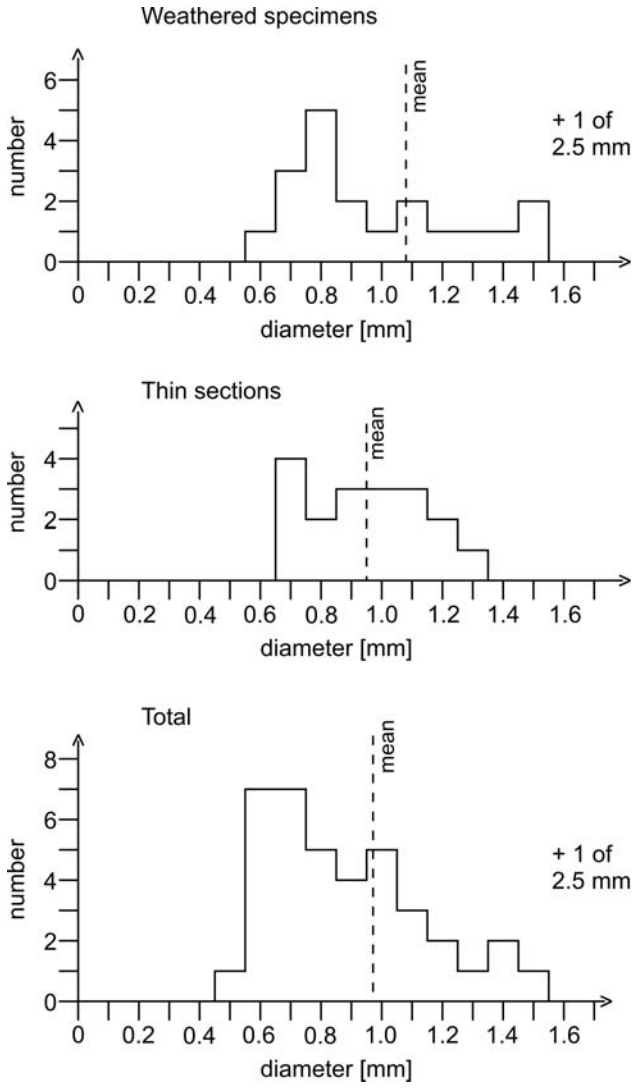
Family **HETEROPHYLLIDAE** Dybowski 1873
Plate 3, figure 13

Material. Numerous fragments from the biostrome (PB) of the western scarp. 41 measured specimens; 20 in thin sections, mostly transverse and 21 measured from weathered material. LAS 103, 111, 112.

Description. Up to 9mm long fragments of elongated, prismatic (hexagonal) heterocorals. There is a clear yellowish colour to the skeleton, a characteristic observed in different outcrops throughout the Lower Carboniferous of the British Isles. The outer surface is "ornamented" by concentric structures, 0.1mm high and 0.05-0.2mm in diameter, interpreted as the base of longer spines which have been destroyed during transportation of the specimens (see Cossey 1997). Most sections of weathered material and thin sections, show 6 septa meeting at or near the axis. In two small corallites (0.5mm) only 5 septa are observed. The peripheral edges of the septa are thickened, cross the wall and form costae. The cardinal and counter cardinal septa are easily distinguished, since only the two alar septa are separated.

The tabuale are domed. The diameter of the heterocorals ranges from 0.5mm (for stages with 5 septa) to 1.5mm; a diameter of 2.5 is observed only once. Following the previous work of Poty (1978, 1981), Rodriguez and Comas-Rengifo (1989) and Cossey (1997) the frequency of the measured diameters are shown in histograms (text-fig. 6).

Generic discussion. Heterocorals with six septa of Lower Carboniferous age have mostly been assigned to *Hexaphyllia* Stuckenberg 1904. However, Poty (1978) demonstrated that a six septa stage occurs equally in *Heterophyllia* McCoy 1849, being somewhat smaller in diameter than in *Hexaphyllia*. Cossey (1997) found significant variations in the number of septa (3-6) in *Hexaphyllia,* which is very high in early ontogenetic stages. Rodriguez and Comas-Rengifo (1989) showed that 44% of their 700 adult *Hexaphyllia* specimens had



TEXT-FIGURE 6
Histograms of the number/diameter of the heterocorals recovered from the base of the Potts Beck Limestone (bed f). A: weathered out specimens, B: specimen in thin sections, C: total.

7-9 septa. Although the histogram (their fig. 3) does not show the gap of Poty (1978), the first peak in the small diameters may represent the young stages of *Heterophyllia*, subsequently older and larger stages are hidden in the *Hexaphyllia* range, but may be detected by the abundance of 7-9 septa stages. Separation of two morphologically similar genera using only a biometric character is highly questionable. Up to now, it is not clear if *Hexaphyllia* is a younger synonym of *Heterophyllia.*

Cossey (1997) demonstrated the synonymy of a number of species. According to his measured corallite diameter (traditionally used to differentiate species in *Hexaphyllia*) *Hexaphyllia marginata* (Fleming 1828) has a wide variability and most traditional species are ontogenetic stages of this species.

A significant number of the Asby Scar heterocorals (text-fig. 6) have diameters ranging from 0.7-0.8mm. The mean for the entire measured specimens is 0.964mm. 75% of the corals range from 0.6-1.1mm in diameter. Larger specimens are rare. There is a major gap between 1.5 and 2.5mm (text-fig. 6).

According to Poty (1978, 1981) it would appear that young stages of *Heterophyllia* as well as *Hexaphyllia* occur in the Asby Scar heterocoral assemblage. However, since no specimens with more than six septa have been found in the assemblage, it is very unlikely that *Heterophyllia* is only present in its immature (6 septa) stage, and it is more likely that all of the Asby Scar material is actually *Hexaphyllia*. It then becomes difficult to separate the two genera based on diameter since the Asby Scar material closes the gap in Poty´s histograms (1978, 1981). Thus *Hexaphyllia* cannot be differentiated from *Heterophyllia* based on this character alone and would become its younger synonym.

In contrast to Cossey (1997), we do not see any evidence for a continuous range of corallite diameters up to 2.6mm. In fact, we observe a concentration of thinner corallites (0.6-1.1mm). The observation that larger heterocorals are very rare is in agreement with Poty (1981) and Rodriguez and Comas-Rengifo (1989).

Possible explanations of this pattern are, first, a selective removal of thicker corallites (Cossey 1997), or secondly, the existence of more than one species (Poty 1981). A number of points have to be taken into account.

The Asby Scar material was transported. The effect of this transport on the heterocorals must have been destructive as seen in broken spines and broken corallites. Otherwise the heterocorals are incorporated into a sediment of very different grain sizes having single grains much thicker and larger than the largest heterocorals. Thus removal during transport should not change the original distribution. Single corallites in the growth range 1.6-2.4mm should occur. Otherwise the single heterocoral with a corallite diameter of 2.5mm might be an unusual "giant" specimen of the same species since its size is the only obvious difference.

The number of corallites recovered at Little Asby Scar is not significantly high to decide whether we accept selective removal or whether we accept that there are two species. Accepting the selective transport theory of Cossey (1997), all specimens belong to *Hexaphyllia marginata*. Following Poty (1981), the smaller specimens belong to *Hexaphyllia mirabilis* (Duncan 1867) and the larger one to *Hexaphyllia marginata* (Fleming 1828).

Subclass **Tabulata** Milne-Edwards and Haime 1850
Plate 3, figure 14

Tabulate corals occur relatively frequent within the biostrome (PB). Ramsbottom (1981) reported *Syringopora geniculata* Phillips (1836) and *Michelinia* sp.

The specimens recovered during this study are mostly small fragments of one to several corallites, but also include some larger fragments of almost complete colonies. The tabulate corals are silicified and often incomplete. The outer form of the corallite is generally better preserved, but the inner part is rarely well preserved. Thus important diagnostic internal characters of the corallites are often missing making identification difficult.

***Syringopora* sp. ?**

Material. 4 larger silicified fragments of corallum and numerous small fragments. Thin sections: LAS 57

Description. The corallum is fasciculate. The corallites are cylindrical and connected by horizontal tubuli and platforms. Two morphotypes could be differentiated by the size of the corallites, the wall-thickness, and the intercolonial distances.

Morphotype 1: The corallites are 2.5-3mm in diameter, the wall is 0.4-0.5mm thick and the intercolonial corallite-distances are 3-4.5mm.

Morphotype 2: The corallite-diameter is 1.5-1.9, the wall-thickness 0.1-0.3mm thick and the intercolonial corallite-distances are only 0.5-2.3mm.

Tabulae are rare in both morphotypes.

A genetic or specific designation of both morphotpyes is not possible. Tourneur et al. (1989) suggest that silification commonly makes diagnostic descriptions of Lower Carboniferous tabulate corals difficult. A designation to *Syringopora* Goldfuss seems likely, but further investigations are needed and at present we refer the material to "syringoporoid corals".

BIOSTRATIGRAPHY

Biostratigraphic implications of the coral assemblages

Assemblage AA

The oldest coral assemblage (AA) consists only of *Lithostrotion vorticale* (text-fig. 5) and its biostratigraphic relevance is low. *Lithostrotion vorticale* appears from the Holkerian to the Brigantian.

Assemblage PB

The early Asbian is characterized by coral fauna F of Mitchell (1989). This comprises *Dibunophyllum bourtonense*, *Koninckophyllum vaughani*, "*Caninia*" *juddi*, *Siphonodendron pauciradiale*, *Siphonodendron junceum*, *Aulophyllum redesdalense*, *Clisiophyllum keyserlingi*, and *Siphonophyllia benburbensis*. [The appearance of some of these species in the early Asbian is questionable; e.g. *Siphonodendron junceum* does not appear until the later Asbian in Belgium (Poty 1985, Aretz 2001), or Ireland (Cozar et al. 2005)].

The assemblage PB, recovered from the lowermost bed of the Potts Beck Limestone (bed f of George et al. 1976), is relatively diverse and contains different colonial and solitary taxa. However, all of the taxa of this assemblage (text-fig. 5) are known to appear before the Asbian. Our intense search at the boundary level for any of the diagnostic Asbian rugose coral taxa of Mitchell's fauna F has not been successful. All solitary corals with a complex axial structure recovered from the biostrome were sectioned and examined carefully in the hope that we might identify *Dibunophylum,* but were all found to belong to the Axophyllidae. The prominence of the medium plate of the axial structure might be reduced or become inconspicuous (= gangamophyllid), but there is no doubt that these specimens belong to this family (see taxonomy section). Although abundant, *Axophyllum vaughani* is not an indicative Asbian taxa, since it appears in the Holkerian and it is known in the stratotype section of that substage (Ramsbottom 1981; Mitchell 1989).

Assemblage KS 1

Asbian rugose coral taxa have been found higher up in the succession (text-fig. 5). Numerous *Dibunophyllum bipartitum* have been found in the coral assemblage KS 1 east of the fault zone. *Siphonodendron martini*, and *Caninophyllum archiaci* (also re-

corded from this assemblage) are already known from older strata (e.g. Mitchell 1989).

Assemblage KS 2

Assemblage KS2 contains a typical late Asbian coral fauna including several members of the Lithostrotionidae which are useful biostratigraphic markers (text-fig. 5). *Siphonodendron junceum* and *Lithostrotion maccoyanum* occur in the late Asbian (see discussion above). *Siphonodendron pauciradiale* appears in the early Asbian. The other taxa of the assemblage KS 2 do not have much stratigraphic value, but are often accessory taxa in the upper Viséan.

D. bipartitum and *L. maccoyanum* are considered to represent fauna G of Mitchell (1989) (=later Asbian). *L. maccoyanum* is an excellent stratigraphic marker, since its range is relatively small (late Asbian – early Brigantian). However, *D. bipartitum* occurs already in the biozone Cf6α (Poty and Hannay 1994), which indicates an early Asbian age. No coral that marks the Brigantian, e.g. *Actinocyathus* or *Orionastraea*, has been found in the studied section.

Summary

Taking into account only the stratigraphical distribution of corals (text-figs. 7, 8A), assemblage AA is mostly likely Holkerian in age. The age of the coral fauna of the boundary bed (PB) is uncertain, but is most probably Holkerian, due to the absence of any Asbian taxon; however, an Asbian age cannot be ruled out. KS 1 is early Asbian in age, since it contains Asbian corals and the first later Asbian taxa do not occur until assemblage KS 2.

From the coral dataset presented here and the uncertainty about the previous record of *Dibunophyllum* (Riley 1993), the Holkerian/Asbian boundary might be best placed somewhere between assemblages PB and KS 1. This coral-based boundary does not correspond to the originally defined boundary at the base of the bioherm (PB). During this study, only corals which appear already in the Holkerian have been recovered from the Potts Beck Limestone.

Discussion

The problems in the recognition of the base of the Asbian are not restricted to the Little Asby Scar section. Riley (1990) in his work on the Wolston Shale Group of the Craven Basin shifted the base of the Asbian into the Pendleside Limestone Formation.

The original definition of the Holkerian/Asbian boundary (George et al. 1976:11) does not contain a biostratigraphic marker. It was originally established as the boundary between the Ashfell Limestone and the Potts Beck Limestone (text-fig. 3). Therefore, it is purely a lithostratigraphic boundary, which eventually coincides with a mesothem boundary of Ramsbottom (1973).

The first appearance dates (FAD) of the coral taxa mentioned by George et al. (1976) do not correspond to the then defined Holkerian/Asbian boundary. Additionally, Dunham and Wilson (1985) questioned the Asbian FAD of the brachiopod *Daviesiella llangollensis* based on the appearance of Holkerian foraminiferan assemblages in the *Daviesiella* beds of the Wye Valley section, North Derbyshire.

Ramsbottom (1981) give a detailed distribution of the macrofauna in the boundary beds (a-i) at Little Asby Scar (text-fig. 3). It is notable that *Dibunophyllum bourtonense* was the only Asbian marker which he recorded from bed f, the basal Asbian bed following the original definition of George et al. (1976). Riley (1993) noted that the record of *Dibunophyllum bourtonense* has never been repeated and that Ramsbottom's original specimen has been lost (pers. com. Riley). Despite our extensive searching we have found no record of *Dibunophyllum,* or even of the family Aulophyllidae, within the biostrome (text-figs. 5, 7A).

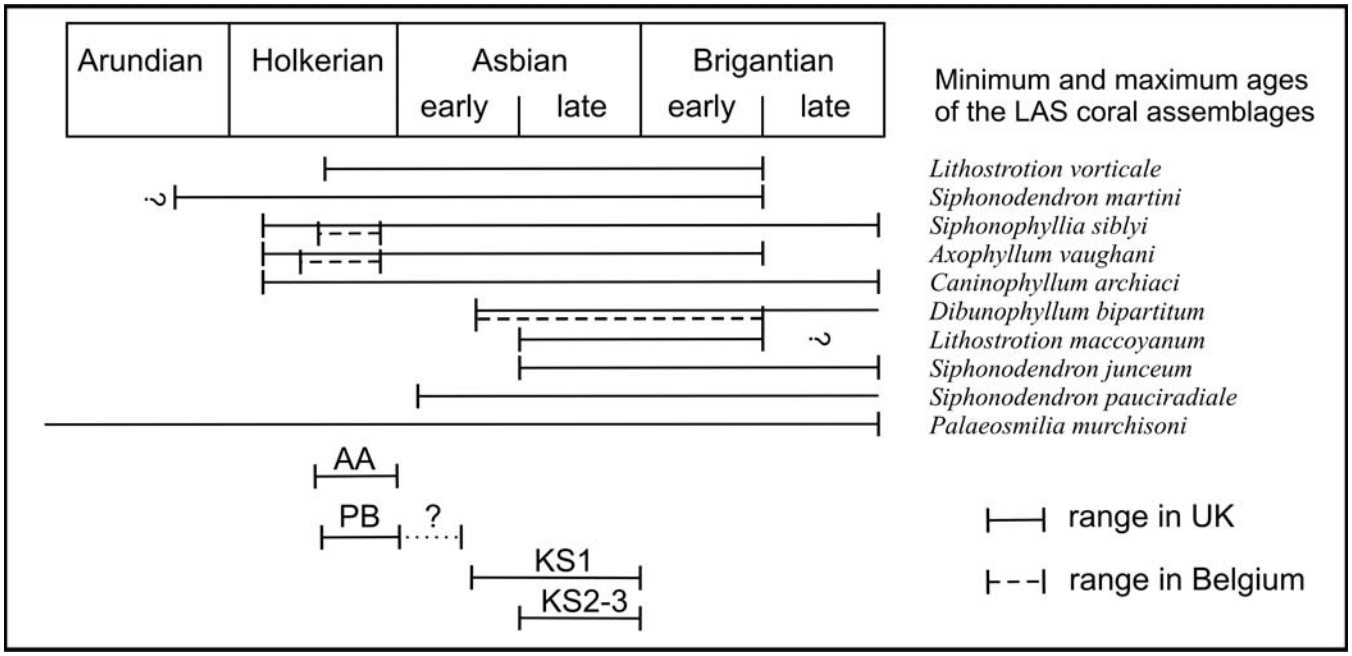
The distribution of other macrofauna in Ramsbottom (1981) indicates *Gigantoproductus* ex. gr. *maximus* in bed a (= top of the Ashfell Limestone). Pattison (1981) reported *Gigantoproductus maximus* only from the Potts Beck Limestone, and Legrand-Blain (1990) indicated that *Gigantoproductus* appeared in the Asbian. Therefore an Asbian brachiopod below the boundary is somewhat surprising; in addition none of the typical Asbian brachiopods of George et al. (1976) have been listed in Ramsbottom (1981).

Probably a good hint in George et al. (1976) for the biostratigraphic base of the Asbian substage is the statement, "R. Conil (pers. com.) confirms that on evidence of the foraminifera, the base of the stage coincides with the Belgian biozonal change between the V3a and V3b …." (George et al. 1976:11). This faunal change is defined at the base of the foraminiferan biozone Cf6 (see also Conil et al. 1977), which is marked by the entry of *Neoarchaediscus*, *Vissariotaxis*, and double walled Palaeotexulariidae (Conil et al. 1991). According to Poty (pers. com.) the first upper Viséan corals (*Dibunophyllum*, *Diphyphyllum*) occur at the base of the Thon Samson Member, which coincides with boundary of Cf6.

The foraminiferan datasets of the stratotype reveal some discrepancies. Strank (in Ramsbottom 1981) observed that Asbian foraminiferans first appeared 19.6m above the Holkerian/Asbian boundary. However, White (1992) recorded the first Asbian taxa (*Vissariotaxis* sp.) in bed g (only 3 m above the boundary) and the first late Asbian taxa in Ramsbottom's bed E (text-fig. 3). Somerville (pers. com.) questioned the correct identification of *Vissariotaxis* by White. Some thin sections made for the identification of corals and microfacies analysis (Aretz and Nudds, in press) are relatively rich in foraminiferans and have been analysed by Dr. L. Hance (Louvain-la-Neuve). The first double-walled Palaeotextulariidae has been found 1 m below the boundary, while the first indicators of the biozone Cf6γ appear with coral assemblage KS1 (text-fig. 8A). However, an earlier FAD of double-walled Palaeotextulariidae can not be ruled out, since our sampling of the Ashfell Limestone was very limited.

Only preliminary conodont data (Ramsbottom 1981) are available so far, and again the characteristic taxon (*Gnathodus bileneatus*) of George et al. (1976) is not listed at Little Asby Scar.

Summing up the datasets of the different fossil groups, it becomes clear that none of them supports a biostratigraphic boundary at the present position of the Holkerian/Asbian boundary (i.e. below bed f). Due to the discrepancies between the first appearance of so-called Asbian taxa and the defined boundary, Riley (1993) proposed to relocate the boundary 19.6m up section in the stratotype where the first Asbian foraminiferans (sensu Strank) appear and *Dibunophyllum* also occurs (Riley 1993). However, the datasets of White (1992) and the present study report Asbian foraminiferans well below this



TEXT-FIGURE 7
Stratigraphic range of selected coral taxa. Indicating minimum and maximum ages of the coral assemblages.

level. Our datasets suggest that at Little Asby Scar the bases of the first Asbian biozones are not synchronous; "Asbian" foraminiferans and possibly brachiopods seem to appear earlier than "Asbian" corals.

Correlation with Belgium

It is interesting to correlate the Little Asby succession to the succession of the Dinant-Namur Basin (Belgium) based on the coral fauna (text-fig. 11B), since both successions belong to the same geotectonic unit (Southern shelf of Laurussia) and occurred in comparable shallow-water facies. The coral assemblage recovered from the biostrome (PB)(=bed f) at Little Asby Scar is very similar to the coral fauna of the Seilles Member (lower Grands Malades Formation) in Belgium. *Dibunophyllum* first appears at the base of the Thon Samson Member, but the species *D. bipartitum* (present in KS 1 and 2) does not appear until the Poilvache Member of the River Bonne Formation. *Siphonodendron junceum* and *Lithostrotion maccoyanum* (both in KS 2) appear at the base of the Anhée Formation.

An attempted correlation with Belgian sedimentary sequences (Hance et al. 2001) indicates the boundary of sequence 7/8 above the beds of the Potts Beck Limestone, which contain assemblage PB. The coral assemblage KS 1 and 2 indicate sequence 9 for the Knipe Scar Limestone. Therefore, sequence 8 would be represented by most of the Potts Beck Limestone.

This simplistic approach is not fully backed by the foraminiferan datasets (text-fig. 8B). The appearance of double-walled Palaeotextularidae in the top of the Ashfell Limestone already indicates a correlation of these beds to the base of the River Bonne Formation. This discrepancy may be partly due to the absence of corals in the Bay Bonnet Member in Belgium (mainly stromatolithic limestones), which may be result in a miscorrelation of bed f to the Seilles Member, but the correlation to the Bonne River Formation should be confirmed by the coral fauna.

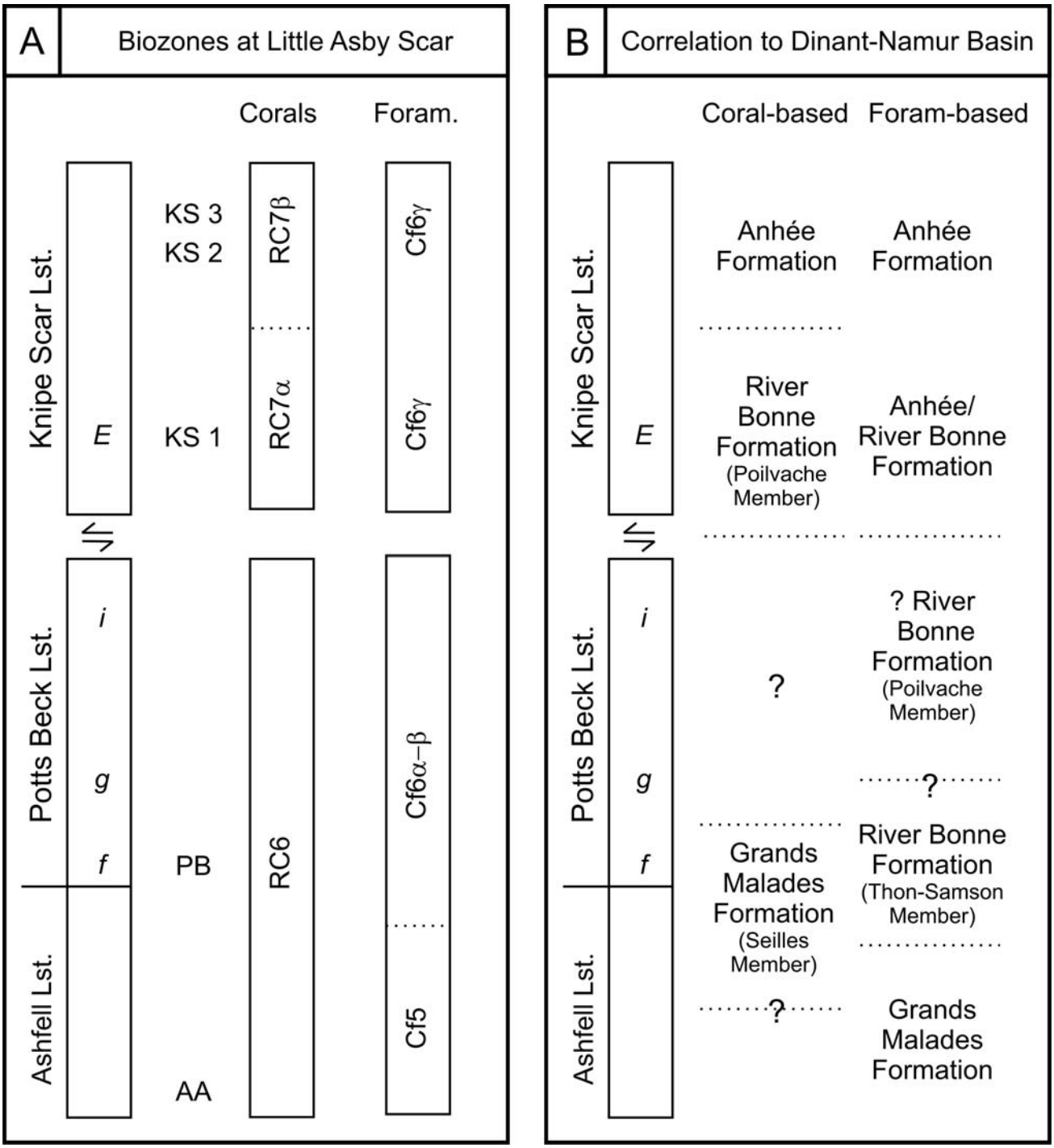
The simultaneous appearance of index taxa of corals and foraminiferans at the base of the Bonne River Formation in Belgium is possibly the effect of the disappearance of the unsuitable facies of the Bay Bonnet Member, which may have obscured the FAD of possible markers. Regions with more open marine facies during Bay-Bonnet time should record an evolution and distribution different from Belgium.

However, in the upper part coral- and foraminiferan-based correlations agree much better. The first markers for Cf6γ co-occur with KS1. Since Cf6γ slightly predates RC7β, this level may be correlated to the top of the Poilvache Member (River Bonne Formation). However, the foraminiferan dataset confirms that *Siphonodendron junceum* does not appear at Little Asby Scar until the later Asbian. Therefore, the application of the boundary of biozones RC7α and RC7β should be possible in Britain as also confirmed by Cozar et al. (2005).

The use of the presence/absence criteria of corals and/or foraminifera does not take into account the facies dependency of these groups (e.g. Gallagher 1998). However, biostratigraphic correlation is consistent in the Belgian Dinant-Namur basin, but inter-regional correlations may be somewhat difficult. Thus, the same has to be tested in Britain, and may be more important due to the higher differentiation of the British shelf system.

Implications

The original definition of the Asbian stratotype is purely lithostratigraphic. The mudstone bed e (text-fig. 3), which is variable in thickness, disappears for at least some hundred meters in the sections west of the stratotype section, and therefore is already in itself an unsuitable marker bed. Lithostratigraphic



TEXT-FIGURE 8
A. Biozonal Scheme for corals and foraminiferans for the Little Asby Scar section (using the Belgian terminology); B. The correlation of the Little Asby Scar section to the formations of the Belgian Dinant-Namur Basin reveals major differences when using different biozones.

boundaries are mostly diachronous, and therefore are not suitable for the definition of substages in the Mississippian of Britain.

The base of the Asbian substage should defined by biostratigraphic means, although the potential markers are benthic organisms with facies dependencies. Two groups seem to be the best options: corals or foraminiferans.

Foraminiferans as microfossils might be considered more suitable markers, due to their abundance. However, Gallagher (1998) showed that many Asbian foraminiferan taxa, including some index fossils, are facies dependent. Ramsbottom (1981:1.2) pointed out that, "The base was originally defined on the basis of the entry of corals of the D1 Zone, including *Dibunophyllum* in the basal beds of the Asbian", and highlighted the differences of the base of the D1 zone in northern

England and its somewhat younger position in the Avon Gorge section. This statement clearly indicates the importance of the appearance of *Dibunophyllum* for the original definition of the Asbian substage. Following the intention of all previous authors and in accordance with the appearance of *Dibunophyllum* at the base of Warnantian in Belgium, the base of the Asbian should therefore approximate to the first appearance of *Dibunophyllum*. Hence Riley (1993) proposed to relocate the boundary 19.6m up section to the first appearance of *Dibunophyllum*, which he considered also approximated to the appearance of Asbian foraminiferans (*sensu* Strank). However, because more recent foraminiferan datasets (White, and this study) now suggest that Asbian taxa appear lower in the succession, Riley's proposal should be reconsidered. In addition *Dibunophyllum bipartitum*, the first dibunophyllid coral in the Little Asby Scar section, may be not the oldest species of the genus.

This study clearly shows that, at least in the Little Asby Scar section, the bases of coral and foraminiferan biozones do not correspond, and, moreover, that the original boundary of George et al. (1976) does not correspond to any boundary of the biozones. To ensure the chronostratigraphic status of an Asbian substage, a formal decision on a new definition based on a suitable marker must be made. Candidates may be found among foraminiferans and rugose corals, but further detailed work on their distribution is needed.

According to the results of this study, this will lead to a relocation of the boundary in the Little Asby section. Taking into account the poor quality of the natural exposures at Little Asby Scar and the associated problems with faulting, a relocation of the stratotype section to a continuous section (e.g. cliff or quarry) is necessary, and a consensus on the criterion to define this boundary is therefore needed. All regions of the British Isles should be included in the search for a new section, but key locations might be found in Derbyshire and North Wales.

CONCLUSIONS

A rich and diverse coral fauna has been found in various parts of the stratotype section. The rugose corals belong to 7 genera with 12 species. Among many common taxa, some taxa are relatively rare. The diameters of heterocorals have been measured and histograms show the difficulties of separating genera and species based on this character. The taxonomic description of the tabulate corals is hampered by silification of the material.

The rugose corals recovered from the biostrome (assemblage PB) at the Holkerian/Asbian boundary stratotype at Little Asby Scar, and previously defined as being lowest Asbian, do not include any Asbian taxa, and may in fact be of Holkerian age. Some of the taxa do persist into the Asbian, but this assemblage does not confirm previous results (George et al. 1976, Ramsbottom 1981). The first typical Asbian corals appear in the higher coral assemblages, KS 1 - 3, all of which belong to the Knipe Scar Limestone. No coral taxa which appear in the Asbian have been recovered from the Potts Beck Limestone.

The Holkerian/Asbian boundary as defined by George et al. (1976) is a lithostratigraphic boundary, which is not supported by any biostratigraphy. There are no potential index taxa in either corals, brachiopods, foraminferans or conodonts at this level. The first coral, which definitely appears in the Asbian is *Dibunophyllum bipartitum* and this does not occur until the lower Knipe Scar Limestone east of the fault zone. None of the existing foraminferan datasets (Strank, White, Hance) support a Holkerian/Asbian boundary in its present position, but they are not in agreement in their definition of the base of the Asbian.

After agreement on a biostratigraphic marker for the base of the Asbian, the stratotype should be relocated into a section of better outcrop quality, possibly in Derbyshire or North Wales. It is desirable, that the base of the Asbian will be defined near to the FAD of *Dibunophyllum* (after the evolution of the genus is better constrained).

However, without any formal decision the base of the Asbian substage has to be retained at its present position at the base of the Potts Beck Limestone.

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