# Late Visean rugose coral faunas from South-Eastern Ireland: composition, depositional setting and palaeoecology of *Siphonodendron* biostromes

Ian D. Somerville[1], Pedro Cózar[2], Sergio Rodríguez[2]

Somerville, I.D., Cózar, P. & Rodríguez, S., 2007: Late Visean rugose coral faunas from South-Eastern Ireland: composition, depositional setting and palaeoecology of *Siphonodendron* biostromes. – In: Hubmann, B. & Piller, W. E. (Eds.): Fossil Corals and Sponges. Proceedings of the 9th International Symposium on Fossil Cnidaria and Porifera. – Österr. Akad. Wiss., Schriftenr. Erdwiss. Komm. 17: 307–328, 1 Tab., 5 Figs., Wien.

**Abstract:** *Siphonodendron* biostromes are recorded from well-bedded dark grey limestones of Brigantian (late Visean) age in the Carlow area, SE Ireland. The limestones formed on a shallow water shelf on which periodic subaerial exposure occurred. A coral biostrome in the lower part of the Clogrenan Formation can be correlated between quarries up to 50 km apart. All of the biostromes are dominated by tabular or low bulbous *Siphonodendron* coralla with pronounced peripheral growth strategies. The dimensions of fasciculate coralla are typically 20–30 cm high and 70–90 cm in width, but some coralla reach 4.5 m across. The corallites in many coralla have the same upper growth level. Associated colonial rugose corals are *Diphyphyllum, Lonsdaleia, Lithostrotion, Actinocyathus*, and the tabulate *Syringopora*, but all form accessory roles in the constructions. The biostrome at Dunamase Quarry is the most diverse with 11 genera and 14 species. Gigantoproductid brachiopods are an important element, commonly forming concentrations of *in situ* shells below, within or above the biostrome. The Carlow biostromes are closely comparable with the *Siphonodendron* biostromes in SW Spain, but differ from the '*pauciradiale* reefs' of NW Ireland, which formed in deeper water and contain many overturned coralla.

**Key words:** rugose corals, *Siphonodendron*, biostromes, Late Visean, Ireland, Spain

**Contents**



[1] UCD School of Geological Sciences, University College Dublin, Belfield, Dublin 4, Ireland, e-mail: ian.somerville@ucd.ie

[2] UEI-Departamento de Paleontología, Instituto de Geología Económica CSIC-UCM, Facultad de Ciencias Geológicas, José Antonio Novais 2, 28040-Madrid, Spain, e-mail: pcozar@geo.ucm.es, sergrodr@geo.ucm.es

## 1. INTRODUCTION

### 1.1. Geological setting

Most of the south-eastern part of Ireland in the late Visean was covered by a shallow-water carbonate shelf with little or no siliciclastic input from the Pre-Carboniferous and Igneous rocks of the Leinster Massif farther to the east (Fig. 1). Apart from a few working quarries on the east side of the Castlecomer Syncline and scattered borehole sections, the Upper Visean limestones are poorly known. In the Carlow-Kilkenny region adjacent to the Leinster Massif these limestones have been assigned to two formations: the Ballyadams Formation (Asbian) and the overlying Clogrenan Formation (Brigantian). The type section of the Ballyadams Formation is in Ballyadams Quarry, 7 km SW of Athy, where it is over 70 m thick (Tietzsch-Tyler & Sleeman, 1994; McConnell & Philcox, 1994; Cózar & Somerville, 2005). A thicker section occurs in the Durrow-2 borehole (>220 m) in Co. Laois (Fig. 1), west of the Castlecomer Syncline (Somerville et al., 1996a; Gatley et al., 2005). Although a total thickness of 400–700 m for the formation has been inferred (McConnell & Philcox, 1994), recent studies have suggested that it is probably between 300–400 m thick (Cózar & Somerville, 2005). The type section of the Clogrenan Formation is in Clogrenan Quarry, 5 km SW of Carlow town (Tietzsch-Tyler & Sleeman, 1994), where a 67 m-thick section is exposed, most of which, apart from the lower 5 m, belongs to the Clogrenan Formation (Cózar & Somerville, 2005). This formation is known to increase in thickness northwest of Carlow (from data in the Guileen-1 Borehole) towards the Stradbally-Dunamase region of Co. Laois (Fig. 1), with a composite succession 96 m thick (Cózar & Somerville, 2005).

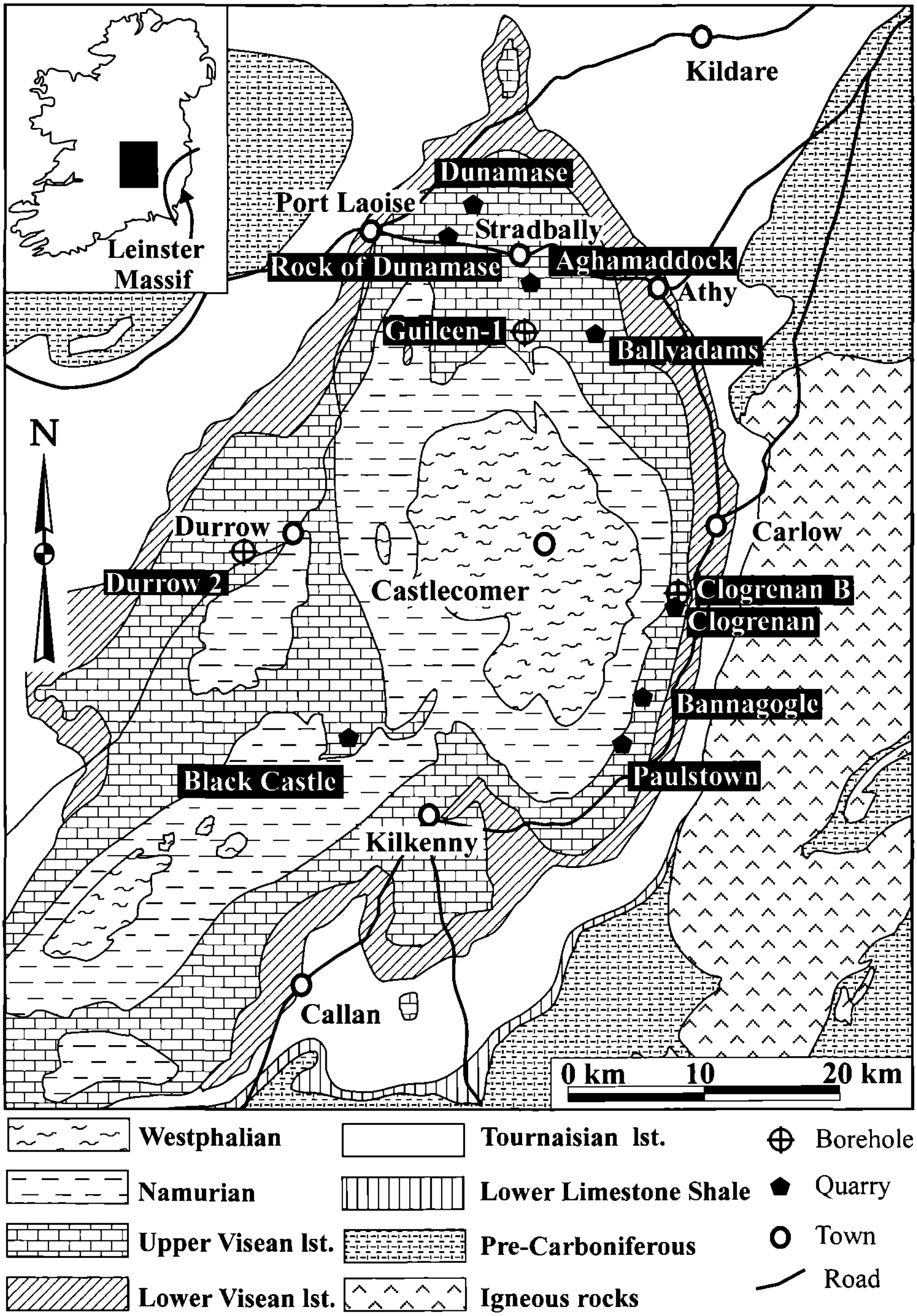


Fig. 1: Location of the quarry and boreholes studied in the Carlow area, SE Ireland.

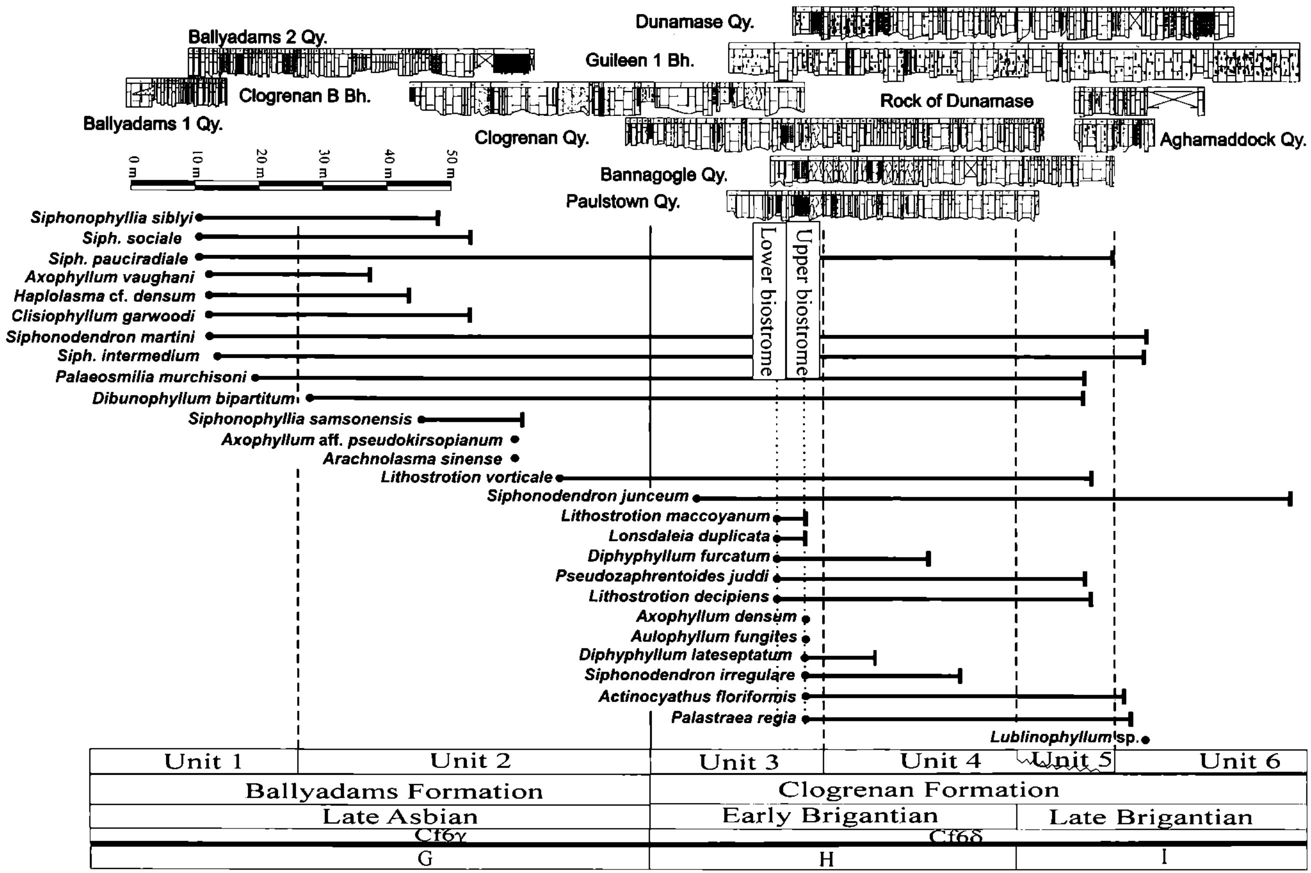


Fig. 2: Stratigraphic range chart of selected rugose coral taxa in the Ballyadams and Clogrenan formations in the Carlow area (Foraminifera subzones from CONIL et al., 1990; Coral assemblage biozones from MITCHELL, 1989).

## 1.2. Lithostratigraphic units in the late Visean

The Ballyadams Formation exposed in the type section is composed of two units (units 1 and 2; Fig. 2). Unit 1 (30 m thick) consists of fine- to medium-grained well-bedded limestones with common thin shale interbeds. These limestones are rich in algae and have prominent brachiopod bands. Unit 2 (74 m thick) is a cyclic unit with an alternation of dark grey thin-bedded fine-grained limestones (lime mudstones/wackestones), passing up into pale grey massive coarse-grained limestones (algal-rich packstones/grainstones). Six cycles are recognised in the formation; the lower four in Ballyadams Quarry and the upper two cycles in Clogrenan B Borehole (Fig. 2), Each cycle ranges in thickness from 8–17 m. Palaeokarstic surfaces are developed at the top of the massive pale grey beds representing the top of the cycles. Subaerial exposure features include alveolar textures and palaeosols. A prominent palaeokarst is developed at the top of unit 2 (top of Ballyadams Formation), near the base of the Clogrenan Quarry section.

The Clogrenan Formation is composed of four units (units 3–6; Fig. 2). In the type section in Clogrenan Quarry (and all sections in Co. Carlow and Co. Kilkenny) only units 3 and 4 are exposed. The laterally equivalent and upper units (units 5 and 6) are exposed in Dunamase Quarry (and other sections in Co. Laois), along with unit 4 and the top of unit 3 at the base of the quarry. Unit 3 is 27 m thick and is composed of medium-coarse-grained well-bedded limestones (crinoidal-intraclastic packstone/grainstone) with scattered colonial coral horizons, including several distinct *Siphonodendron* biostromes (described below in sections 4 and 5). Several palaeokarst surfaces are present in this unit with associated thin shales and clays, but no cyclicity was observed. Unit 4 (46 m thick) is composed mostly of coarse- to very coarse-grained crinoidal-bryozoan-intraclastic packstones/grainstones. Palaeokarst surfaces are absent or poorly developed. Chert nodules and bands are well developed in this unit (Fig. 3). Coral biostromes and brachiopod bands are present in wackestone/packstone beds. Unit 5 (c. 32 m thick) is characterised by thick beds of fine- to medium-grained crinoidal limestone with interbedded shales arranged in small-scale cycles (2–5 m thick). Gigantoproductid brachiopod bands are developed in this unit. Unit 6 (>24 m thick) is composed of alternating coarse-grained and fine-grained limestones rich in chert. Colonial corals are locally common, as in the Rock of Dunamase section.

## 1.3. Aims and objectives

The main aims of this paper are, firstly, to document the distribution and stratigraphic range of rugose coral taxa from the two upper Visean formations in the Carlow area of SE Ireland. Secondly, a detailed analysis is presented of the biostromal horizons, developed mostly within unit 3 in the Brigantian. These will be compared with similar biostromes and bioherms of approximately equivalent age in Western Europe.

# 2. MATERIALS AND METHODS

A detailed logging and sampling investigation of quarry sections and boreholes was undertaken in the Carlow area. Rugose coral faunas were collected from all the sections

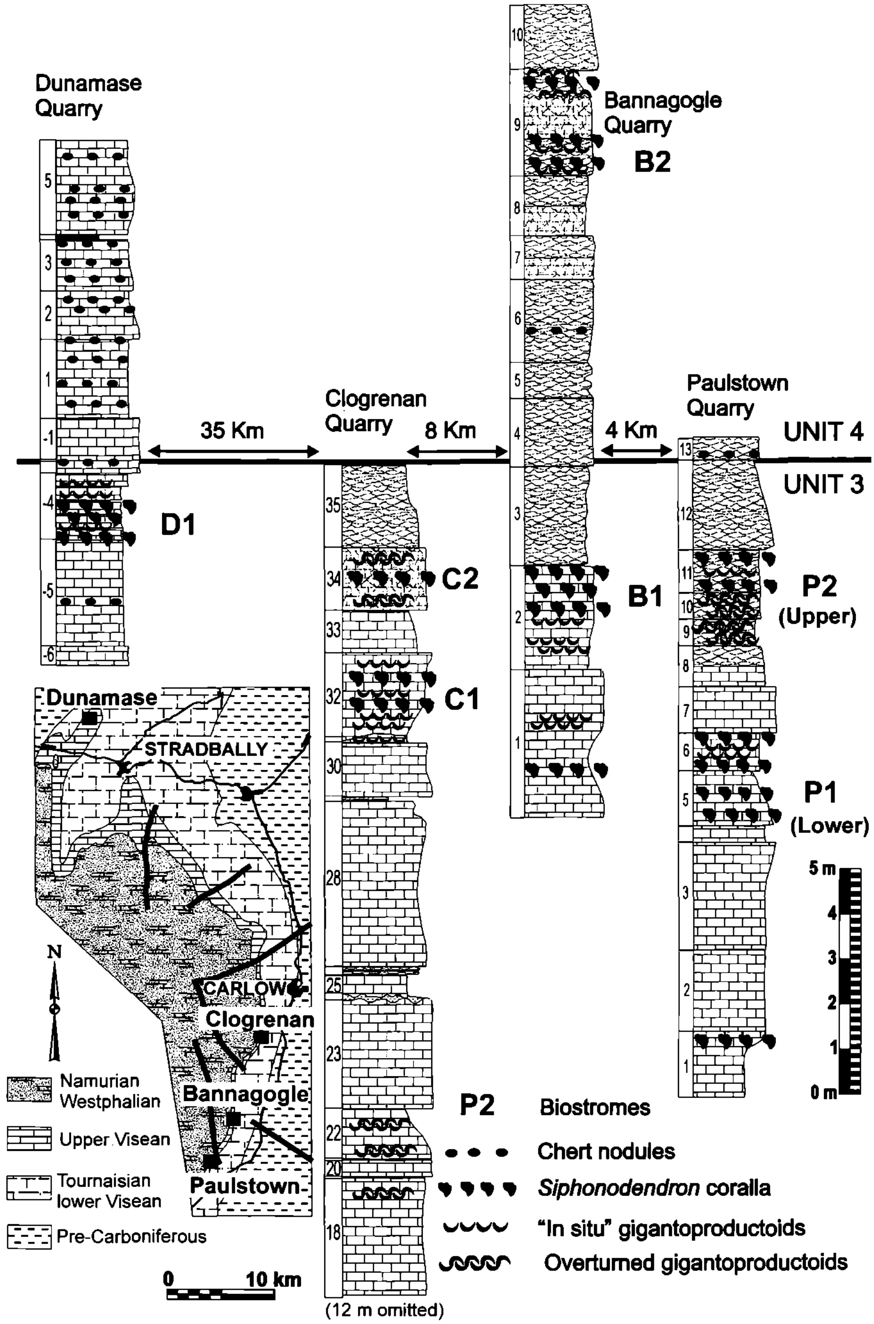


Fig. 3: Detailed logs of part of the four quarry sections exhibiting *Siphonodendron* biostromes at the top of unit 3 in the Clogrenan Formation.

and their precise horizons determined. The stratigraphic ranges of selected taxa from these sections are shown in the composite range chart (Fig. 2). As part of this study, a bed-by-bed sampling programme was carried out with a sampling interval of approximately one sample every metre. Thin sections were prepared from all samples (1) to establish the precise age of both formations, using foraminifera and calcareous algae, (2) to document all biotic and non-biotic components, and lithological characteristics (grain size, colour, texture, structures) of the limestones, and (3) to achieve accurate biostratigraphical and lithostratigraphical correlations between sections.

Seven sections were studied in detail: Ballyadams Quarry (Co. Laois), Clogrenan and Bannagogle quarries (Co. Carlow), Paulstown Quarry (Co. Kilkenny), Dunamase Quarry and the nearby Rock of Dunamase (Co. Laois), as well as the Guileen-1 Borehole (GU-1) near Stradbally (Co. Laois). Most of the sections are within the Clogrenan Formation (apart from Ballyadams Quarry). The petrography of the limestones and biostratigraphic details of the microfossils are documented in the paper by Cózar & Somerville (2005). The biostratigraphic results are briefly summarised below.

## 3. BIOSTRATIGRAPHIC AGE

### 3.1. Rugose coral assemblages
(Fig. 2)

The Ballyadams Formation contains several diagnostic rugose corals typical of Coral Zone G (Mitchell, 1989). In the lower part of the Ballyadams Quarry in unit 1 a diverse late Asbian coral assemblage was recovered including: *Axophyllum vaughani* (Saleé), *Clisiophyllum garwoodi* (Saleé), *Haplolasma* cf. *densum* (Lewis), *Palaeosmilia murchisoni* Milne-Edwards & Haime, *Siphonodendron intermedium* Poty, *S. martini* (Milne-Edwards & Haime), *S. pauciradiale* (M'Coy), *S. sociale* (Phillips) and *Siphonophyllia siblyi* Semenoff-Tian-Chansky. A similar assemblage occurs in unit 2 with the addition of *Dibunophyllum bipartitum* (M'Coy), *Lithostrotion vorticale* (Parkinson), *Siphonophyllia samsonensis* (Saleé) (= *S. benburbensis* Lewis of other authors) and *Axophyllum* aff. *pseudokirsopianum* Semenoff-Tian-Chansky. This late Asbian coral assemblage is comparable with assemblages recorded from other coeval shelf limestones in Ireland (Somerville et al., 1992; Strogen et al., 1995; Somerville et al., 1996b; Jones & Somerville, 1996; Somerville, 1997; Gallagher & Somerville, 1997; Rodríguez & Somerville, this volume).

The Clogrenan Formation contains several diagnostic rugose corals typical of Coral Zone H (Mitchell, 1989), including in unit 3 (Fig. 2): *Actinocyathus floriformis* (Martin), *Aulophyllum fungites* (Fleming), *Dibunophyllum bipartitum, Diphyphyllum furcatum* (Hill), *D. lateseptatum* (M'Coy). *Lithostrotion decipiens* (M'Coy), *L. maccoyanum* (Milne-Edwards & Haime), *Lonsdaleia duplicata* (Martin), *Palastraea regia* (Phillips), *Pseudozaphrentoides juddi* (Thompson), *Siphonodendron junceum* (Fleming), *S. pauciradiale,* and the tabulate coral *Syringopora* sp.. *A. floriformis* is also locally abundant in unit 6, at the Rock of Dunamase, together with *Lublinophyllum*, a colonial cyathopsid that represents its first recorded occurrence in Ireland. A similar early Brigantian assemblage was recorded from the Liscarroll Limestone Formation in North Co. Cork (Gallagher & Somerville, 1997). Elsewhere, Nudds (1979) recorded *Orionastraea rete* Hudson from near the top of the Clogrenan Formation (late Brigantian) in Black Castle Quarry, 8 km NW of Kilkenny town (Fig. 1).

### 3.2. Microfossils

The Ballyadams Formation contains abundant late Asbian foraminifera typical of the Cf6γ Subzone (Conil et al., 1980, 1991) including archaediscids at *angulatus* stage, *Cribrostomum lecomptei* Conil & Lys, *Bibradya, Koskinobigenerina, Cribrospira panderi* (von Moeller), *Bradyina rotula* (d'Eichwald) and *Neoarchaediscus* in the upper part. Algae include: dasyclads (*Koninckopora, Nanopora,* and *Coelosporella* in the upper part), abundant *Ungdarella, Epistacheoides* and *Aoujgalia*, and palaeoberesellids (*Kamaenella and Kamaena*). The Clogrenan Formation contains a more diverse and abundant assemblage of Brigantian foraminifera belonging to the Cf6δ Subzone (Conil et al., 1980, 1991) including the first appearance of *Archaediscus karreri, Asteroarchaediscus, Howchinia, Loeblichia, Planospirodiscus, Biseriammina, Tubispirodiscus* and *Euxinita efremovi* (Vdovenko & Rostovseva). In the upper part of the formation occur *Janischewskina, Climacammina* and *Endothyranopsis sphaerica* (Rauzer-Chernoussova & Reitlinger). There is also a marked increase in the abundance of algae, e.g. *Nanopora* and restriction of *Koninckopora, Kamaenella* and *Ungdarella* to the lower part of the formation. Also, in the lower part of the Clogrenan Formation is the first appearance of the red alga *Neoprincipia*, the calcifolial *Falsocalcifolium punctatum* (Maslov) and incertae sedis *Claracrusta* and *Saccaminopsis fusulinaeformis*. The latter taxon occurs abundantly in several discrete horizons.

## 4. DISTRIBUTION AND COMPOSITION OF BIOSTROMES

Coral biostromes described from the four quarry sections occur within thick-bedded medium-dark grey bioclastic limestones (skeletal wackestones-grainstones) of the Clogrenan Formation. They form at two distinct horizons near the top of unit 3 (lower and upper biostromes in Figs. 2, 3), with a further horizon in unit 4, exposed only in Bannagogle Quarry (Fig. 3). They contain conspicuous horizons of brachiopod concentrations, with both thin-walled productids and thick valves of *Gigantoproductus* sp.. Many of these shells are in concave-up *in situ* growth position (Fig. 3). Thin-sections from beds containing colonial corals have abundant crinoids, but bryozoans are commonly absent. Foraminifera and dasycladacean algae are locally common in the finer grained wackestones and rare to absent in the grainstones. Chaetetid sponges in some cases occur in the same beds as colonial corals. The biostrome in Dunamase Quarry, in contrast, has a wackstone-fine packstone matrix between coralla that contains crinoids, brachiopods and bryozoans, with common sponge spicules and foraminifera. Algae are very rare with an absence of dasyclads in the section.

### 4.1. Bannagogle Quarry

Two coral biostromes occur in this working quarry; one near the top of unit 3, 4.7 m above the base (B1), and the other 15.1 m above the base (B2) in unit 4 (Fig. 3). The

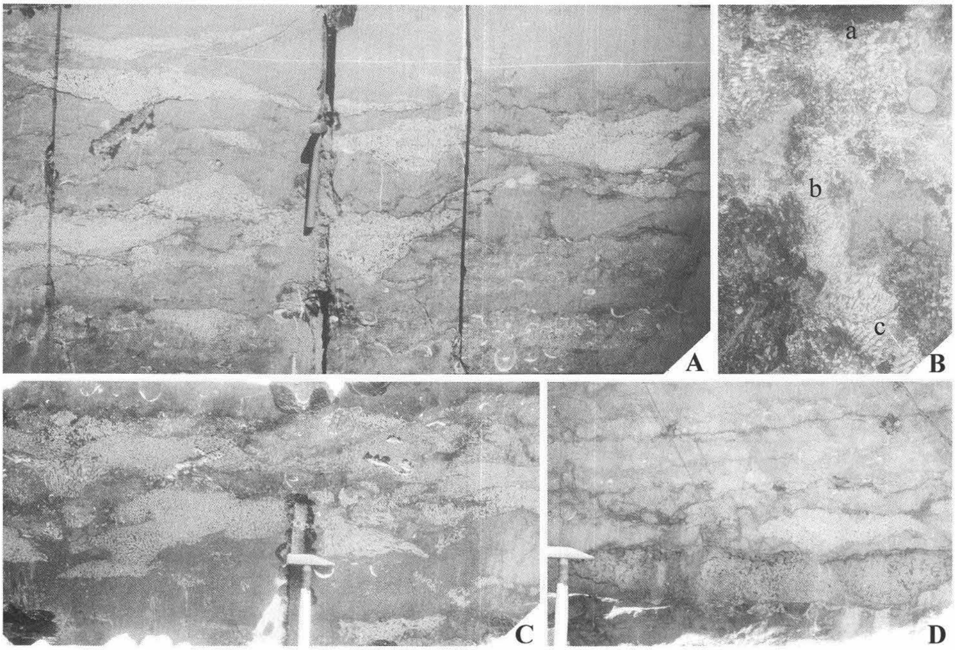


Fig. 4: (A) View of vertical cut face exposing mostly coralla of *Siphonodendron* in the lower biostrome (B1) in Bannagogle Quarry (Scale = hammer is 40 cm).
(B) Plan view of coralla at the top of the upper biostrome (P2) of Paulstown Quarry. Note interfingering of three different species (a) = *Diphyphyllum furcatum*, (b) = *Siphonodendron pauciradiale* and (c) = *S. irregulare* (Scale = coin is 2.6 cm in diameter).
(C) Vertical polished face in Paulstown Quarry (upper biostrome) shows close proximity of neighbouring coralla and their markedly tabular form (Scale = hammer is 30 cm).
(D) Vertical polished face in Paulstown Quarry (upper biostrome) showing pronounced tabular growth form of *Siphonodendron* (lowest corallum is approx. 15 cm high and 1.2 m long – Scale = hammer is 30 cm).

lower biostrome is 1.3 m thick and consists of dark grey crinoidal packstone (bed 2). It occurs above a bed rich in discrete bands of *Gigantoproductus* sp., with most of the valves concave-up and in growth position. Bed 1 also contains rare small coralla of *in situ Siphonodendron*. The lower biostrome is well exposed in an extensive bench near the base of the quarry and has numerous 3-D saw-cut faces (Fig. 4A). A total of 112 corals were collected from this biostrome comprising 92 colonial and 20 solitary specimens. The following taxa were recorded (number of specimens in brackets): abundant fasciculate coralla of *Siphonodendron pauciradiale* (57), *S. junceum* (9), *Diphyphyllum furcatum* (12), and rare *Lonsdaleia duplicata* (1), with the majority of the larger coralla *in situ*. Rare cerioid *Lithostrotion maccoyanum* (2), *L. decipiens* (1) and *Actinocyathus floriformis* (10) coralla are also recorded, as are tabulate coralla of *Syringopora* sp., but the latter are sparse. Solitary corals in this bed include *Aulophyllum fungites* (3), *Axophyllum vaughani* (2), *Dibunophyllum bipartitum* (5), *Palaeosmilia murchisoni* (1), and *Pseudozaphrentoides juddi* (9) (Table 1). The overlying limestone beds are distinctly

| Rugose species | Dunamase | Clogrenan | Bannagogle | Paulstown P1 | Paulstown P2 |
|---|---|---|---|---|---|
| *Actinocyathus floriformis* | ★ | | ★ | | ★ |
| *Aulophyllum fungites* | ★ | | ★ | | ★ |
| *Axophyllum vaughani* | ★ | | ★ | | ★ |
| *Caninophyllum archiaci* | ★ | | | | |
| *Dibunophyllum bipartitum* | ★ | ★ | ★ | | |
| *Diphyphyllum furcatum* | ★ | ★ | ★ | ★ | ★ |
| *Diphyphyllum lateseptatum* | | | | | ★ |
| *Lithostrotion decipiens* | ★ | | ★ | ★ | |
| *Lithostrotion maccoyanum* | | ★ | ★ | | ★ |
| *Lithostrotion vorticale* | ★ | | ★ | ★ | |
| *Lonsdaleia duplicata* | ★ | | ★ | ★ | |
| *Palaeosmilia murchisoni* | | | ★ | | ★ |
| *Palastraea regia* | ★ | | | | |
| *Pseudozaphrentoides juddi* | (★) | ★ | ★ | | ★ |
| *Siphonodendron intermedium* | ★ | | | | |
| *Siphonodendron irregulare* | | | | | ★ |
| *Siphonodendron junceum* | | ★ | ★ | | ★ |
| *Siphonodendron martini* | ★ | | | | |
| *Siphonodendron pauciradiale* | (★) | (★) | (★) | (★) | (★) |
| Number of species | 14 | 6 | 13 | 5 | 11 |
| Number of genera | 11 | 5 | 10 | 4 | 8 |

★ Present (★) Dominant species

Tab. 1: Comparison of rugose coral taxa from the upper biostromes in unit 3 (Clogrenan Formation) in the four quarry sections (see Fig. 3 for location of horizons). N.B. only data from C1 biostrome (Clogrenan) is plotted, and data for B2 biostrome (Bannagogle) is excluded as it lies in unit 4.

nodular (bioturbated) with very poor macrofauna and only rare solitary corals preserved.

The lower biostrome is dominated by tabular and low bulbous *Siphonodendron* and *Diphyphyllum* coralla (using the terminology of Scrutton, 1998) with distinctly conical bases. The coralla are typically 50–90 cm in width and 15–20 cm in height. Rare coralla are up to 4.5 m across and up to 30 cm in height. Coralla are typically 2–5 cm apart, although in some cases they may abut or stack on one another or can be up to 10 cm apart. On average 15% of the coralla are overturned, including most small coralla, 25% are upright and *in situ* showing an approximately symmetrical fan shape, whereas over 60% are in growth position, but with sub-horizontally directed growth of corallites towards the margins (Fig. 4A, 5). A discontinuous brachiopod shell band occurs at the base of the biostrome, and some coralla grew on the shells or on solitary corals to which

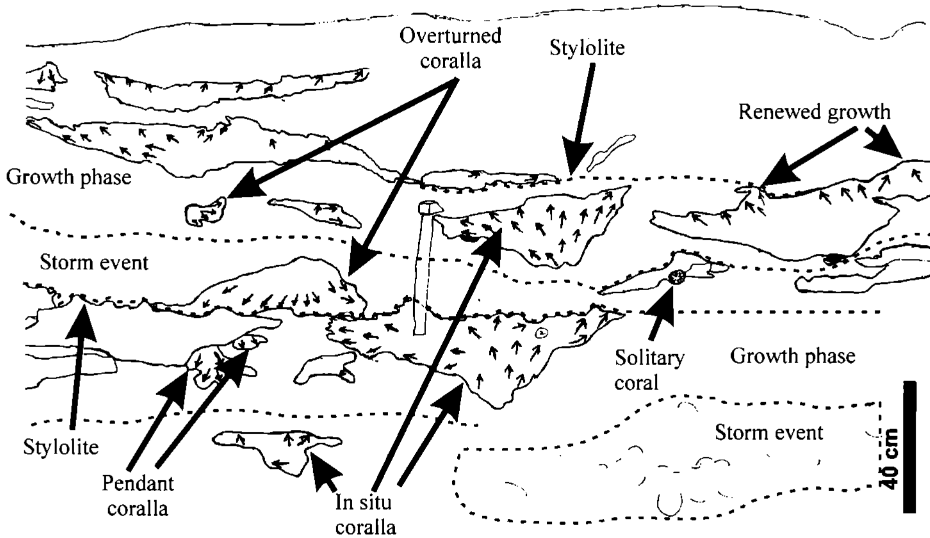


Fig. 5: Interpretative drawing of lower biostrome (B1) from Bannagogle Quarry (illustrated in Fig. 4A) to show detail of the *Siphonodendron* coralla and growth phases. Arrows within coralla indicate orientation and growth direction of corallites. Hammer is 40 cm long. See text for further explanation.

they are still attached. Very rarely, small coralla occur with pendant growth, growing vertically down from an overhanging larger *Siphonodendron* corallum (Fig. 5).

The upper biostrome (B2) is 2.5 m thick (bed 9; Fig. 3), although only the upper 80 cm contains abundant corals. The bed is a crinoid-rich grainstone with abundant *in situ* *Diphyphyllum lateseptatum* coralla. *Gigantoproductus* sp. occurs in the bed, but most valves are overturned. The bed also contains numerous gastropods, and at the top of the bed are concentrations of smaller brachiopods and *Lithostrotion decipiens* coralla in a finer grained matrix.

### 4.2. Paulstown Quarry

Two coral biostromes occur in this working quarry 6.4 m and 11.5 m above the base, respectively, near the top of unit 3 (Fig. 3). The lower biostrome (P1) is 2.2 m thick and comprises two beds, a lower coarse-grained pale grey crinoidal grainstone bed at the base, 1.3 m thick (bed 5), which becomes finer grained and darker grey at the top, followed by a dark grey wackestone bed 0.9 m thick (bed 6). A total of 27 mostly colonial coral specimens were collected from this biostrome. The lower bed contains abundant fasciculate coralla, mostly *Siphonodendron pauciradiale* (17) with very rare *Diphyphyllum furcatum* (1), with the majority of the larger coralla *in situ* (Table 1). Smaller coralla on the other hand are mostly overturned. Cerioid *Lithostrotion decipiens* (5) and *L. vorticale* (1) coralla also occur and tabulate corals (*Syringopora* sp.) are sparse.

A rich concentration of *Gigantoproductus* sp. with most of the valves concave-up and in growth position occurs at the base of the overlying wackestone (bed 6). Above the shell band are large *in situ Siphonodendron* coralla, over one metre in width, with scattered *Lonsdaleia duplicata* (2) and *Lithostrotion* coralla. Solitary corals also occur in this bed, including *Palaeosmilia murchisoni*.

The upper biostrome (P2) is one metre thick and occurs within a bed of dark grey grainstone (bed 11; Fig. 3). A total of 65 corals were collected from this biostrome comprising 58 colonial and 7 solitary specimens. Fasciculate corals: *Siphonodendron pauciradiale* (28), *S. junceum* (4), *S. irregulare* (1), *Diphyphyllum furcatum* (12), and *D. lateseptatum* (2), are abundant, with many coralla upright and *in situ* (Fig. 4C-4D), and some overturned (Table 1). Cerioid corals are represented by *Actinocyathus floriformis* (9) and *Lithostrotion maccoyanum* (2). Solitary corals are also conspicuous and include *Aulophyllum fungites* (4), *Axophyllum vaughani* (1), *Palaeosmilia murchisoni* (1), and *Pseudozaphrentoides juddi* (1).

There are twice as many rugose genera and species in the upper biostrome as in the lower biostrome (see Table 1). The *Siphonodendron* coralla are laterally elongate (commonly 1m in width, Fig. 4D), but small in height (20–30 cm). They have common tabular or low bulbous geometries. This biostrome has more abundant brachiopods associated with the coralla, as well as gastropods and rare chaetetid sponges. The top of this biostrome has *Siphonodendron* coralla (both upright, *in situ* and overturned). One corallum was observed attached to a *Lithostrotion* corallum. The bed immediately above the biostrome contains abundant *Gigantoproductus* shells with the vast majority *in situ* and concave up. Isolated *Siphonodendron* coralla also occur in this unit.

*Siphonodendron pauciradiale* and *Diphyphyllum furcatum* are the most dominant species in both biostromes (Fig. 4B), representing over 60% of the total coral assemblage. Coralla of these species also occur sporadically in the section between the two coral biostromes, but, like the associated brachiopods, are commonly overturned. The upper biostrome has a high diversity of rugose corals (8 genera and 10 species) and is comparable with the lower biostrome (B1) in Bannagogle Quarry (10 genera and 13 species; Table 1). However, there is a 75% increase in the number of diphyphyllid coralla (8% of all coralla in Bannagogle (B1) biostrome, compared to 25% of all coralla in Paulstown (P2) biostrome). Both of these biostromes can be correlated with the biostrome (D1) near the base of Dunamase Quarry (Fig. 3; see below), which has the highest diversity (11 genera and 14 species; Table 1). The same colonial genera are present (with the exception of *Palastraea regia* in Dunamase Quarry) in all three biostromes (B1, P2 and D1) from the upper biostrome horizon in unit 3.

### 4.3. Clogrenan Quarry

Two biostromes occur, c. 24 m and 27 m, respectively, above the base of Clogrenan Quarry. The lower biostrome (C1) consists of a 2.1 m-thick massive bed (bed 32; Fig. 3) containing bands of *in situ* concave-up gigantoproductoids and *in situ* coralla of *Siphonodendron pauciradiale*, *S. junceum* and *Diphyphyllum furcatum* (Table 1), but the number of specimens collected was very low. Associated solitary corals include *Dibunophyllum bipartitum* and *Pseudozaphrentoides juddi*. Chaetetid sponges also occur. The overlying bed is a dark grey wackestone (bed 33), succeeded by the upper biostrome (C2) which is represented by an irregular-bedded limestone (bed 34, 1.5 m thick). The latter contains gigantoproductids at the base and is dominated by *in situ* upright coralla of *Siphonodendron junceum* 1 m above the base. This biostrome has a very low diversity, and data for C2 biostrome is not included in Table 1. At the top of this bed most of the coralla are overturned. The overlying nodular limestone (bed 35) is capped by an irregular surface that represents the top of unit 3. This horizon can be recognised in Bannagogle Quarry (top of bed 3) and Paulstown Quarry (top of bed 12) above a similar biostromal development (Fig. 3). The unit 3/unit 4 boundary also marks a significant change in microfacies (CÓZAR & SOMERVILLE, 2005).

### 4.4. Dunamase Quarry

A coral-rich biostrome (D1) approximately 1.5 m thick, comprising 5 limestone beds, each bed on average 30 cm thick, separated by thin shale seams occurs at the base of Dunamase Quarry, at the top of unit 3 of the Clogrenan Formation (Fig. 3). The limestones are mostly fine-grained dark grey to black wackestones with abundant solitary and colonial corals. A total of 77 coral specimens were collected from this biostrome (74 rugose, and 3 tabulate coralla). Colonial corals are more abundant (44 specimens) compared to solitary corals (30 specimens). Fasciculate coralla (31 specimens) are more than twice as abundant as massive forms (13 specimens), although some of the cerioid forms have a sub-cerioid habit (e.g. *Actinocyathus floriformis*). The majority of the fasciculate coralla are in growth position.

The composition of the coral assemblage comprises 11 genera and 14 species (table 1), which include: *Actinocyathus floriformis* (4), *Aulophyllum fungites* (3), *Axophyllum vaughani* (3), *Caninophyllum archiaci* (MILNE-EDWARDS & HAIME) (3), *Dibunophyllum bipartitum* (7), *Diphyphyllum furcatum* (4), *Lithostrotion decipiens* (2) ), *L. vorticale* (2), *Lonsdaleia duplicata* (3), *Palastraea regia* (6), *Pseudozaphrentoides juddi* (14), *Siphonodendron intermedium* (7), *S. martini* (2), and *S. pauciradiale* (14). In addition 3 specimens of the tabulate coral *Syringopora* sp. and one specimen of the sponge *Chaetetes* sp. were recovered. It is clear from the above data, that the two dominant species are the fasciculate *S. pauciradiale* and the solitary rugosan *P. juddi*, which occur in equal numbers. Another conspicuous element in the biota is the large-shelled *Gigantoproductus*, mostly concentrated in bands, with individual specimens concave-up and *in situ*.

## 5. DEPOSITIONAL SETTING AND PALAEOECOLOGY OF BIOSTROMES

### 5.1. Depositional environment of biostromes

The biostromes in unit 3 in the Carlow area are developed within a relatively shallow-water tidally-influenced limestone succession, as indicated by the high proportion of packstones and grainstones with little micrite and the presence of subaerial exposure features, such as palaeokarsts and bentonitic clays (see ESTEBAN & KLAPPA, 1983). The latter occur in the region within both units 2 and 3 (below the biostromes), in the late Asbian and early Brigantian, respectively (Cózar & Somerville, 2005). The absence of oolitic and cross-bedded grainstone and common wackestone lithofacies in strata containing the biostromes suggests a somewhat protected shallow-water lagoon behind a shoal. However, the absence of laminated micrites and fenestral fabrics in unit 3 implies open-marine connections, supported by the associated stenohaline fauna (crinoids, brachiopods). The presence of oncoids in beds from unit 3 are characteristic of a lagoonal setting (Wright, 1983), and the association of biostromes with common dasycladacean green algae (e.g. *Coelosporella*) demonstrates photic shallow-water conditions in a partially protected or semi-restricted lagoon. Moreover, the vertical constraints on colonial growth would appear to be related to upward construction of biostromes above fair-weather wave-base where tidal action brought about a change to a higher-energy turbulent depositional setting.

## 5.2. Palaeoecology

The biostromes are closely associated with laterally continuous commonly *in situ* bands of *Gigantoproductus* below, within and above *Siphonodendron* coralla. These intervals of brachiopod bands can be traced for tens of kilometres between sections and appear to maintain approximately their stratigraphic horizon (Fig. 3). However, the brachiopods are invariably not in growth position, and in some cases they form only shell concentrations. Nevertheless, they clearly represent the establishment of uniform stable conditions of sedimentation across the shelf with only gradual subsidence. These large thick-valved brachiopods commonly occur concave-up in growth position at the base of biostromes. However, they rarely acted as hard substrates for attachment by colonial corals. Their presence demonstrates that bottom current activity was mostly too weak to displace them. The widespread development of biostromes at the same stratigraphic level, especially the upper biostrome near the top of unit 3, in sections up to 50 km apart, demonstrates that the shallow-water shelf maintained favourable conditions for coralla to thrive in great profusion. These biostromes are dominated by large fasciculate corals with the two main species *Siphonodendron pauciradiale* and *Diphyphyllum furcatum*. Cerioid massive coralla (*Lithostrotion decipiens*, *Actinocyathus floriformis* and *Palastraea regia*) on the other hand are much smaller and comparatively rare. Many of the fasciculate coralla are *in situ* and upright, but pronounced lateral growth was an important factor in producing the tabular growth forms of the *Siphonodendron* coralla which could extend in either direction (see below).

### *5.2.1. Detailed analysis of the lower biostrome, Bannagogle Quarry*

In general, the lower biostrome (B1) in Bannagogle Quarry is dominated by *Siphonodendron* and *Diphyphyllum* coralla that were typically tabular or low bulbous in shape with pronounced peripheral growth strategies (cf. Scrutton, 1998). This biostrome with its primarily lateral growth component without a distinct vertical ecological zonation, resembles the 'coral carpets' described from biostromes in the Recent (Riegl & Piller, 1999) and Miocene (Riegl & Piller, 2000), and is typical of many of the biostromes in the Carlow area. Within this biostrome at least 3 and possibly 5 discrete levels of coral growth can be recognised separated by erosional or hiatus events (Fig. 4A). The common bowl-shape or conical base to coralla is an initial characteristic growth feature, typically 15–20 cm wide and 5–10 cm high. This was generally followed by pronounced laterally directed growth of corallites, which may coincide with a change in sedimentation rate (Fig. 4A). The predominance of coralla in growth position aided in the formation of bafflestones that can be referred to as an autobiostrome (KERSHAW, 1994) (whereby only 15% of the coralla are overturned), but internally within any one biostrome there are horizons of autoparabiostromes, with higher numbers of inverted coralla. The levels of coral growth termination where they all attain approximately the same height above the base, are separated by thin horizons containing inverted coralla and concentrations of shells with different orientations, many convex up and fragmented (coquinas). These are interpreted as storm-events. They are commonly marked at outcrop by thin shale seams and prominent stylolites directly overlain by overturned coralla (Figs. 4A, 5, lower left centre). These coralla retain their growth form and configuration even where they are inverted, indicating a lack of fragmentation and absence of long-distance transport. The thin shale seams within biostromes represent periodic influxes of terrigenous sediment that may have blanketed coralla causing cessation of growth. They also probably acted as the locus of diagenetic modification, causing stylolites to form as irregular sub-horizontal boundaries between limestone beds (Fig. 5). Thus, it is possible to recognise a rhythmic pattern: a *Siphonodendron* growth phase interrupted by periodic storm events, which in turn is followed by renewed growth.

Rare colonies were able to continue growth from the flat upper surface, but only from a relatively low number of sites and only forming small fans (Figs. 4A, 5). Rarely, a lateral expansion of renewed growth extended beyond the margin of the underlying colony. This may be a function of lack of accommodation favouring lateral growth rather than vertical growth. Renewed growth may indeed be possible following a period of subsidence and /or change in relative sea-level.

#### *5.2.2. Analysis of the upper biostrome, Paulstown Quarry*

The upper biostrome (P2) can be readily distinguished from the lower biostrome (P1) by the following features: (1) higher diversity (more genera and species), and more numerous closely spaced coralla with generally larger dimensions (Fig. 4C); (2) less abundant massive *Lithostrotion* coralla; and (3) coralla in the upper biostrome have a flattened tabular form (Figs. 4C, 4D), whereas those of the lower biostrome are more bulbous or hemispherical in shape. A pseudo-atoll growth structure can be recognised in coralla from the upper biostrome on extensive bedding planes in the quarry, with a central depressed area to a colony (marked by a dearth of corallites), beyond which there is pronounced radial and lateral growth away from the centre. Very shallow-water depths may be implied, constraining the upper vertical growth limit. Another interesting aspect to the coral growth is that no directional currents (waves or tides) are considered to have exerted a strong influence on growth, since, although certain coralla show pronounced lateral growth in one direction, other coralla on the same bedding plane show distinct radial growth patterns. Microfacies components in these beds are not oriented either. There is also evidence of competition for space between neighbouring coralla, with different species abutting and interfingering with one another (Fig. 4B).

## 6. COMPARISONS WITH OTHER UPPER VISEAN BIOSTROMES

### 6.1. Bricklieve Mountains, NW Ireland

Upper Visean limestones in the Bricklieve Mountains area of Co. Roscommon and Co. Sligo, NW Ireland host *Siphonodendron* biostromes (Caldwell & Charlesworth, 1962; Dixon, 1972; Aretz, 2002). The strata were originally defined as the Bricklieve Limestone 'Group' (Caldwell & Charlesworth, 1962) for exposures north of the Curlew Mountains, and the Cavetown Limestone 'Group', south of the Curlew Mountains, for exposures around Cavetown Lough (Caldwell, 1959). However, because of the close similarity of the lithofacies and the presence of laterally extensive *Siphonodendron* biostromes, both 'groups' are now combined and referred to as the Bricklieve Limestone Formation (MacDermot et al., 1996).

Caldwell & Charlesworth (1962) first noted the stratigraphic significance of the rugose coral biostromes, with a thick (30–50 m) lower biostromal unit dominated by *Siphonodendron pauciradiale* (their *pauciradiale* 'reef'), followed higher in the succession by *S. martini* biostrome (15–20 m thick), and several thin (1 metre thick) biostromal developments of *Siphonodendron junceum* (their *junceum* 'reefs') in the upper part of the formation. The biostromes from the different stratigraphic levels are characterised by their low diversity, with commonly only a single species forming the dominant component.

The *pauciradiale* biostrome of Caldwell & Charlesworth (1962) forms a laterally extensive structure between Kesh Corann and Cavetown (20 km apart) with only slight thinning of the unit. It was recognised by those authors that the term 'reef' may not be appropriate, as the corals probably did not form an effective wave-resistant structure and probably lacked depositional relief. The biostrome is dominated by *Siphonodendron pauciradiale* with occasional *S. martini* and rare cerioid rugose coral coralla (*Lithostrotion decipiens*) in the lower part. Locally, dense packing of *Siphonodendron* coralla occurs with stacking of one colony on top of another. However, many of the fasciculate coralla in the main biostromal development are not *in situ*, and many corallite fragments are found between coralla. A concentration of large solitary rugose corals (*Siphonophyllia samsonensis* = *S. benburbensis* of other authors) that show little evidence of rolling occurs at the base. The initial coralla were stunted compared with those in the main body of the biostrome and grew as squat shrub-like structures (Caldwell & Charlesworth, 1962). The coralla higher up in the biostrome were taller and of more open construction producing bush-like structures. The fringing corallites of coralla commonly are interlaced to form a dense network. The change in growth habit was suggested by Caldwell & Charlesworth (1962) to indicate a change in environment – possibly slight deepening of the waters reducing current and wave control. Gaps between corallites are occupied by bioclastic detritus (principally crinoids, with a low proportion of recognisable coral debris) and minor amounts of terrigenous mud. Much of this intercorallite sediment was probably of extrinsic origin.

Other organisms associated with the biostrome include sedentary and sessile benthos (fenestellid and trepostome bryozoans, spinose and pedunculate brachiopods, crinoids and solitary corals). Vagile inhabitants include trilobites, echinoids, foraminifera and gastropods (CALDWELL & CHARLESWORTH, 1962). Recent examination of thin-sections from this biostrome revealed sparse foraminifera, sponge spicules, aoujgaliids and *Saccamminopsis* sp. (CÓZAR and SOMERVILLE, unpublished data).

In a recent study of the *pauciradiale* biostrome, ARETZ (2002, personal communication) noted that there is a heterogenous patchwork of biostromal units with rapid vertical and lateral shifts in lithofacies. He also remarked that no cyclicity in the growth of the biostromes can be recognised. He interpreted the biostrome as lacking a persistent framework, except, perhaps locally, where colonies were concentrated and grew on each other. Also, no encrusters are recorded in the *pauciradiale* biostrome. ARETZ (2002) considered that the *pauciradiale* biostromes formed in low-energy environments just below wave-base. Periodic destruction of the coralla is due to their growth into higher hydrodynamic regimes or minor sea-level fluctuations. There is also a high proportion of micrite in the sections, especially between corallites.

CALDWELL (1959) recognised the same *pauciradiale* biostrome within his unit 2 (30 m thick), which is well exposed on the northeast side of Clogher Lough in the Cavetown area. This unit is represented by well-bedded, fine-grained crinoidal limestones with much tabular chert. This biostrome contains abundant silicified *in situ* coralla of *Siphonodendron pauciradiale* with rare *Lithostrotion decipiens* and *Solenodendron furcatum* coralla (CÓZAR et al., 2005). The overlying rocks of unit 3 (15 m thick) comprise thickly-bedded medium-coarse grained crinoidal packstone/grainstone containing *Lithostrotion vorticale* and *Syringopora* sp. with common chert nodules. A sample from these beds yielded a diverse late Asbian (Cf6γ Subzone) foraminiferal assemblage including: *Paraarchaediscus* at *angulatus* stage, *Nodosarchaediscus* sp., *Neoarchaediscus* sp. and *Saccamminopsis fusulinaeformis* (CÓZAR and SOMERVILLE, unpublished data).

### 6.2. *Siphonodendron* Limestone (SW Spain)

In the Sierra Morena area of southwest Spain rugose coral biostromes rich in *Siphonodendron* were described from Asbian shallow-water shelf sequences in the Los Santos de Maimona Basin (RODRÍGUEZ & FALCES, 1992; RODRÍGUEZ et al., 1994; RODRÍGUEZ, 1996). The coral biostromes vary in thickness from 20 m to 6 m, thinning from southeast to northwest across the basin and cover an area of at least 36 $km^2$. The thickest and best-exposed section is in the basal unit 1 – *Siphonodendron* Limestone at Los Santos Hill in the southeast, where the biostromes are interpreted to form true wave-resistant reef structures and are associated with *in situ* gigantoproductid brachiopods and solenoporacean algae (RODRÍGUEZ, 1996). Interestingly, recent studies on solenoporids by RIDING (2004) has suggested that some of them (e.g. *Solenopora*, *Parachaetetes* and *Pseudosolenopora*) are not calcified red algae, but have close affinity with chaetetids.

The following remarks can be made comparing the *Siphonodendron* biostromes from unit 3 in the Carlow area, SE Ireland with those of the *Siphonodendron* Limestone of SW Spain.

(1) Dimensions of *Siphonodendron* coralla in Carlow are similar in height but much wider than those in Spain. There is a well-defined upper limit of growth in coralla in both cases, typically at the same horizon within a biostrome. Moreover, coralla in both regions show the same pattern of renewed growth, focused in a few specific points on the flat-topped coralla.
(2) Individual coralla in Carlow biostromes tend to have a smaller, narrower base and then rapidly expand laterally forming tabular thickets; those in Spain can be more fan-shaped, although dense packing can still produce tabular thickets. Micro-atoll structures are recognised in both regions.
(3) There is a common association of *in situ* concave-up *Gigantoproductus,* generally at the base of biostromes in both regions. In some cases coralla are attached to *in-situ* brachiopod shells.
(4) A relatively high diversity of rugose coral taxa is present in the Carlow biostromes (generally 8–9 genera and 10–11 species, but rising to 11 genera and 14 species in Dunamase), similar to the Maimona biostromes (7 genera and 9 species). However, the diversity is closely related to the presence of solitary taxa, which can be locally high. Moreover, in the Carlow biostromes, the diversity of colonial corals (phaceloid and cerioid) involved in the actual bioconstructions is higher than in Spain, where more than 95% of the bioconstructions in Los Santos de Maimona involve only three species.
(5) The dominant fasciculate species in Carlow is *Siphonodendron pauciradiale*, whereas in Maimona it is the larger species *S. martini or S. irregulare*. Massive cerioid coralla (e.g. *Lithostrotion*) present in Carlow do not occur in Spanish biostromes.
(6) The biostromes differ slightly in age. In Carlow they are mostly early Brigantian, whereas in Maimona they are late Asbian (Rodríguez & Falces, 1992). This may explain the high diversity in the Brigantian biostromes in Carlow, as several coral taxa did not appear until the Brigantian (e.g. *Actinocyathus floriformis* and *Palastraea regia*).
(7) The biostromes in both regions contain an abundance of *in situ* fasciculate coralla alterrnating with intervals containing mostly overturned or fragmented coralla, interpreted as storm deposits.
(8) There are no solenoporids in the Carlow biostromes, whereas in Spain solenoporids can act as a local solid substrate for the siting of true coral frameworks.
(9) No red crusts on the top of coralla linked to subaerial exposure in Spanish biostromes are known from Carlow. Although palaeokarsts are present in the succession in Carlow they do not occur at the same stratigraphic horizons as the biostromes. However, cavities occur in some thin-sections above or in between the biostromes, which are related to palaeokarsts.
(10) Biostromes form discrete levels in both regions, separated by crinoidal grainstones and nodular bioturbated limestones (Carlow) or marls (Spain) with rare corals.

### 6.3. Royseaux (SE Belgium)

At Royseux, SE Belgium, two thin rugose coral biostromes have been reported from Upper Visean dark grey bioclastic limestones of the Anhée Formation (Aretz, 2001). The coral faunas in the Anhée Formation have been previously documented (Poty, 1981; Poty et al., 1988, 1991, 2001) and they represent the highest diversity for any Mississippian section in Belgium. They establish the age of the biostromes as latest Asbian (RC7β Coral Zone; Cf6γ foraminifera Subzone; see Conil et al., 1980, 1991). The biostromes have been described from two parallel trench sections c. 100 m apart and within Parasequence 2, a 5 m-thick stratigraphical interval, showing shallowing-upward cycles and palaeosols at the top of cycles (Aretz, 2001). The lower biostrome (42 cm thick) is dominated by *Siphonodendron junceum* with scattered *Lithostrotion maccoyanum*, and *S. pauciradiale* and *Syringopora* sp. in the upper part. The colony size and shape was very variable although they acted as bafflers. The upper biostrome (60–80 cm thick) is more complex, with a lower unit of *S. junceum* bafflestone overlain by a pebbly rudstone horizon, and an upper unit of *S. martini* bafflestone. The Belgian *Siphonodendron* biostromes have a similar shallow-water depositional setting to those in Carlow and contain similar taxa in the succession (including *Lithostrotion*, *Diphyphyllum* and *Dibunophyllum bipartitum*), although their faunas are not as diverse. In contrast, *S. pauciradiale* is only a minor component of the constructions in Belgium. There are similarities also in that the biostromes are developed above beds containing *Gigantoproductus*, chaetetids and heterocorals. Calcareous algae are also rare in the biostromes in both areas.

## 7. CONCLUSIONS

1. Rich rugose coral assemblages dominated by solitary forms are recorded from late Asbian limestones (upper part of the Ballyadams Formation). More diverse assemblages are recorded in the Brigantian Clogrenan Formation, with abundant fasciculate and cerioid taxa, as well as solitary corals.
2. *Siphonodendron* biostromes occur in well-bedded dark grey limestones of the Clogrenan Formation (Brigantian; late Visean age) in the Carlow area, southeast Ireland. Coral biostromes in the lower part of the formation (unit 3) can be correlated between quarries nearly 50 km apart, and independently correlated by the lateral persistence of faunal marker horizons (brachiopod bands) and palaeokarst surfaces.
3. The biostromes developed in a relatively shallow-water, tidally-influenced shelf environment in a succession marked by periodic subaerial exposure. Daycladacean green algae are locally abundant as well as oncoids, suggesting a partially-restricted and protected, relatively quiet water lagoon, but with open-marine access.
4. All of the biostromes are dominated by *Siphonodendron pauciradiale* coralla that are generally tabular with pronounced peripheral growth strategies. The dimensions of fasciculate coralla are typically 20–30 cm high and 70–90 cm in width, but some coralla reach 4.5 m across. The corallites in many coralla have the same upper growth level. The mostly *in situ* coralla form bafflestones that are regarded as autobiostromes, but periodic storm events formed autoparabiostromes when some of the coralla were overturned.
5. Associated taxa in the biostromes are rugosan *Diphyphyllum, Lonsdaleia* and the cerioid genera *Lithostrotion* and *Actinocyathus*, together with the tabulate *Syrin-*

*gopora* and sparse solitary taxa, but all form accessory roles in the constructions. The biostromes at Carlow are diverse with typically 8–10 genera and 10–12 species, but at Dunamase Quarry this rises to 11 genera and 14 species.

6. Gigantoproductid brachiopods are an important related element, commonly forming concentrations of *in situ* shells below, within or above the biostrome, but they rarely formed sites for attachment for the coralla.
7. The Carlow *Siphonodendron* biostromes are different from the *pauciradiale* biostromes in the Bricklieve Mountains, NW Ireland even though they contain the same dominant species. The Carlow biostromes have a much higher diversity (genera and species) and formed in a shallower setting. Also, they show less fragmentation of coralla and a higher proportion of *in situ* coralla than those biostromes in NW Ireland, where over 50% of the coralla are overturned and abraded, reflecting growth in a more open marine shelf, commonly affected by storms.
8. The Carlow *Siphonodendron* biostromes show many characteristics in common with the biostromes from the *Siphonodendron* Limestone in SW Spain, even though the dominant species there is the larger species, *S. martini*. Both regions have biostromes with relatively high diversity, generally influenced by the presence of sparse solitary corals. However, the Carlow biostromes have a higher diversty of colonial corals (fasciculate and cerioid) resulting from their slightly younger Brigantian age, at a time when many new colonial genera had appeared. Belgian *Siphonodendron* biostromes, although they are very thin and not laterally extensive, occur in a succession containing shallowing-upward cycles with palaeosols at the top of cycles, comparable to those at Carlow. They are dominated by *S. junceum* with *S. martini*, but *S. pauciradiale* has a less important role in the constructions. In common with the Carlow *Siphonodendron* biostromes, they are developed above beds with chaetetids and gigantoproductid brachiopods, although neither were involved in the biostromes.
9. An unusual aspect of the Carlow *Siphonodendron* biostromes is their great areal extent and uniformity of thickness and facies. This signifies prolonged stability on the shelf with a fine balance maintained between carbonate production and subsidence.

**Acknowledgements:** We would like to thank all the quarry managers in the Carlow area who granted us access to their working quarries and helped with the sampling. We are grateful for the helpful reviews of Gregg Webb and Xiangdong Wang. This contribution has been developed with the aid of the European Community funding a fellowship (for P. Cózar) of the Ministerio Español de Educación, Cultura y Deporte in Ireland.

## References

Aretz, M., 2001: The Upper Viséan coral horizons of Royseux. The development of an unusual facies in Belgian Early Carboniferous. – Bulletin of the Tohoku University Museum, **1**: 86–95, Sendai.

Aretz, M., 2002: Habitatanalyse und Riffbildungspotential kolonialer rugoser Korallen im Unterkarbon (Mississippium) von Westeuropa. – Kölner Forum für Geologie und Paläontologie, **10**: 1–155, Köln.

Caldwell, W.G.E., 1959: The Lower Carboniferous rocks of the Carrick on Shannon Syncline. – Quarterly Journal of the Geological Society of London, **115**: 163–187, London.

CALDWELL, W.G.E. & CHARLESWORTH, H.A.K., 1962: Viséan coral reefs in the Bricklieve Mountains of Ireland. – Proceedings of the Geologists' Association, **73**: 359–382, London

CONIL, R., GROESSENS, E. LALOUX, M., POTY, E. & TOURNEUR, F., 1991: Carboniferous guide foraminifera, corals and conodonts in the franco-belgian and campine basins: their potential for widespread correlation. – Courier Forschunginstitut Senckenberg, **130**: 15–30, Frankfurt.

CONIL, R., LONGERSTAEY, P.J. & RAMSBOTTOM, W.H.C., 1980: Matériaux pour l'étude micropaléontologique du Dinantien de Grande-Bretagne. – Mémoires de l'Institut de Géologie de l'Université de Louvain, **30**: 1–187.

CÓZAR, P. & SOMERVILLE, I.D., 2005: Stratigraphy of Upper Viséan rocks in the Carlow area, southeast Ireland. – Geological Journal, **40** (1): 35–64, Chichester.

CÓZAR, P., SOMERVILLE, I.D., ARETZ, M. & HERBIG, H.-G., 2005: Biostratigraphical dating of Upper Viséan limestones (NW Ireland) using foraminifera, calcareous algae and rugose corals. – Irish Journal of Earth Sciences, **23**: 1–21, Dublin.

DIXON, O.A., 1972: Lower Carboniferous rocks between the Curlew and Ox Mountains Northwestern Ireland. – Journal of the Geological Society of London, **128**: 71–101, London.

ESTEBAN, M. & KLAPPA, C., 1983: Subaerial exposure environment. – In: SCHOLLE, P.A., BEBOUT, D.G. & MOORE, C.H. (Eds.): Carbonate depositional environments. – American Association of Petroleum Geologists, Memoir, **33**: 2–54.

GALLAGHER, S.J. & SOMERVILLE, I.D., 1997: Late Dinantian (Lower Carboniferous) platform carbonate stratigraphy of the Buttevant area North Co. Cork, Ireland. – Geological Journal, **32**: 313–335, Chichester.

JONES, G.I. & SOMERVILLE, I.D., 1996: Irish Dinantian Biostratigraphy: practical application. – In: STROGEN, P., SOMERVILLE, I.D. & JONES, G.I. (Eds.): Recent Advances in Lower Carboniferous Geology. – Geological Society Special Publication, **107**: 371–385, London (Geological Society).

KERSHAW, S., 1994: Classification and geological significance of biostromes. – Facies, **31**: 81–92, Erlangen.

MCCONNELL, B. & PHILCOX, M.E., 1994: Geology of Kildare – Wicklow. A geological description to accompany the Bedrock Geology 1:100,000 Map Series, Sheet 16, Kildare – Wicklow, with contributions by SLEEMAN A.G., STANLEY, G., FLEGG, A.M., DALY, E.P. & WARREN, W.P. Edited by B. MCCONNELL., Geological Survey of Ireland, 57pp., Dublin.

MACDERMOT, C.V., LONG, C.B. & HARNEY, S.J., 1996: Geology of Sligo – Leitrim. A geological description of Sligo, Leitrim and adjoining parts of Cavan, Fermanagh, Mayo and Roscommon, to accompany bedrock geology 1:100,000 scale map series, Sheet 7, Sligo – Leitrim with contributions by CLARINGBOLD K., STANLEY G., DALY D. and MEEHAN, R., Geological Survey of Ireland, 100pp., Dublin.

MITCHELL, M., 1989: Biostratigraphy of Viséan (Dinantian) rugose coral faunas from Britain. – Proceedings of the Yorkshire Geological Society, **47**: 233–247, Leeds.

NUDDS, J.R., 1979: The Carboniferous coral *Orionastraea* in Ireland. – Journal of Earth Sciences, Royal Dublin Society, **2**: 65–70, Dublin.

POTY, E., 1981: Recherches sur les Tétracoralliaires et les Hétérocoralliaires du Viséen de la Belgique. – Mededelingen Rijks Geologische Dienst, **35** (1): 1–161, Netherlands.

POTY, E., CONIL, R., GROESSENS, E., LALOUX, M. & LAURENT, S., 1988: Royseux. – In: LALOUX, M., BOUCKAERT, J., CONIL, R., GROESSENS, E., LAURENT, S., OVERLAU, P., PIRLET, H., POTY, E., SCHILTZ, M. & VANDENBERGHE, N.: Pre-Congress excursion to the Carboniferous stratotypes in Belgium. – Bulletin de la Société géologique de Belgique, **95** (3): 243–247, Brussels.

POTY, E., HANCE, L., LEES, A. & HENNEBERT, M., 2001: Dinantian lithostratigraphic units (Belgium). – In: BULTYNCK & DEJONGHE (Eds.): Guide to a revised lithostratigraphic scale of Belgium. – Geologica Belgica **4**/1–23: 69–94, Brussels.

POTY, E., TOURNER, F. & JAVAUX, E., with collaboration of DREESEN, R., GROESSENS, E., HIBO, D., LAUWERS, A. & LEES, A., 1991: The uppermost Devonain and Lower Carboniferous coral faunas of Bel-

gium. – Guidebook to the 6th Symposium on fossil Cnidaria and Porifera, Münster: 1–98, Münster.
RIDING, R., 2004: *Solenopora* is a chaetetid sponge, not an alga. – Palaeontology, **47** (1): 117–222.
RIEGL, B. & PILLER, W.E., 1999: Frameworks revisited: Reefs and coral carpets in the northern Red Sea. – Coral Reefs, **18**: 305–316.
RIEGL, B. & PILLER, W.E., 2000: Biostromal coral facies – A miocene example from the Leitha Limestone (Austria) and its actualistic interpretation. – Palaios, **15**: 399–413, Boulder.
RODRÍGUEZ, S., 1996: Development of coral reef-facies during the Viséan at Los Santos de Maimona, SW Spain. – In: STROGEN, P., SOMERVILLE, I.D. & JONES, G.I. (Eds.): Recent Advances in Lower Carboniferous Geology. – Geological Society Special Publication, **107**: 145–152, London (Geological Society).
RODRÍGUEZ, S. & FALCES, S., 1992: Corales Rugosos. – In: RODRÍGUEZ, S. (Ed): Análisis Paleontológico y Sedimentológico de la Cuenca Carbonifera de Los Santos de Maimona (Badajoz, SW Spain). – Coloquios de Paleontologia, **44**: 159–218, Madrid.
RODRÍGUEZ, S. & SOMERVILLE, I.D., 2007: Comparisons of rugose corals from the Upper Viséan of SW Spain and Ireland: implications for improved resolution in late Mississippian coral biostratigraphy (this volume).
RODRÍGUEZ, S., ARRIBAS, M.E., FALCES, S., MORENO-EIRIS, E. & DE LA PEÑA, J., 1994: The *Siphonodendron* Limestone of Los Santos de Maimona, SW Spain: development of an extensive reef-flat during the Viséan in Ossena-Morena, SW Spain. – Courier Forschunginstitut Senckenberg, **172**: 203–214, Frankfurt.
SCRUTTON, C.T., 1998: The Palaeozoic corals. II: structure, variation and palaeoecology. – Proceedings of the Yorkshire geological Society, **52**: 1–57, Leeds.
SOMERVILLE, I.D., 1997: Rugosa coral faunas from Upper Viséan (Asbian-Brigantian) buildups and adjacent platform limestones, Kingscourt, Ireland. – Boletin Real Sociedad Española de Historia Natural, (Sec. Geologie), **92**(1–4): 35–47, Madrid.
SOMERVILLE, I.D., STROGEN, P. & JONES, G.I., 1992: Biostratigraphy of Dinantian limestones and associated volcanic rocks in the Limerick Syncline, Ireland. – Geological Journal, **27**: 201–220, Chichester.
SOMERVILLE, I.D., JONES, G.I. & PHILCOX, M.E., 1996a: Supra-Waulsortian workshop. – Irish Association for Economic Geology, 1–78, Dublin.
SOMERVILLE, I.D., STROGEN, P., JONES, G.I. & SOMERVILLE, H.E.A., 1996b: Late Viséan buildups of the Kingscourt Outlier, Ireland: Possible precursors for Upper Carboniferous bioherms. – In: STROGEN, P., SOMERVILLE, I.D. & JONES, G.I. (Eds.): Recent Advances in Lower Carboniferous Geology. – Geological Society Special Publication, **107**: 127–144, London (Geological Society).
STROGEN, P., SOMERVILLE, I.D., JONES, G.I. & PICKARD, N.A.H., 1995: The Lower Carboniferous (Dinantian) stratigraphy and structure of the Kingscourt Outlier, Ireland. – Geological Journal, **30**: 1–23, Chichester.
TIETZSCH-TYLER, D. & SLEEMAN, A.G., 1994: Geology of Carlow – Wexford. A geological description to accompany the Bedrock Geology 1:100.000 Scale Map Series, Sheet 19, Carlow – Wexford, with contributions from MCCONNELL, B.J., DALY, E.P., FLEGG, A.M., O'CONNOR, P.J., PHILCOX, M.E. & WARREN, W.P., Edited by B. MCCONNELL, Geological Survey of Ireland, 56pp., Dublin.
WRIGHT, V.P., 1983: Morphogenesis of oncoids in the Lower Carboniferous Llanelly Formation of South Wales. – In: PERYT, T. M. (Ed.): Coated grains, 424–434, Berlin, Springer-Verlag.