Rugose coral associations from the late Visean (Carboniferous) of Ireland, Britain and SW Spain

Ian D. SOMERVILLE[1], Sergio RODRÍGUEZ[2]

SOMERVILLE, I.D. & RODRÍGUEZ, S., 2007: Rugose coral associations from the late Visean (Carboniferous) of Ireland, Britain and SW Spain. – 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: 329–351, 1 Tab., 3 Figs., Wien.

Abstract: Eight Upper Visean rugose coral associations (RCA 1–8) have been identified, involving 37 genera and 55 species /species groups, from Ireland, Britain and SW Spain. Three of the associations: *Aulophyllum-Dibunophyllum* (RCA 1), *Siphonodendron-Diphyphyllum-Actinocyathus* (RCA 4) and *Koninckophyllum-Siphonodendron-Siphonophyllia* (RCA 6) occur mostly in the Brigantian, and four: *Palaeosmilia-Axophyllum-Clisiophyllum* (RCA 2), *Siphonodendron-Solenodendron* (RCA 3), *Dibunophyllum-Axophyllum-Siphonodendron* (RCA 5) and *Lithostrotion-Siphonodendron* (RCA 7) are typical of the Asbian. RCA 8 (*Cyathaxonia-Rylstonia-Rotiphyllum*) is not biostratigraphically important, as it contains long-ranging genera.

Three associations (RCA 1, 7, 8) have generally low diversity (2–3 genera); four (RCA 2, 3, 5 & 6) moderate diversity (4–5 genera); and only RCA 4 (particularly RCA 4B) has high diversity (6–11 genera). Four associations are dominated by colonial corals (RCA 3, 4, 6 & 7); RCA 7 has abundant cerioid *Lithostrotion*, the others are dominated by fasciculate *Siphonodendron*; RCA 3 and RCA 4 often form biostromes. Six of the associations are characteristic of shallow-water shelf environments (RCA 1, 2, 4, 5, 6 & 7), with RCA 7 characterised by an *in situ* wave-resistant coral framework (bioherm). RCA 3 is a deeper water shelf assemblage and RCA 8 is a mainly deeper slope/ramp association of solitary rugosans in a basinal setting, but also occurs rarely in shallow-water lagoons.

Key words: Rugosa, Upper Visean, Mississippian, coral associations, Ireland, Britain, Spain

Contents

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

[2] Universidad Complutense de Madrid, Facultad de Ciencias Geológicas e Instituto de Geología Económica, Departamento y U.E.I. de Paleontología, Ciudad Universitaria s/n c/José Antonio Novais 2, 28040 Madrid, Spain, e-mail: sergrodr@geo.ucm.es

1. INTRODUCTION AND BACKGROUND

In the Early Carboniferous (Mississippian) much of western Europe (Palaeotethys) lay in the equatorial or southern tropical belts, where extensive shallow seas were the locus of significant carbonate deposition (Rowley et al., 1985; Scotese & McKerrow, 1990; Scotese, 2001). This period of time coincides with episodes of transgressions, where flooding of continental areas created widespread shallow-water carbonate shelves. In Late Visean times (Asbian-Brigantian stages) many basins in Europe and North Africa accumulated substantial thicknesses of limestones in which rugose corals are locally abundant. It has long been recognised that many Upper Visean sections show cyclicity which is linked to global relative changes in sea-level (glacio-eustatic), and more localised sedimentological and structural influences (see Walkden, 1987; Veevers & Powell, 1987; Gallagher & Somerville, 1997, 2003; Smith & Read, 2000; Wright & Vanstone, 2001). This cyclicity involves repeated changes in lithofacies, either within carbonate-dominated shoaling-upward cycles, or in cyclothems with alternation of carbonates and siliciclastic rocks. This cyclicity is related to changes in water depth which is reflected in compositional variations in the fossil communities. Bottom-attached benthic fossils (dominantly corals and brachiopods), as well as microscopic organisms (such as foraminifera and calcareous algae) were especially affected by these changes (see SOMERVILLE, 1979a, 1979b; GALLAGHER, 1996, 1998; HORBURY & ADAMS, 1996; JOHNSON & NUDDS, 1996; GALLAGHER & SOMERVILLE, 1997, 2003; CÓZAR & SOMERVILLE, 2005).

RAMSBOTTOM (1973) first proposed a schematic model for Early Carboniferous rocks in Britain to show the relationships between lithological and faunal changes to fluctuating depth of water associated with transgressions and regressions. He recognised 5 major carbonate lithofacies types which accumulated in shelfal areas. Four of these five shelfal lithofacies types contain rugose corals, with only the shallowest water lagoonal phase being devoid of rugosans. These lithofacies were further elaborated (RAMSBOTTOM in MCKERROW, 1978) and twelve faunal communities were recognised in shelfal areas and mud-mounds, with at least 7 communities containing rugose corals. The pioneering palaeoecological work on Upper Visean-Namurian (late Mississippian) rugose corals was that of HILL (1938–1941) who recognised three main ecological associations (phase faunas): (i) *Cyathaxonia* fauna (which includes small, solitary, mostly non-dissepimented rugosans); (ii) Caniniid-Clisiophyllid fauna (large dissepimented solitary rugosans); and (iii) 'reef-coral' fauna (colonial rugosans), occurring in different lithofacies in Britain and Ireland. A similar type of study was carried out by VUILLEMIN (1990) on Tournaisian and Low-mid Visean rugose corals from Armorica, in which four main associations were recognised. In the Mississippian of the western United States, SANDO (1980) identified rugose and tabulate coral faunas from 6 lithofacies, comprising 2 deep-water and 4 shallow-water facies. This study recorded the distribution of 37 rugose genera (25 solitary and 12 colonial taxa) that corresponds exactly to the total number of genera identified in this study, and with a very similar ratio of solitary to colonial genera – see below. However, only 12 of the genera in SANDO's work are recognised in the late Visean of western Europe.

2. MATERIALS AND METHODS

This paper is concerned with identifying rugose coral associations in assemblages recorded from Upper Visean shelves and shelf margins in western Europe (principally from Ireland, Britain and SW Spain, but also from Belgium, France, and in some cases from Morocco, North Africa). The study focused mainly on the distribution of dissepimented and non-dissepimented rugosans, but tabulate corals were also recorded. The rugose coral associations (RCA) distinguished (Table 1) are characterised according to: (i) composition of the taxa (both dominant and accessory); (ii) preservation and orientation (upright *in situ*, overturned, or transported); (iii) macrofacies (determined at outcrop-involving bed thickness, grain size, colour, shale content, presence of sedimentary structures and textures); (iv) microfacies (limestones classified in thin-section by texture); and (v) components identified in thin-section and their relative abundance (semi-quantitative). The horizon (formation), age and location of representative sections are recorded. The interpretation of the depositional setting for each rugose coral association is followed by remarks on the distinctiveness of each association and its relationship to the host lithofacies.

The database comprises sections in Ireland, Britain and SW Spain where the authors have undertaken detailed sampling of Upper Visean coral assemblages over the last two

Rugose Coral Association (RCA)	**Taxonomic diversity (common genera)**	**Abundance (no. of specimens)**	**Main growth form**	**Colonial coral type**	**Transport index**	**Bioherms/ biostromes**
1. ***Aulophyllum-Dibunophyllum***	Low (2–3)	Moderate	Solitary corals dominant	Fasciculates rare	Low	None
2. ***Palaeosmilia-Axophyllum-Clisiophyllum***	Moderate (3–5)	Moderate	Solitary corals dominant	Fasciculates minor component	Moderate–high	None
3. ***Siphonodendron-Solenodendron***	Low–Moderate (2–4)	Moderate (locally high)	Colonial corals dominant (Locally abundant solitary)	Fasciculates dominant; Cerioids rare	High	Biostromes & thickets
4. ***Siphonodendron-Diphyphyllum-Actinocyathus***	High (6–11)	High	Colonial corals dominant	Fasciculate >Cerioids (high no. cerioid genera)	Very low	Biostromes (mostly in situ) (bafflestone)
5. ***Dibunophyllum-Axophyllum-Siphonodendron***	Moderate (4–5)	Moderate	Solitary corals dominant	Fasciculate > Cerioids	Moderate–high	None
6. ***Koninckophyllum-Siphonodendron-Siphonophyllia***	Low–high (locally) (2–6)	Low–Moderate	Colonial corals dominant (rare)	Fasciculate > Cerioids	Very low	Bioherms (buildups)
7. ***Lithostrotion-Siphonodendron***	Low (2–3)	High	Colonial corals dominant	Cerioids > Fasciculate	Very low	Bioherms (coral reef) (framestone)
8. ***Cyathaxonia-Rylstonia-Rotiphyllum***	Low–Moderate (3–4)	Low–Moderate	Solitary corals only	None	Low	None

Tab.1: Summary of main characteristics of Late Visean rugose coral associations.

Rugose Coral Association (RCA)	Associated algae	Other biota	Energy index	Limestone microfacies	Depositional setting	Age
1. ***Aulophyllum-Dibunophyllum***	Green & red algae (rare) oncoids	Crinoids Bryozoans Brachiopods Heterocorals	Low (mostly)	Wackestone Packstone some Grain-stone	Moderately shallow-water shelf	Brigantian (rarely late Asbian)
2. ***Palaeosmilia-Axophyllum-Clisiophyllum***	Green & red algae (abundant)	Crinoids Brachiopods Foraminifera Heterocorals	Moderate–high (ooids)	Wackestone Packstone Grainstone	Very shal-low-water shelf (well lit)	Late Asbian (Brigantian -rarely)
3. ***Siphonodendron-Solenodendron***	Green & red algae (rare)	Crinoids Bryozoans Brachiopods Heterocorals Sponges	Low (occas. High) - (storm-related)	Wackestone Packstone Grainstone (intraclastic, graded)	Deep-water shelf	Asbian
4. ***Siphonodendron-Diphyphyllum-Actinocyathus***	Green & red algae (rare)	Crinoids Bryozoans Brachiopods (giganto-prod.) Heterocorals Chaetetids	Low–moderate	Wackestone Packstone Some Grain-stone (bafflestone)	Shallow-water shelf	Brigantian (type 4B) late Asbian (type 4A)
5. ***Dibunophyllum-Axophyllum-Siphonodendron***	Green algae (rare) & red algae	Crinoids Brachiopods Foraminifera Heterocorals Sponges	Low	Wackestone Packstone	Moderately shallow-water shelf	Late Asbian (Brigantian)
6. ***Koninckophyllum-Siphonodendron-Siphonophyllia***	Green algae (phylloids)	Crinoids Bryozoans Brachiopods Foraminifera Sponges	Low	Lime-mud-stone, Wackestone boundstone	Deep water Outer shelf mud-mound lagoons (rare)	Asbian-Brigantian
7. ***Lithostrotion-Siphonodendron***	Green & red algae (rare)	Brachiopods Chaetetids	Moderate–high	Coral Boundstone (framestone)	Shallow-water shelf (oolitic shoal)	Asbian
8. ***Cyathaxonia-Rylstonia-Rotiphyllum***	Red algae (rare)	Crinoids Bryozoans Brachiopods Foraminifera Sponges	Very low	Wackestone Packstone	Moderately deep-water upper slope/ ramp (rare lagoons)	Asbian-Brigantian Late Visean

decades (Ireland: see Somerville et al., 1992, 1996, 2001; Somerville, 1997, 2003; Gallagher & Somerville, 1997; Cózar & Somerville, 2005; Cózar et al., 2005b; Rodríguez & Somerville, 2007; Britain: Somerville, 1979a, b; Somerville & Strank, 1984; Nudds & Somerville, 1987; SW Spain: Rodríguez et al., 1992, 2001a, b, 2002, 2003; Rodríguez & Falces, 1992, 1996; Rodríguez & Rodríguez-Curt, 2002; Rodríguez & Somerville, 2007). Also, the comprehensive work of Mitchell (1989) documenting Visean coral faunas from outcrops and boreholes in England and Wales and published in many memoirs for the British Geological Survey has been an important source of information. In addition, many published studies on Visean rugose coral faunas in western Europe have been utilised (e.g. Hill, 1938–41, 1973; Fedorowski, 1981; Poty, 1981; Poty et al., 1991; Poty & Hannay, 1994).

3. RUGOSE CORAL ASSOCIATIONS

The results of a detailed comparability analysis of rugose coral assemblages collected by the authors from Upper Visean strata in Ireland, Britain and Spain, together with incorporated data obtained from a survey of all the published literature by other workers over the last century, has enabled eight rugose coral associations (RCA 1–8) to be distinguished (Table 1). A total of 37 genera and 55 species (or species groups) were identified in this study. Eight genera are represented by more than one species: *Siphonodendron* (9), *Lithostrotion* (4), and *Axophyllum*, *Clisiophyllum*, *Cyathaxonia*, *Diphyphyllum*, *Orionastraea*, *Siphonophyllia*, *Solenodendron* (all with 2 species/species groups). The generic composition includes 26 solitary and 11 colonial taxa. In the latter group, 7 are fasciculate and 4 massive (mainly cerioid) genera. It is also important to note the stratigraphic range of these rugose coral taxa, with some 22 genera and 25 species common to both stages. However, 2 genera and 6 species are mostly restricted to the Asbian, whereas 10 genera and 14 species first appear in the Brigantian.

3.1. *Aulophyllum-Dibunophyllum* association (RCA 1)

Dominant Taxa: *Aulophyllum fungites*, *Dibunophyllum bipartitum*, *Koninckophyllum magnificum* group, *Siphonodendron junceum/pauciradiale/ intermedium*.
Accessory Taxa: *Auloclisia* sp., *Axoclisia* sp., *Siphonophyllia samsonensis*, *Pseudozaphrentoides juddi*, *Diphyphyllum lateseptatum*, *Actinocyathus floriformis*, *Caninia cornucopiae*, *Amplexizaphrentis* sp., *Clisiophyllum keyserlingi* group (rare), *Palastraea regia* (rare).
Macrofacies: Thin-bedded, fine-grained dark grey bioturbated limestones alternating with thin shales (marls). Trace fossils include *Zoophycos* and *Thalassinoides*.
Microfacies: Skeletal wackestones/packstones, rare grainstones.
Components: crinoids, bryozoans (fenestellids and trepostomes), large gigantoproductoid brachiopods, gastropods, locally common *Hexaphyllia*; ostracods, oncoids, sparse foraminifers (including encrusting *Pseudolituotuba*), *Girvanella*, encrusting microproblematicum *Aphralysia*, stacheiinids, dasycladacean and codiacean green algae.
Preservation: Corallites of colonial corals often fragmented and abraded; large solitary corals usually well-preserved, often entire and little rolled, but the dissepimentarium may

be abraded. Calices are often present especially in argillaceous limestones and scolecoid aulophyllids are common in this facies.

Horizons: **SW Spain**: Units 8-10, La Cantera section, (Rodríguez et al., 2001a, b); El Castillo, Sierra Morena, (Rodríguez et al., 2001a, b); **N. Ireland**: Rockfield Limestone Formation (upper part), Cookstown North Quarry, Co. Tyrone, N. Ireland (Somerville, 1999); Carganamuck Limestone Formation (lower part), Carganamuck Quarry, Co. Armagh, (Somerville et al., 2001; Cózar et al., 2005a); **Britain**: Four Fathom Limestone, Alston Block, northern England, UK (Johnson & Nudds, 1996); Petershill Formation, Bathgate Hills, Scotland, (Jameson, 1987).

Age: Late Asbian – Brigantian (mostly).

3.1.1. Depositional setting

A low-energy quiet water environment, moderately shallow-water shelf, below normal wave-base but above storm wave-base (Figs. 1, 3). Presence of green algae may indicate euphotic light conditions. Abundant well-preserved trace fossils suggests active infauna and mixing of slightly argillaceous carbonate sediment. Presence of oncoids and algal-coated grains indicates periodic agitation and rolling. Large *Gigantoproductus* and spinose productids are frequently *in situ* in concave-up position of growth.

3.1.2. Remarks

RCA 1 contains a relatively restricted suite of rugosans dominated by large solitary corals characterised by complex axial structures, and fasciculate colonies of small diameter, especially *Siphonodendron junceum*. Probably a low diversity community with little evidence of transport. A characteristic feature of RCA 1 is the strong bioturbation in the enclosing lithofacies, which formed in a quiet-water, low- energy lagoonal facies. Jameson (1987) noted that many of the aulophyllids in the lower Reservoir Member of the Petershill Formation show current orientation, but that these currents, although strong, were not strong enough as to dislodge, transport or bury them. RCA 1 is commmonly encountered in the Brigantian.

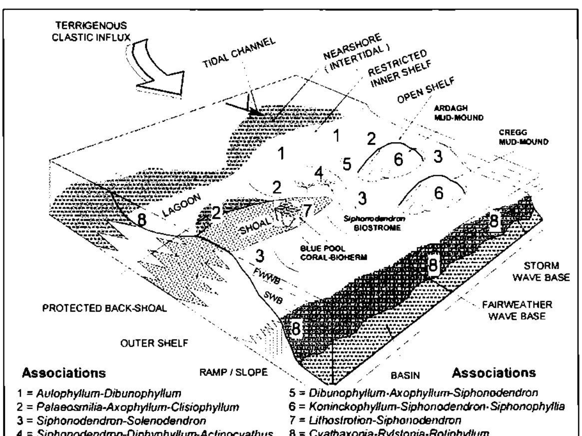

Fig. 1:
Schematic 3-D reconstruction of the distribution of rugose coral associations from nearshore to basin margin environments during Late Visean times.

3.2. *Palaeosmilia-Axophyllum-Clisiophyllum* association (RCA 2)

Dominant Taxa: *Palaeosmilia murchisoni, Axophyllum vaughani* group, *Clisiophyllum garwoodi* group, *Siphonodendron intermedium/martini/sociale.*
Accessory Taxa: *Haplolasma* cf. *densum* group, *Siphonophyllia siblyi, S. samsonensis, Dibunophyllum bipartitum.*
Macrofacies: Thick-bedded to massive, fine- to coarse-grained pale grey limestones, often bioturbated or burrow mottled.
Microfacies: Skeletal wackestones/packstones/grainstones.
Components: crinoids, brachiopods, foraminifers, heterocorals, locally abundant dasyclads (*Koninckopora*), stacheiinids (*Ungdarella* and *Aoujgalia*) and palaeoberesellids (*Kamaena/Kamaenella*); micritised bioclasts, coated grains, ooids and peloids.
Preservation: Corallites of colonial corals often fragmented and abraded, colonies often overturned; solitary corals often with poorly-preserved dissepimentarium.
Horizons: **SW Spain**: Units 1–4, 6, 13–15 La Cantera (RODRÍGUEZ et al., 2001a, b); Units 4–6 El Collado, El Castillo, Sierra Morena (RODRÍGUEZ et al., 2001a, b); Unit 1A at Los Santos de Maimona (RODRÍGUEZ & FALCES, 1992; RODRÍGUEZ et al., 1992); **Ireland**: Units 1–2, Ballyadams Formation, Ballyadams Quarry Co. Laois, and Clogrenan Quarry, Co. Carlow (CÓZAR & SOMERVILLE, 2005); Ballyclogh Limestone Formation (Dromdowney Member), north Co. Cork (GALLAGHER & SOMERVILLE, 1997); Dromkeen Limestone Formation, Co. Limerick (SOMERVILLE et al., 1992); Mullaghfin Formation, Kingscourt, Co. Meath (STROGEN et al. 1995; SOMERVILLE, 1997); **Britain**: Bee Low Limestone Formation, Derbyshire (MITCHELL, 1971); Eglwyseg Limestone Formation, North Wales (SOMERVILLE, 1979b);

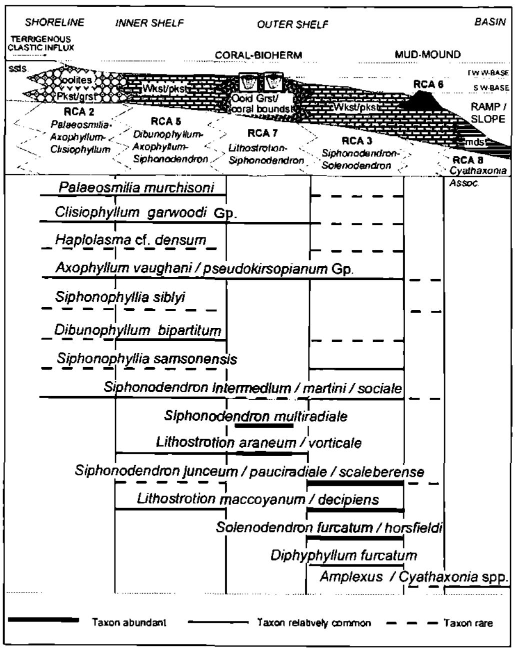

Fig. 2:
Schematic profile across the shelf during Asbian time: spatial distribution of rugose coral associations, and the range and relative abundance of selected coral taxa.

Urswick Limestone Fomation, South Cumbria (Mitchell in Rose & Dunham, 1977); Hotwells Limestone Formation, Bristol and Burrington Combe, Mendips (Mitchell in Green & Welch, 1965; Kellaway, 1967).
Age: Late Asbian.

3.2.1. Depositional setting

A moderate to high-energy turbulent well-lit very shallow-water shelf environment, above and below normal wave-base (Figs. 1, 2). Occasional evidence of subaerial exposure (palaeokarsts, alveolar textures, bentonitic clays) occur in the sampled sections. Corals in this association are found within massive pale grey algal-rich limestones in the upper part of shallowing-upward cycles (shoals), associated with abundant kamaenids, ungdarellid red algae, dasycladacean green algae, ooids and coated grains.

3.2.2. Remarks

RCA 2 is characterised by a moderately rich and diverse suite of solitary corals with fasciculate corals forming a less important component. Although *Siphonodendron* is present, it is not as abundant as in other associations, and comprises mostly large species of *Siphonodendron*. This is one of the most widespread and common associations in late Asbian shallow-water shelf limestones in Ireland, Britain and SW Spain and elements of this association dominate Coral Biozone Fauna G of Mitchell (1989) in Britain and in Ireland (Jones & Somerville, 1996). It approximately coincides with Hill's (1938–1941) 'Caniniid-Clisiophyllid' fauna. This association corresponds to the 'Oolitic Limestone

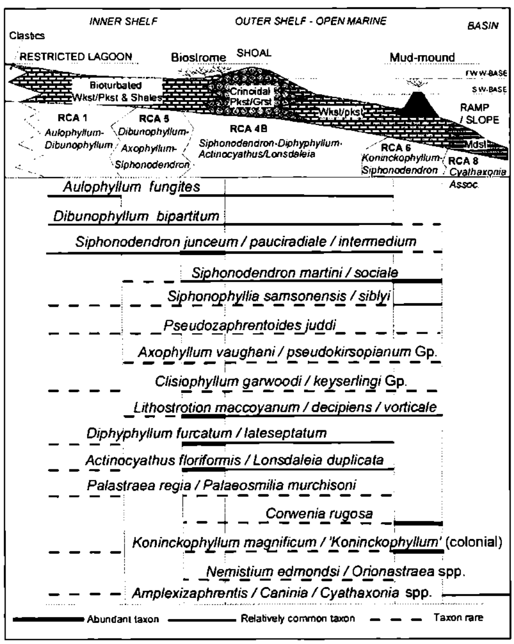

Fig. 3:
Schematic profile across the shelf during Brigantian time: spatial distribution of rugose coral associations, and the range and relative abundance of selected coral taxa.

community' of Ramsbottom (in McKerrow, 1978) characterised by large solitary corals, often abraded.

3.3. *Siphonodendron-Solenodendron* association (RCA 3)

Dominant Taxa: *Siphonodendron junceum/pauciradiale/irregulare/intermedium/martini/sociale/scaleberense, Solenodendron furcatum/horsfieldi, Siphonophyllia samsonensis.*
Accessory Taxa: *Lithostrotion maccoyanum/decipiens, Diphyphyllum furcatum, Koninckophyllum magnificum* group, *Dibunophyllum bipartitum, Axophyllum vaughani* group, *Clisiophyllum garwoodi* group, *Palaeosmilia murchisoni, Haplolasma* cf. *densum, Caninophyllum archiaci, Syringopora* sp., *Michelinia* sp.
Macrofacies: Well-bedded fine-grained dark grey limestones often rich in chert and with thin shale bands and seams. *Chondrites* trace fossils.
Microfacies: Skeletal wackestones/packstones; crinoidal/intraclastic grainstones, some recrystallised wackestones.
Components: crinoids, brachiopods, bryozoans, foraminifers, *Fasciella*, dasyclads (*Koninckopora/Palepimastopora*) and red algae, *Aphralysia*, chaetetids and sponge spicules, calcispheres, gastropods, heterocorals (*Hexaphyllia* sp. and *Heterophyllia* sp.), *Saccamminopsis*. Presence of common gigantoproductid brachiopods oriented with the concave side upwards.
Preservation: Corallites of colonial corals and solitary corals often well preserved but with silicified margins.
Horizons: **SW Spain**: Units 12–13, La Cantera, and Units 1–3 El Collado, El Castillo, Sierra Morena (Rodríguez et al., 2001a, b), and Peñas Rubias (Rodríguez et al., 2003); **Ireland**: Bricklieve and Glencar Limestone formations, Co. Roscommon & Co. Sligo (Oswald, 1955; Caldwell & Charlesworth, 1962; Hubbard, 1966, 1970; Dixon, 1970, 1972; Kelly, 1989; Aretz, 2002; Cózar et al., 2005b); Maydown Limestone Formation, Co. Armagh (Mitchell & Mitchell, 1983); Durnish Formation, Co. Limerick (Shepherd-Thorn, 1963; Sleeman & Pracht, 1999); Burren Formation (Fanore Member), Co. Clare (Gallagher, 1992); **Britain**: Loggerheads Limestone Formation, Mold, and Prestayn Limestone Formation, Rhyl, North Wales (Somerville, 1979a; Nudds & Somerville, 1987).
Age: Early to Late Asbian.

3.3.1. Depositional setting

A low-energy moderately deep-water shelf environment, below normal wave-base and above storm wave-base (Figs. 1, 2). Concentration of corals (especially large caniniids and heterocorals) and other bioclasts at the base of some beds implies possible storm influence.

3.3.2. Remarks

RCA 3 is characterised by rich and low-moderately diverse coral assemblages, with abundant fasciculate colonies, frequently overturned, and some large solitary caniniids (*Siphonophyllia samsonenis* Salée (1913) = *Caninia benburbensis* Lewis 1927 of earlier workers;

we follow the synonomy used in POTY, 1981). The latter occur occasionally upright and in growth position (cf. HUBBARD, 1970, Pl. 44, Fig. 1), surrounded by fasciculate *Siphonodendron* colonies that may afford protection. The largest fasciculate species *S. scaleberense* is often recorded in this association within dark grey cherty bioturbated limestones (NUDDS & SOMERVILLE, 1987; CÓZAR et al., 2005b). *Solenodendron* is variable in its distribution. A similar assemblage with *Siphonophyllia*, *Solenodendron* and heterocorals is reported from the Upper Tournaisian and Lower Viséan rocks of Armorica (VUILLEMIN, 1990) and High Tor Limestone (Arundian) from Gower Peninsula, South Wales (BEUS, 1984). Massive cerioid colonies represent a minor component of biostromes (cf. HUBBARD, 1966) and are usually represented by species of *Lithostrotion* with small diameter corallites. There can be, locally, extremely high concentrations of large, often geniculate, *Siphonophyllia* (11 adults/metre^2) on bedding planes (e.g. Streedagh Point and Serpent Rock, Co. Sligo, NW Ireland; HUBBARD, 1966, 1970; DIXON, 1970). It is considered that they accumulated during periods of low sedimentation, but have a random orientation and clearly have rolled and suffered disturbance in life due to winnowing and scouring. RCA 3 comprises relatively deep-water shelf communities, biostromes and coral thickets, but with localised storm reworking and transport. This association can be interbedded with strata containing RCA 2, and is common in the Asbian.

3.4. *Siphonodendron-Diphyphyllum-Actinocyathus* association (RCA 4)

Dominant Taxa: *Siphonodendron junceum/pauciradiale/irregulare/intermedium, Diphyphyllum furcatum, D. lateseptatum, Actinocyathus floriformis, Lonsdaleia duplicata, Lithostrotion maccoyanum/decipiens/vorticale.*
Accessory Taxa: *Pseudozaphrentoides juddi, Dibunophyllum bipartitum, Palastraea regia, Nemistium edmondsi, Corwenia rugosa, Orionastraea phillipsi/rete, Aulophyllum fungites, Koninckophyllum magnificum* group, *Palaeosmilia murchisoni, Axophyllum* sp., *Syringopora* sp.
Macrofacies: Well-bedded fine-grained dark grey bioclastic limestones.
Microfacies: Skeletal wackestones/packstones; some crinoidal grainstones.
Components: crinoids, gigantoproductoid brachiopods, bryozoans, heterocorals, sparse foraminifers, dasyclads and red algae, chaetetid sponges, *Saccamminopsis.*
Preservation: Corallites of colonial corals usually well-preserved, solitary corals often abraded.
Horizons: **SW Spain**: Unit 1 (*Siphonodendron* Limestone) and Unit 3, Los Santos de Maimona (RODRÍGUEZ & FALCES, 1992; RODRÍGUEZ et al., 1992); **Ireland**: Units 3–4 Clogrenan Formation, Co. Carlow and Co. Laois (SOMERVILLE et al., 2007; CÓZAR & SOMERVILLE, 2005); **Britain**: Petershill Formation (Upper Reservoir Member), Scotland (JAMESON, 1987); Upper Longcraig Limestone, Dunbar, Scotland (CRAIG & DUFF, 1975); Monsal Dale Limestone Formation, Derbyshire (MITCHELL, 1971); Cefn Mawr Limestone Formation and Trefor Limestone Formation, North Wales (SOMERVILLE, 1979a,b; SOMERVILLE & STRANK, 1984); Gleaston Formation, South Cumbria (MITCHELL in ROSE & DUNHAM, 1977); Jew Limestone, Alston Block, northern England (BURGESS & MITCHELL, 1976; MITCHELL in ARTHURTON & WADGE, 1981); Lower Hawes and Hardraw Scar Limestones, Askrigg Block, northern England (BURGESS & MITCHELL, 1976; ARTHURTON et al., 1988).
Age: Mostly Brigantian (rarely late Asbian).

3.4.1. Depositional setting

A moderate-energy shallow-water shelf environment, above and below normal wave-base (Figs. 1, 3). Periodic shoaling events culminate in subaerial exposure and development of palaeokarstic surfaces (cf. Somerville, 1979a, SOMERVILLE & STRANK, 1984; RODRÍGUEZ et al., 1992; CÓZAR & SOMERVILLE, 2005).

3.4.2. Remarks

RCA 4 has been subdivided into an older Asbian association (RCA 4A) and a younger Brigantian association (RCA 4B) (Table 1). The latter is common and contains abundant fasciculate and massive colonies mostly *in situ*, forming thickets and biostromes. Typically 60–80% of *Siphonodendron* colonies in biostromes of RCA 4B are in growth position (SOMERVILLE et al., 2007; CÓZAR & SOMERVILLE, 2005). Gigantoproductid brachiopod bands occur below, within and above the horizons of colonies. Chaetetid sponges are frequently associated with the colonial corals and may even encrust cerioid forms (JAMESON, 1987). RCA 4B is one of the richest and most diverse associations (typically 6–11 genera), and may contain all four massive (mostly cerioid) genera in the Upper Visean (*Lithostrotion*, *Actinocyathus*, *Palastraea*, and *Orionastraea*). It is also characterised by the presence of large solitary rugosans with wide dissepimentaria (e.g. koninckophyllids, dibunophyllids, pseudozaphrentoidiids and palaeosmiliids). This association corresponds to Coral Biozone Faunas H and I of MITCHELL (1989) in Britain and in Ireland (JONES & SOMERVILLE, 1996), and is common in the early Brigantian. MITCHELL (1971) records 29 species and 17 genera from the Monsal Dale Limestone Formation in Derbyshire, including several species of the rare genus *Orionastraea*. Similar rich and diverse associations of RCA 4B form discrete bands at the top of the Trefor Limestone Formation, Llangollen, North Wales (SOMERVILLE, 1979b), cycle 2 and top of cycle 7 in Cefn Mawr Limestone Formation, Mold, North Wales (SOMERVILLE, 1979a); Hardraw Scar Limestone, Askrigg Block (ARTHURTON et al., 1988). This rich coral assemblage is closely comparable to HILL's (1938–1941) 'coral-reef' fauna.

In the late Asbian *Siphonodendron* Limestone from unit 1 (Los Santos de Maimona, SW Spain) *in situ* colonies form a reef framework (RCA 4A; Rodríguez *et al.*, 1992). Gigantoproductid brachiopod bands within the horizons of colonies may act as a site for attachment (RODRÍGUEZ et al., 1992). This low–moderate diversity assemblage (RCA 4A) forming biostromes is probably a fore-runner to the more diverse assemblages (RCA 4B) in the Brigantian. This association corresponds closely to the 'Brachiopod calcarenite community' of RAMSBOTTOM (in MCKERROW, 1978).

A comparable association (RCA 4A) is recorded from the upper part of the Joinville Limestone in Boulonnais, N. France (POTY & HANNAY, 1994) which is also characterised by abundant *Gigantoproductus* brachiopods. Unlike the red bioclastic limestone host lithofacies in northern France, a similar rich and diverse assemblage (RCA 4A) is recorded at Royseux in Belgium, from stratigraphically equivalent dark grey well-bedded limestones of the Anheé Fornation (POTY, 1994; POTY et al., 1988, 2001). *Siphonodendron* biostromes have also been described recently from the upper part of this formation at Royseux, of latest Asbian age (ARETZ, 2001).

A very rich and diverse association of colonial and solitary rugose corals (RCA 4B) is recorded from the Brigantian Akerchi Formation at Akerchi and Idmarrach in Morocco

(SAID et al., 2007). Many of the coral colonies, particulary *Siphonodendron junceum* are attached to *in situ* gigantoproductid brachiopods.

3.5. *Dibunophyllum-Axophyllum-Siphonodendron* association (RCA 5)

Dominant Taxa: *Dibunophyllum bipartitum, Axophyllum pseudokirsopianum* group, *Siphonodendron junceum, pauciradiale/irregulare/intermedium/sociale, Lithostrotion decipiens/vorticale.*
Accessory Taxa: *Arachnolasma sinense, Clisiophyllum garwoodi, Pseudozaphrentoides juddi, Palaeosmilia murchisoni, Siphonophyllia samsonensis* and the tabulate *Syringopora.*
Macrofacies: Well-bedded fine- to coarse-grained dark grey bioclastic limestones.
Microfacies: Skeletal intraclastic wackestones/packstones; rare skeletal grainstones.
Components: crinoids, brachiopods, sparse foraminifers, rare dasyclads (*Koninckopora*), kamaenids and stacheiinids (*Aoujgalia*), micritised bioclasts, peloids, heterocorals (*Heterophyllia* sp.), *Girvanella*, microproblematicum *Fasciella*, calcispheres, turreted gastropods; ostracods, trilobites, bored bioclasts and sponge spicules.
Preservation: Corallites of colonial corals and solitary corals often well preserved.
Horizons: **SW Spain**: Unit 13, El Collado, El Castillo, Sierra Morena (RODRÍGUEZ et al., 2001a, b); **Ireland**: Unit 2, Ballyadams Formation, Ballyadams Quarry Co. Laois (CÓZAR & SOMERVILLE, 2005).
Age: Late Asbian – Brigantian.

3.5.1. Depositional setting

A low-energy moderately shallow-water shelf environment, below normal wave-base and above storm wave-base (Figs. 1, 2). These beds often form the lower deeper-water transgressive phase of shallowing-upward cycles, culminating in the shallow-water regressive phases dominated by RCA 2 that often alternate (see above).

3.5.2. Remarks

RCA 5 comprises locally abundant abraded large solitary corals, especially dibunophyllids. Axophyllids are characterised by having complex axial structures. Massive cerioid *Lithostrotion* colonies are comparatively rare, and fasciculate corals are not as common as in other associations. RCA 5 has moderate diversity and is typical of low-energy shallow-water shelves in the Asbian and Brigantian, but is not common.

3.6. *Koninckophyllum-Siphonodendron-Siphonophyllia* association (RCA 6)

Dominant Taxa: *Koninckophyllum magnificum* group, colonial *'Koninckophyllum'*, *Aulokoninckophyllum* sp., *Siphonodendron pauciradiale/intermedium/martini/sociale/ scaleberense, Siphonophyllia siblyi, Lithostrotion vorticale.*
Accessory Taxa: *Dibunophyllum bipartitum, Corwenia rugosa, Axophyllum vaughani, Amplexus coralloides* (rare), *Cyathaxonia cornu* (rare), *Amplexocarinia* (very rare) and the tabulate corals *Syringopora, Michelinia* and *Multithecopora.*

Macrofacies: Massive to well-bedded fine-grained pale grey limestones (microbial mud-mounds and bioherms).
Microfacies: Skeletal-peloidal wackestones/packstones; lime mudstones with cavities and fenestrae lined with fibrous calcite, microbial/cyanobacterial boundstones, often recrystallised.
Components: crinoids, brachiopods, bryozoans (fenestellids, trepostomes and encrusting forms), sparse foraminifers (encrusting *Pseudolituotuba* and *Tetrataxis*), dasyclads and red algae (in intermound facies), *Aphralysia, Girvanella*, phylloid algae (*Archaeolithophyllum*), sponge spicules.
Preservation: Corallites of colonial and solitary corals usually well preserved. Corallites encased in radiaxial fibrous calcite.
Horizons: **SW Spain**: Units 9–14, 18–24, Sierra Estrella (RODRÍGUEZ et al., 2001a,b); **Ireland**: Mud-mounds at Ardagh Quarry, Kingscourt, and Cregg, Co. Meath; Co. Sligo and west Co. Fermanagh (SOMERVILLE et al., 1996; SOMERVILLE, 1997, 2003); **Britain**: bryozoan buildup at Nant-y-Gamar Quarry, Llandudno, North Wales (BANCROFT et al., 1988), Stebden Hill, Craven reef belt, northern England (MUNDY, 1994).
Age: Asbian – Brigantian.

3.6.1. Depositional setting

A low-energy moderately deep-water outer shelf mud-mound environment (Figs. 1- 3), or relatively shallow-water bioherms and protected areas lateral to mounds (perimound facies), and often colonised by microbial communities. Intermound areas clearly built up into the photic zone with presence of *Koninckopora* and kamaenids.

3.6.2. Remarks

In RCA 6 corals are normally very rare in the core of most Asbian mud-mounds and buildups, with usually only non-dissepimented corals (*Amplexus and Amplexocarinia*) present (BANCROFT et al., 1988; COSSEY & MUNDY, 1990; MUNDY, 1994). This association corresponds to the 'Lower Reef Slope Mollusc community' of RAMSBOTTOM (in MCKERROW, 1978). Occasionally, dissepimented solitary rugosans (*Siphonophyllia siblyi* and *Axophyllum vaughani)* and colonies of *Siphonodendron pauciradiale* are present, as in the Asbian mud-mounds at Cregg, Co. Meath, and in NW Ireland (SOMERVILLE, 1997, 2003; figs, 1–2). Locally, large colonies of *Siphonodendron* are developed (mostly species with large-diameter corallites), especially near the top of mounds, as in the Brigantian mud-mound at Ardagh (SOMERVILLE et al., 1996; Figs, 1–3). Some taxa appear to show adaptation to this ecological niche (e.g. the colonial *'Koninckophyllum'* and *Cyathaxonia cornu*) that are either unknown or very rare in coeval bedded limestones. This association corresponds in part to the 'Algal Reef community' of RAMSBOTTOM (in MCKERROW, 1978; MUNDY, 1994), which represents the shallowest water deposits of 'reef' (mud-mound) communities, where *in situ* frameworks were subject to wave and current action at the outer margins of shelves.

In the Montagne Noire in southern France, ARETZ & HERBIG (2003a) record a shallow-water late Viséan mud-mound at Roc du Cayla that has locally rich horizons of *Amplexus*, and absence of *in situ* dasycladacean algae. In Morocco SAID et al. (2007) record a rich RCA 6 assemblage from the Brigantian member (TZ3) of the Tizra Formation. There, the fasciculate colonial corals occur at the top of large mud-mounds similar to those of the Ardagh mound in Ireland.

3.7. ***Lithostrotion-Siphonodendron*** **association (RCA 7)**

Dominant Taxa: *Lithostrotion vorticale, L. araneum, Siphonodendron multiradiale, S.* sp. nov.
Accessory Taxa: *Clisiophyllum garwoodi, Axophyllum pseudokirsopianum* group, *Amygdalophyllum* spp., *Syringopora.*
Macrofacies: Biohermal massive limestones.
Microfacies: Skeletal boundstones to rudstones.
Components: Encrusting *Girvanella, Renalcis, Aphralysia* and bryozoans; brachiopods, oncoids, chaetetids, crinoids, foraminifers. Some green and red algae also occur.
Preservation: Colonial corals well preserved, mostly in life-position; solitary corals entire and little rolled.
Horizons: **SW Spain**: Antolín, Guadiato area (Rodríguez & Rodríguez-Curt 2002); **Britain**: Hunts Bay Oolite Formation, Blue Pool, Gower, South Wales, (Ramsay, 1987; Nudds & Somerville, 1987; Aretz, 2002; Aretz & Herbig, 2003b).
Age: Asbian.

3.7.1. Depositional setting

One of the best examples of this association is in the Asbian Blue Pool bioherm within the Hunts Bay Oolite Formation, Gower Peninsula, South Wales. This patch reef (13 m high) occurs in a shallow-water moderate- to high-energy environment (Figs. 1, 2), comprising trough cross-bedded oolitic and bioclastic grainstones and packstones (Ramsay, 1987; Aretz & Herbig, 2003b). The bioherm contains an abundance of large cerioid *Lithostrotion* colonies in the core and a smaller number of fasciculate *Siphonodendron* colonies with accessory *Syringopora* in the outer core and flanks. Most of the colonies are preserved in growth position with dense packing, and corals growing upon each other (Aretz, 2002; Aretz & Herbig, 2003b). The species *Siphonodendron multiradiale* appears to be restricted to this biohermal facies (Nudds & Somerville, 1987) and has not been reported from adjacent bedded bioclastic shelf limestones.

3.7.2. Remarks

RCA 7 is dominated by large massive cerioid colonies of *Lithostrotion* growing in a turbulent setting.

The Asbian Blue Pool bioherm, that clearly forms a wave-resistant coral framework, represents a rare example of an ecological coral reef in the Mississippian (Aretz, 2002; Aretz & Herbig, 2003b). Comparable bioherms with frameworks provided by *Siphonodendron, Lithostrotion* and tabulate corals are known from the late Visean in Queensland, Australia (Webb, 1989). There, these rugosans make up 70% of the bioherm framework with a distinct ecological zonation, with *Siphonodendron* colonies more abundant in the lower part and *Lithostrotion* colonies in the upper part (cf. Blue Pool). At Antolín (Guadiato area, SW Spain) this association commonly is found in boulders that are found in breccias located in ramp facies (RODRÍGUEZ & RODRÍGUEZ-CURT, 2002). It is clear that the boulders were derived from an *in situ* shelf margin biohermal setting that is no longer preserved. RCA 7, characterised by the presence of large massive *Lithostrotion* colonies, has close affinity with the 'Coral calcarenite community' of RAMSBOTTOM (in MCKERROW, 1978).

3.8. *Cyathaxonia-Rylstonia-Rotiphyllum* association (RCA 8)

Dominant Taxa: *Cyathaxonia cornu, C. rushiana, Rylstonia benecompacta, Rotiphyllum rushianum, Ufimia bradbournense.*
Accessory Taxa: *Zaphrentoides* spp., *Zaphrentites* spp., *Fasciculophyllum* spp., *Amplexizaphrentis enniskilleni*, *Caninia* aff. *cornucopiae* (rare), *Michelinia* sp.
Macrofacies: Marls/shales alternating with thin-bedded dark grey-black argillaceous fine-grained bioclastic limestones, and laminated calcisiltstones.
Microfacies: Skeletal wackestones, some packstones.
Components: crinoids, bryozoans (fenestellids and trepostomes), brachiopods, tabulate corals, oncoids, sparse foraminifers, stacheiinids, trilobites, ostracods, goniatites.
Preservation: Solitary corals usually well preserved, but commonly broken apexes and/or crashed calices.
Horizons: **SW Spain**: Units 4–6 from Los Santos de Maimona (RODRÍGUEZ & FALCES, 1992; RODRÍGUEZ et al., 1992); Units 10–18 Sierra de la Estrella (RODRÍGUEZ et al., 2001a,b); **Ireland**: Upper Glencar Limestone Formation, west Co. Fermanagh (BRUNTON, 1987); Meenymore and Bellavally formations, Co. Sligo and Co. Leitrim (BRANDON & HODSON, 1984); 'Cyathaxonia Beds', Loughshinny, Co. Dublin (MATLEY & VAUGHAN, 1906, 1908; GEORGE et al., 1976); **Britain**: Pendleside Limestone, Clints Rock Quarry, Rylstone, Craven Basin, Yorkshire (HUDSON & FOX, 1943; HUDSON, 1944; ARTHURTON et al., 1988); Cawdor Limestone Formation, Cawdor Quarry, Matlock, Derbyshire (MITCHELL in SMITH et al. 1967, table 1); Oystermouth Beds, Gower, South Wales (DIXON & VAUGHAN, 1911; GEORGE et al., 1976).
Age: Asbian-Brigantian.

3.8.1. Depositional setting

A low-energy, moderately deep shelf/ramp slope, below normal wave-base, often in a basinal setting (Figs. 1–3). Absence of green algae may indicate dysphotic and or turbid conditions of sedimentation. Occasionally, the association is recorded in very shallow water nearshore, hypersaline lagoonal environments with much fine terrigenous input (Fig. 1).

3.8.2. Remarks

RCA 8 is dominated by small non-dissepimented solitary corals with low to moderate diversity. Similar associations are found from the Devonian to Permian (HILL, 1938–41,

-who referred to it as the *Cyathaxonia* fauna); VUILLEMIN, 1990; KULLMANN & RODRÍGUEZ, 1994; KULLMANN, 1997; SCRUTTON, 1998, -who also referred to it as the Laccophyllid fauna). Usually, these small solitary corals have been regarded as typical deep-water basin slope dwellers in an association that includes cephalopods, and corresponds to the 'Mud community' of RAMSBOTTOM (in MCKERROW, 1978). However, they are also present in quiet shallow turbid water with restricted circulation, where dissepimented corals can hardly survive, e.g. in the argillaceous Asbian Glencar Limestone Formation, Co. Fermanagh (BRUNTON, 1987). Unusual examples are provided by the Brigantian Meenymore and Bellavally formations, NW Ireland. There, small solitary corals of this association occur in a succession of laminated algal micrites showing stromatolites, shales, dolomites, and evaporites which formed in an nearshore hypersaline intertidal lagoonal setting (WEST et al., 1968; BRANDON, 1972, 1977; BRANDON & HODSON, 1984; Fig. 3, Tab. 1). Elements of this association, particularly *Cyathaxonia cornu*, can occur locally in Asbian mud-mounds in RCA 6 (Fig. 2; see above).

RCA 8 has also been recorded from an unusual pale grey limestone lithofacies at the top of the Joinville Limestone, Boulonnais, N. France, of Brigantian age (POTY & HANNAY, 1994). A comparable association is recorded from the late Tournaisian Black Rock Limestone, Burrington Combe, Mendips, SW England ('Middle Fauna' of MITCHELL, in GREEN & WELCH, 1965; RAMSBOTTOM & MITCHELL, 1980). However, this assemblage contains some solitary taxa with well-developed dissepimentaria, e.g. *Caninophyllum* and *Cyathoclisia*. In the western United States SANDO (1980) recognised a similar deep-water coral association containing 6 non-dissepimented solitary rugosan genera (including *Cyathaxonia*), the weakly dissepimented '*Caninia*' and tabulates.

4. CONCLUSIONS

Eight Upper Visean rugose coral associations (RCA 1–8) have been identified, based on an integrated analysis of the faunal composition (coral taxa present, abundance and diversity), preservation and orientation, and their relationship to the host or enclosing lithofacies. This involved identification of 37 genera and 55 species and species groups, principally from Ireland, Britain and SW Spain. The generic composition includes 26 solitary and 11 colonial forms; 7 of the latter group are fasciculate and 4 are massive, mostly cerioid colonies.

Three of the associations (RCA 1, 4, 6): are found mostly in rocks of Brigantian age, and four associations (RCA 2, 3, 5 and 7): are typical of the Asbian. However, RCA 8 is not biostratigraphically important, as it contains mostly long-ranging solitary genera, many of which are already known from the late Devonian and extend up to the Permian.

Three of the associations (RCA 1, 7, 8) have relatively low diversity (2–3 common genera), four associations (RCA 2, 3, 5 & 6) have moderate diversity (4–5 common genera), and only RCA 4 (particularly RCA 4B) has high diversity (6–11 common genera).

Four of the eight associations are dominated by colonial corals (RCA 3, 4, 6 & 7), but only RCA 7 has abundant cerioid *Lithostrotion*. The other associations are dominated by fasciculate genera, mostly *Siphonodendron*, but occasionally *Solenodendron* and *Diphyphyllum* can be locally abundant. RCA 3 and RCA 4 often form biostromal developments.

Six of the associations are characteristic of shallow-water shelf environments (RCA 1, 2, 4, 5, 6 & 7), as indicated by the host limestone textures, presence of dasycladacean algae, oncoids, ooids and palaeokarstic surfaces in the successions. RCA 7 however, is unusual, as it developed an *in situ* wave-resistant coral framework (bioherm) within a very shallow-water turbulent setting. RCA 3 on the other hand is a deeper-water shelf assemblage that was affected by periodic storms and bottom currents, as suggested by the abundance of overturned fasciculate colonies in some beds. RCA 6 is an outer shelf deep-water mud-mound assemblage, with coral taxa specially adapted to this niche. RCA 8 is a mainly deeper slope/ramp association of solitary rugosans in a basin margin setting. However, the same association can also be recorded rarely in nearshore shallow-water, protected depositional environments such as hypersaline lagoons with restricted circulation.

Acknowledgements: Research in Spain has been carried out with support of the Spanish DGICYT (projects BTE2000–1423 and BTE2003–02065). We wish to acknowledge the helpful reviews of Markus Aretz and Yoichi Ezachi that significantly improved an earlier version.

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.

Aretz, M. & Herbig, H.-G., 2003a: Contribution of rugose corals to Late Viséan and Serpukhovian bioconstructions in the Montagne Noire (Southern France). – In: Ahr, W., Harris, A.P., Morgan, W.A. & Somerville, I.D. (Eds.): Permo-Carboniferous Carbonate Platforms and Reefs. – Society for Economic Paleontologists and Mineralogists, Special Publication **78** & American Association of Petroleum Geologists Memoir, **83**: 119–132, Tulsa.

Aretz, M. & Herbig, H.-G., 2003b: Coral-rich bioconstructions in the Viséan (Late Mississippian) of Southern Wales (Gower Peninsula, UK). – Facies, **49**: 221–242, Erlangen.

Arthurton, R.S. & Wadge, A.J., 1981: Geology of the country around Penrith. – Memoir of the Geological Survey, G.B., Sheet 24, 177 p., London.

Arthurton, R.S., Johnson, E.W. & Mundy, D.J.C., 1988: Geology of the country around Settle. – Memoir of the Geological Survey, G.B., Sheet 60, 147 p., London.

Bancroft, A.J., Somerville, I.D. & Strank, A.R.E., 1988: A bryozoan buildup from the Lower Carboniferous of North Wales. – Lethaia, **21**: 51–65, Oslo.

Beus, S.S., 1984: Fossil associations in the High Tor Limestone (Lower Carboniferous) of South Wales. – Journal of Paleontology, **58**: 651–667, Tulsa.

Brandon, A., 1972: The upper Viséan and Namurian Shales of the Doagh Outlier, County Fermanagh, Northern Ireland. – Irish Naturalists' Journal, **17**: 159–70, Belfast.

Brandon, A., 1977: The Meenymore Formation – an evaporitic intertidal formation in the Upper Viséan (B_2) of northwest Ireland. – Institute of Geological Sciences Report No. 77/23, London.

Brandon, A. & Hodson, F., 1984: The Stratigraphy and Palaeontology of the late Viséan and early Namurian rocks of North-east Connaught. – Geological Survey of Ireland Special Paper, **6**: 54 p., Dublin.

Brunton, C.H.C., 1987: The palaeoecology of Brachiopods and other faunas, of Lower Carboniferous (Asbian) limestones in West Fermanagh. – Irish Journal of Earth Sciences, **8**: 97–112, Dublin.

Burgess, I.C. & Mitchell, M., 1976: Viséan lower Yoredale limestones on the Alston and Askrigg Blocks and the base of D_2 Zone in northern England. – Proceedings of the Yorkshire Geological Society, **40**: 613–630, Leeds.

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.

Cossey, P.J. & Mundy, D.J.C., 1990: *Tetrataxis*, a loosely attached limpet-like foraminifer from the Upper Palaeozoic. – Lethaia, **23**: 311–322, Oslo.

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, H.E.A. & Somerville, I.D., 2005a: Foraminifera, calcareous algae and rugose corals in Brigantian (late Visean) limestones in NE Ireland. – Proceedings of the Yorkshire Geological Society, **55**: 287–300, Leeds.

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

Craig, G.Y. & Duff, P., 1975: The Geology of the Lothians and South East Scotland – An Excursion Guide. – 204 p., Edinburgh (Scottish Academic Press).

Dixon, E.E.L. & Vaughan, A., 1911: The Carboniferous succession in Gower (Glamorganshire) with notes on its fauna and conditions of deposition. – Quarterly Journal of the Geological Society, London, **67:** 477–567, London.

Dixon, O.A., 1970: Variation in the Viséan coral *Caninia benburbensis* from Northwest Ireland. – Palaeontology, **13**: 52–63, London.

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.

Fedorowski, J., 1981: Carboniferous corals: Distribution and sequence. – Acta Palaeontologica Polonica, **26**(2): 87–160, Warsaw.

Gallagher, S.J., 1992: Lithostratigraphy, biostratigraphy and palaeoecology of Upper Dinantian platform carbonates in parts of southern and western Ireland. – Unpublished Ph.D. thesis, National University of Ireland (University College Dublin).

Gallagher, S.J., 1996: The stratigraphy and cyclicity of late Dinantian platform carbonates in parts of southern and western Ireland. – In: Strogen, P., Somerville, I.D. & Jones, G.I. (Eds.): Recent Advances in Lower Carboniferous Geology. – Geological Society of London, Special Publication, **107**: 239–251, London.

Gallagher, S.J., 1998: Controls on the distribution of calcareous Foraminifera in the Lower Carboniferous of Ireland. – Marine Micropaleontology, **34**: 187–211, Amsterdam.

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**: 312–335, Chichester.

Gallagher S.J. & Somerville, I.D., 2003: Lower Carboniferous (Late Viséan) platform development and cyclicity in southern Ireland: Foraminiferal biofacies and lithofacies evidence. – Rivista Italiana di Paleontologia e Stratigrafia, **109** (2): 152–165, Rome.

George, T.N., Johnson, G.A.L., Mitchell, M., Prentice, J.E., Ramsbottom, W.H.C., Sevastopulo, G.D. & Wilson, R.B., 1976: A correlation of Dinantian rocks in the British Isles. – Special Report of the Geological Society, London, **7**: 1–87, London.

GREEN, G.W. & WELCH, F.B.A., 1965: Geology of the country around Wells and Cheddar. – Memoir of the Geological Survey, U.K, Sheet 280, 225 p., Leeds.
HILL, D., 1938–1941: A monograph on the Carboniferous rugose corals of Scotland. – Palaeontographical Society Monographs, **91**: 1–78, **92**: 79–114, **93**: 115–204, **95**: 205–213, London.
HILL, D., 1973: Lower Carboniferous corals. – In: HALLAM, A. (Ed.): Atlas of Palaeobiogeography, 133–142, Amsterdam (Elsevier).
HORBURY, A.D. & ADAMS, A.E., 1996: Microfacies associations in Asbian carbonates: an example from the Urswick Limestone Formation of the southern Lake District, northern England. – In: STROGEN, P., SOMERVILLE, I.D. & JONES, G.I. (Eds.): Recent Advances in Lower Carboniferous Geology. – Geological Society Special Publication, **107**: 221–237, London.
HUBBARD, J.A.E., 1966: Population studies in the Ballyshannon Limestone, Ballina Limestone and Rinn Point Beds (Viséan) of N.W. Ireland. – Palaeontology, **9**: 252–269, London.
HUBBARD, J.A.E., 1970: Sedimentological factors affecting the distribution and growth of Viséan caninoid corals in north-west Ireland. – Palaeontology, **13**: 191–209, London.
HUDSON, R.G.S., 1944: Lower Carboniferous corals of the genera *Rotiphyllum* and *Permia*. – Journal of Paleontology, **18**: 355–362, Tulsa.
HUDSON, R.G.S. & FOX, T., 1943: An Upper Visean Zaphrentoid fauna from the Yoredale Beds of North-West Yorkshire. – Proceedings of the Yorkshire Geological Society, **25**: 101–126, Leeds.
JAMESON, J., 1987: Carbonate Sedimentation on a Mid-Basin High: the Petershill Formation, Midland Valley of Scotland. – In: MILLER, J., ADAMS, A.E. & WRIGHT, V.P. (Eds.): European Dinantian Environments, Wiley: 309–327, Chichester.
JOHNSON, G.A.L. & NUDDS, J.R., 1996: Carboniferous biostratigraphy of the Rookhope Borehole, Co. Durham. – Transactions of the Royal Society of Edinburgh: Earth Sciences, **86**: 181–226, Edinburgh.
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**: 253–262, London.
KELLAWAY, G.A., 1967: The Geological Survey Ashton Park Borehole, and its bearing on the geology of the Bristol District. – Bulletin of Geological Survey of Great Britain, **27**: 49–153.
KELLY, J.G., 1989: The late Chadian – Brigantian geology of the Carrick-on-Shannon and Lough Allen Synclines, north west Ireland. – Unpublished Ph.D. thesis, University College Dublin, (National University of Ireland).
KULLMANN, J., 1997: Rugose corals in non-reef environments – the case of the "*Cyathaxonia* fauna". – Boletín de la Real Sociedad Española de Historia Natural (Sección Geológica), **92** (1–4): 187–195, Madrid.
KULLMANN, J. & RODRIGUEZ, S., 1994: Biostratigraphic range and biogeographic relationships of the undissepimented solitary corals from the Upper Member of the Picos de Europa Formation (Carboniferous, Asturias, NW Spain). – Courier Forschungsinstitut Senckenberg, **72**: 15–22, Frankfurt.
MATLEY, C.A. & VAUGHAN, A., 1906: The Carboniferous rocks at Rush (County Dublin). – Quarterly Journal of the Geological Society (London), **62**: 275–323, London.
MATLEY, C.A. & VAUGHAN, A., 1908: The Carboniferous rocks at Loughshinny (County Dublin). – Quarterly Journal of the Geological Society (London), **64**: 413–474, London.
MCKERROW, W.S., 1978: The Ecology of Fossils. – 383 p., London (Duckworth).
MITCHELL, M., 1971: Stratigraphical palaeontology of the Carboniferous Limestone Series. – In: STEVENSON, I.P. & GAUNT, G.D.: Geology of the country around Chapel en le Frith. – Geological Survey Memoir, England & Wales, Sheet 99, 444 p., Leeds.
MITCHELL, M., 1989: Biostratigraphy of Viséan (Dinantian) rugose coral faunas from Britain. – Proceedings of the Yorkshire Geological Society, **47**: 233–247, Leeds.

MITCHELL, W.I. & MITCHELL, M., 1983: The Lower Carboniferous (Upper Viséan) succession at Benburb, Northern Ireland. – Institute of Geological Sciences Report No. 82/12, London.

MUNDY, D.J.C., 1994: Microbialite-sponge-bryozoan-coral framestones in Lower Carboniferous (Late Visean) buildups of northern England (UK). – In: BEAUCHAMP, B., EMERY, A.F. & GLASS, D. J. (Eds.): Pangea: Global Environments and Resources. – Canadian Society of Petroleum Geologists Memoir, **17**: 713–729, Calgary.

NUDDS, J.R. & SOMERVILLE, I.D., 1987: Two new species of *Siphonodendron* (Rugosa) from the Viséan of the British Isles. – Proceedings of the Yorkshire Geological Society, **46**: 293–300, Leeds.

OSWALD, D.H., 1955: The Carboniferous rocks between the Ox Mountains and Donegal Bay. – Quarterly Journal of the Geological Society of London, **111**: 167–83, London.

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

POTY, E., 1994: Nouvelles précisions sur les corrélations stratigraphiques du Dinantien du Boulonnais et de la Belgique: application de la biozonation corallienne. – Comptes Rendus de l'Académie des Sciences de Paris, **319**: 467–473, Paris.

POTY, E. & Hannay, D., 1994: Stratigraphy of rugose corals in the Dinantian of the Boulonnais (France). – Mémoires de l'Institut Géologique de l'Université de Louvain, **35**: 51–82, Louvain.

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, P. & DEJONGHE, L. (Eds.): Guide to a revised lithostratigraphic scale of Belgium. – Geologica Belgica, **4**: 69–94, Liège.

POTY, E., Tourner, F. & Javaux, E., with colloaboration of DREESEN, R., GROESSENS, E., HIBO, D., LAUWERS, A. & LEES, A., 1991: The uppermost Devonain and Lower Carboniferous coral faunas of Belgium. – Guidebook to the 6th Symposium on fossil Cnidaria and Porifera, Münster: 1–98, Münster.

RAMSAY, A.S., 1987: Depositional Environments of Dinantian Limestones in Gower, South Wales. – In: MILLER, J., ADAMS, A.E. & WRIGHT, V.P. (Eds.): European Dinantian Environments, 265–308, Chichester (Wiley).

RAMSBOTTOM, W.H.C., 1973: Transgressions and regressions in the Dinantian: a new synthesis of British Dinantian stratigraphy. – Proceedings of the Yorkshire Geological Society, **39**: 567–607, Leeds.

RAMSBOTTOM, W.H.C. & MITCHELL, M., 1980: The recognition and division of the Tournaisian Series in Britain. – Journal of Geological Society, London, **137**: 61–63, London.

RODRÍGUEZ, S. & FALCES, S., 1992: Corales rugosos. – In: RODRÍGUEZ, S. (Ed.): Analisis paleontológico y sedimentológico de la Cuenca Carbonífera de los Santos de Maimona (Badajoz). – Coloquios de Paleontología, **44**: 159–218, Madrid.

RODRÍGUEZ, S. & FALCES, S., 1996: Los corales rugosos del Carbonífero de Ossa-Morena: estado actual de los conocimientos. – Revista Española de Paleontología, Número Extraordinario: 97–102, Madrid.

RODRÍGUEZ, S., FALCES, S., ARRIBAS, M.E., PEÑA, J.A. de la, COMAS-RENGIFO, M.J. & MORENO-EIRIS, E., 1992: Descripción litoestratigráfica y aspectos sedimentológicos de la unidades de la Cuenca Carbonífera de los Santos de Maimona. – Coloquios de Paleontología, **44**: 49–89, Madrid.

RODRÍGUEZ, S. & RODRÍGUEZ-CURT, L., 2002: Reconstrucción de una plataforma carbonatada Viseense no preservada en el Área del Guadiato (Córdoba, SO de España). – Geogaceta, **32**: 283–286 1–4, Madrid.

Rodríguez, S., Rodríguez-Curt, L. & Hernando, J.M., 2001a: Estudio de los Aulophyllidae (Rugosa) del Viseense superior de la Unidad de la Sierra del Castillo (Córdoba, España). – Coloquios de Paleontología, **52**: 47–78, Madrid.

Rodríguez, S., Hernando, J.M. & Said, I., 2001b: Estudio de los corales con aulos del Viseense (Carbonífero) de la Unidad de la Sierra del Castillo (Área del Guadiato, SO de España). – Coloquios de Paleontología, **52**: 85–94, Madrid.

Rodríguez, S., Hernando, J.M. & Rodriguez-Curt, L., 2002: Estudio de los corales lithostrotiónidos del Viseense (Misisipiense) de la Unidad de la Sierra del Castillo (Córdoba), España. – Revista Española de Paleontología, **17**: 13–36, Madrid.

Rodríguez, S., Mas, R., Somerville, I.D., Cózar, P., Rodríguez-Martínez, M. & Benito, M.I, 2003: Carbonate sedimentation from Peñas Rubias, late Viséan, Córdoba (SW Spain). – XV International Congress on Carboniferous and Permian Stratigraphy, Abstracts, 454–456, Utrecht.

Rodríguez, S. & Somerville, I.D., 2007: Comparisons of rugose corals from the Upper Visean of SW Spain and Ireland: implications for improved resolution in late Mississippian coral biostratigraphy (this volume).

Rose, W.C.C. & Dunham, K.C., 1977: Geology and hematite deposits of South Cumbria. – Economic Memoir of the Geological Survey of Great Britain, Sheet 58, 170 p., London.

Rowley, D.B., Raymond, A., Parrish, J.T., Lottes, A.L., Scotese, C.R. & Ziegler, A.M., 1985: Carboniferous palaeogeographic. Phytogeographic and palaeoclimatic reconstructions. – International Journal of Coal Geology, **5**: 7–42.

Said, I., Berkhili, M. & Rodríguez, S., 2007: Preliminary data on the rugose coral distribution from the Upper Visean of the Adarouch area, central Meseta (Morocco) (this volume).

Sando, W.J., 1980: The paleoecology of Mississippian corals in the western conterminous United States. – Acta Palaeontologica Polonica, **25**(3/4): 619–631, Warsaw.

Scotese, C.R., 2001: Paleomap Project. http:// www.scotese.com.

Scotese, C.R. & McKerrow, W.S., 1990: Revised world maps and introduction. – In: McKerrow, W.S. & Scotese, C.R. (Eds.): Palaeozoic Palaeogeography and Biogeography. – Geological Society Memoir, **12**: 1–21, London.

Scrutton, C.T., 1998: The Palaeozoic corals. II: structure, variation and palaeoecology. – Proceedings of the Yorkshire Geological Society, **52**: 1–57, Leeds.

Shephard-Thorn, E.R., 1963: The Carboniferous Limestone succession in North-West County Limerick, Ireland. – Proceedings of the Royal Irish Academy, **62B**: 267–294, Dublin.

Sleeman, A.G. & Pracht, M., 1999: Geology of the Shannon Estuary. A geological description of the Shannon Estuary region including parts of Clare, Limerick and Kerry, to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 17, Shannon Estuary. – Geological Survey of Ireland, 77 p., Dublin.

Smith, E.G., Rhys, G.H. & Eden, R.A., 1967: Geology of the country around Chesterfield, Matlock and Mansfield. – Memoir of the Geological Survey of Great Britain, Sheet 112, 430 p., London.

Smith, L.B. Jr. & Read, F.J., 2000: Rapid onset of late Paleozoic glaciation on Gondwana: evidence of Upper Mississippian strata on the Midcontinent, United States. – Geology, **28**: 279–282, Boulder.

Somerville, H.E.A., 1999: Conodont biostratigraphy and biofacies of Upper Viséan rocks in parts of Ireland. – Unpublished Ph.D. thesis, University College Dublin (National University of Ireland).

Somerville, I.D., 1979a: Cyclothems in the early Brigantian (lower D2) limestones east of the Clwydian Range, North Wales. – Geological Journal, **14**: 69–87, Chichester.

Somerville, I.D., 1979b: A sedimentary cyclicity in early Asbian (lower D1) limestones in the Llangollen district of North Wales. – Proceedings of the Yorkshire Geological Society, **42**: 397–404, Leeds.

SOMERVILLE, I.D., 1997: Rugose coral faunas from Upper Viséan (Asbian-Brigantian) buildups and adjacent platform limestones, Kingscourt, Ireland. – Boletín de la Real Sociedad Española de Historia Natural. (Sección Geológica), **92** (1–4): 35–47, Madrid.

SOMERVILLE, I.D., 2003: Review of Irish Lower Carboniferous (Mississippian) mud-mounds: depositional setting, biota, facies and evolution. – In: AHR, W., HARRIS, A.P., MORGAN, W.A. & SOMERVILLE, I.D. (Eds.): Permo-Carboniferous Carbonate Platforms and Reefs. – Society for Economic Paleontologists and Mineralogists, Special Publication **78** & American Association of Petroleum Geologists Memoir, **83**: 239–252, Tulsa.

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 (this volume).

SOMERVILLE, I.D. & STRANK, A.R.E., 1984: The recognition of the Asbian/Brigantian boundary fauna and marker horizons in the Dinantian of North Wales. – Geological Journal, **14**: 69–86, Chichester.

SOMERVILLE, I.D., STROGEN, P. & JONES, G.I., 1992: Biostratigraphy of Dinantian limestones and associated volcanic rocks of the East Limerick Syncline. – Geological Journal, **27**: 201–220, Chichester.

SOMERVILLE, I.D., STROGEN, P., JONES, G.I. & SOMERVILLE, H.E.A., 1996. Late Viséan buildups at Kingscourt, Ireland. – In: STROGEN, P., SOMERVILLE, I.D. & JONES, G.I. (Eds.): Recent Advances in Lower Carboniferous Geology. – Geological Society of London Special Publication, **107**: 127–144, London.

SOMERVILLE, I.D., STROGEN, P., MITCHELL, W.I., SOMERVILLE, H.E.A. & HIGGS, K.T., 2001: Stratigraphy of Dinantian rocks in WB3 borehole from Co. Armagh, N. Ireland. – Irish Journal of Earth Sciences, **19**: 51–78, Dublin.

STROGEN, P., SOMERVILLE, I.D., JONES, G.LL. & PICKARD, N.A.H., 1995: The Lower Carboniferous (Dinantian) stratigraphy and structure of the Kingscourt Outlier, Ireland. – Geological Journal, **30**: 1–23, Chichester.

VEEVERS, J.J. & POWELL, C.M., 1987: Late Paleozoic glacial episodes in Gondwanaland reflected in transgressive-regressive sequences in Euramerica. – Geological Society of America Bulletin, **98**: 475–487, Washington.

VUILLEMIN, C., 1990: Les Tétracoralliaires (Rugosa) du Carbonifère Inférieur du Massif Armoricain. – Cahiers de Paléontologie, Paris: 1–171.

WALKDEN, G.M., 1987: Sedimentary and diagenetic styles in late Dinantian carbonates of Britain. – In: MILLER, J., ADAMS, A.E. & WRIGHT, P. (Eds.): European Dinantian Environments. – Geological Journal Special Issue, **12**: 131–156, Chichester.

WEBB, G.E., 1989: Late Visean coral-algal bioherms from the Lion Creek Formation of Queensland, Australia. – XI Congrès, International de la Stratigraphie et de Géologie du Carbonifère Beijing, 1987 Compte Rendu, **3**: 282–295.

WEST, I., BRANDON, A. & SMITH, M., 1968: A tidal flat evaporite facies in the Viséan of Ireland. – Journal of Sedimentary Petrology, **38**: 1079–1093, Tulsa.

WRIGHT, V.P. & VANSTONE, S., 2001: Onset of Late Palaeozoic glacio-eustasy and the evolving climates of low latitude areas: a synthesis of current understanding. – Journal of Geological Society, London, **158**: 579–582, London.