Internal structure and depositional environment of Late Carboniferous mounds from the San Emiliano Formation, Cármenes Syncline, Cantabrian Mountains, Northern Spain

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Abstract

Well-exposed mounds are common in limestone of the Late Carboniferous San Emiliano Formation, Cantabrian Mountains (Northern Spain). They occur as obvious primary topographic features. Careful study of the mound intervals and surrounding strata revealed the internal structures of mounds and the factors controlling their growth. The substrate (2–3 m) of the mounds consists of greyish to reddish, bedded oolitic and oncolithic packstone and grainstone. Crinoids, fragments of the alga *Epimastopora*, and, rarely, bryozoans are present. Ooids and oncoids indicate a wave-dominated high-energy environment. Presence of quartz indicates the influence of terrigenous siliciclastic input. Mound intervals (6–12 m thick) are characterized by skeletal–microbial boundstone. Donezellid algae, agglutinated worm tubes, and calcisponges are the dominant fossils. Smaller foraminifers, gastropods, and brachiopods are also present. A peloidal-clotted matrix is characteristic and accounts for more than 30% of the mound volume. Intraframe pores are mainly filled by peloidal sediment and early marine cement. Intermound strata are approximately one-third as thick as time equivalent mounds. Mound fossils (algae, agglutinated worm tubes, and sponges) are uncommon. However, intermound strata are generally more diverse than the mounds, containing fusulinids, smaller foraminifers, bryozoans, gastropods, crinoids, and bioclasts. Some of these fossils have micritic envelopes. Bedded packstone and grainstone, 3–6 m thick, with siliciclastic debris, rugose corals, and chaetetid sponges characterize the capping facies. Coated grains and small ooids are uncommon. This facies indicates shallowing to a higher energy environment and/or a higher input of siliciclastics, inhibiting mound growth. Mounds are interpreted to have accreted in a quiet environment below wave base. This position is comparable to the depositional environment inferred for many Late Paleozoic mounds described elsewhere, e.g., from Texas and New Mexico, Canadian Archipelago, and Carnic Alps in Austria. Mound relief is explained by (1) accumulation of peloidal-clotted sediments limited to boundstone and probably related to microbial activities, (2) widespread marine cementation within this area, and (3) low export of mound fossils to intermound areas. The position of the mounds within the sequence, and their initiation, size and termination, seem to be mainly controlled by sea-level fluctuations and siliciclastic input. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Most studies of Upper Carboniferous buildups focus on phylloid algal mounds, especially those from

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the American Midcontinent. Although phylloid algae are the major mound builders, mounds built by other algae have been reported, e.g., *Anthracoporella* dasycladalean algal mounds (Samankassou, 1998). The growth fabric of algal mounds is an important aspect, which has not been investigated in detail: whether they consist of detrital accumulations of algal thalli (Ball et al., 1977) or of in situ thalli, implying a framework (examples in Samankassou, 1998; Samankassou and West, 2000) needs further investigation. Another important topic is the role of microbial activity in the accumulation, consolidation, and lithification of the mound structure (Pratt, 1982, 1995; Webb, 1996; Kirkland et al., 1998).

Algal mounds in the Cantabrian Mountains have been described by Bowman (1979) and Riding (1979). Diagenetic features of the mounds described herein have been studied by Hensen et al. (1995). The results presented here are based on detailed sampled sections focusing on the microfacies, paleontology, and paleoecology of the mounds. Additional sampling of the facies surrounding the mounds (base, top, and intermound rocks) provided data on the depositional environment of the mounds and on the dynamics of mound growth.

2. Location, stratigraphy

The Cantabrian arc is the northernmost zone of the Iberian Massif (Lotze, 1945; Julivert, 1971). It is subdivided in the Cantabrian, West-Asturian-Leonese, Galacian-Castillan, Ossa-Morena, and South Portuguese zones (see a recent overview in Dallmeyer and Martinez Garcia, 1990). The Cantabrian Zone is subdivided into the allochthonous Asturian-Leonese and the autochthonous Palentine domains. The Asturian-Leonese domain comprises the Somiedo-Correcilla, Sobia-Bodón, Aramo, Ponga, Central Coal Basin, and Picos de Europa Units (Perez Estaun, 1990). The San Emiliano Formation belongs to the Aramo and Sobia-Bodón units, which are located in the western and southwestern parts of the Cantabrian zone, respectively (Perez Estaun et al., 1988).

The Cármenes Syncline is located in the central part of the southern Cantabrian Mountains, Northern Spain (Fig. 1). It consists of Paleozoic strata subdivided into the Valdeteja and San Emiliano Forma-

Fig. 1. Location of the studied sections within the Cármenes Area, Northern Spain. Individual samples taken between Cármenes and

tions (Fig. 2). The Valdeteja Formation represents a large, thick carbonate platform, Namurian–Early Westphalian in age. The San Emiliano Formation, established by Brouwer and van Ginkel (1964), is at least 1800 m thick and consists of deltaic siliciclastics and shallow-marine carbonates of Westphalian age (van Ginkel, 1965; Eichmüller, 1985; Wagner and Bowman, 1983). Fusulinacean data (van Ginkel and Villa, 1996) indicate an age of Lower/Upper Bashkirian for the basal part and Moscovian for the top. These correspond to Yealdonian (Namurian C) and Westphalian B, respectively (Fig. 2). The top of the San Emiliano Formation is marked by a major disconformity overlain by younger Carboniferous rocks (Bowman, 1979). The faunal and floral associations recorded point to a paleogeographical position close to the equatorial realm during the Late Carboniferous.

Limestones layers are generally well exposed (Fig. 3), whereas siliciclastics are covered and exposed only in road cuts and gullies. van den Bosch (1969) has mapped the San Emiliano Formation regionally; several students at the Kiel University, Germany, under the leadership of Priska Schäfer, have recently mapped the Cármenes area in detail. Paleontological and stratigraphic studies have been performed by van Ginkel (1965), Winkler-Prins (1968), Martínez-Cha-
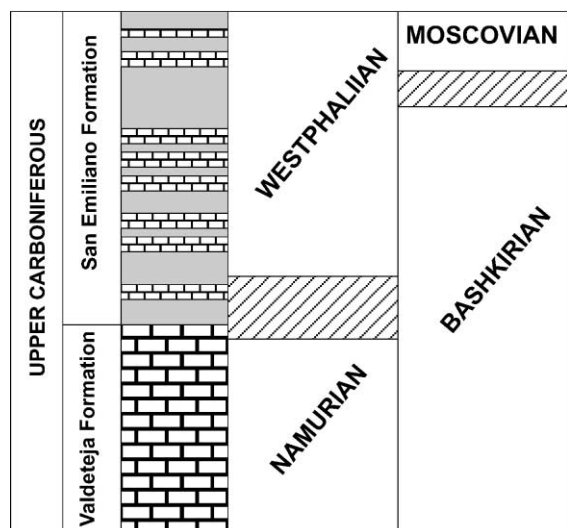
Fig. 2. Stratigraphic position of the San Emiliano Formation in the Cantabrian Mountains, Spain. Hatched fields indicate incertitude in biostratigraphy. Modified from van Ginkel and Villa (1996).

cón (1977), van Ginkel and Villa (1996), Dingle et al. (1993) and others.

Sections investigated for the present studies are located in the southeastern part of Cármenes, near Almuzara, and Barrios de Tercia (Fig. 1). Additional samples were collected from other outcrops between Cármenes and Barrios de Tercia.

3. Facies analysis

The studied succession is characterized by a cyclic alternation of fine-grained marine sandstone, siltstone, grey shale, and limestone (see Dingle et al., 1993 for a recent review). Bedded limestone overlies siliciclastic rocks (fine-grained sandstone and shale), and passes upward into mounded limestone (Fig. 3). Bedded limestone, with siliciclastics, overlies the mounds.

3.1. Mound substrate facies

3.1.1. Description
The substrate of the mounds is 2–3 m of thick-bedded limestone. Individual beds are 20–40 cm thick, and consist of oolitic and oncolithic grainstone and packstone (Fig. 4). They become indistinctly

bedded upward, just beneath the mounds. Quartz content decreases upwards.

Single ooids are generally spherical. Composite ooids (several ooids serving as nuclei for a large new ooid, here called polyooids) are elongated ovals (Fig. 4A). Nearly all ooids have multiple layers of coating, with tangential and radially oriented crystals (Fig. 4B). Polyooids are abundant. Algal fragments and quartz grains are the common nuclei of ooids. The matrix is sparitic and rarely contains bioclasts (e.g., crinoids). Some ooids are abraded.

Oncoids are very irregular in shape, ranging from 3 to 20 mm in diameter. They consist of alternating homogeneous micritic and sparitic laminae, typically around a bioclast (phylloid algae and brachiopods being the most common) (Fig. 4D,E). Some consist of an intergrowth of microbes (*Girvanella*) and fora-

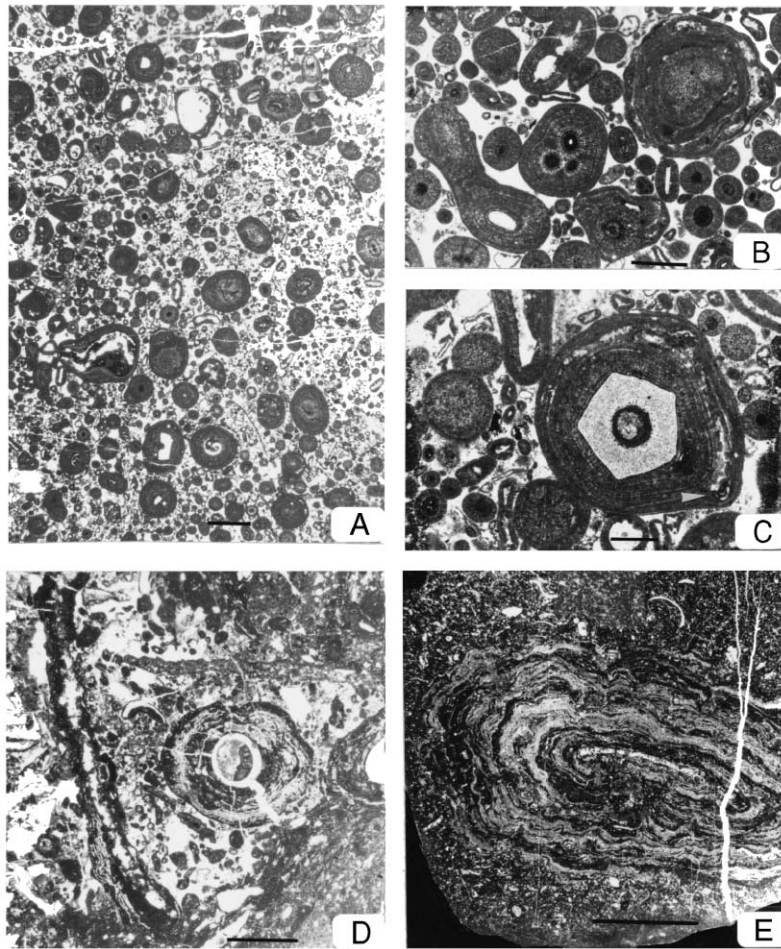Fig. 3. View of a mound close to the village Almuzara (houses lower left). Note the person (arrow) for scale.

Fig. 4. Mound substrate facies. (A) Ooid grainstone; note variation in ooid size and the different nuclei (gastropods, algal fragments, quartz, among others). Scale bar is 5 mm long. (B) Detail of composite ooids (polyooids, these are several ooids serving as nuclei for a large new ooids). Scale bar is 20 mm long. (C) Close-view of an ooid showing multiple growth phase: a first ooid grew around a crinoid fragment; it was overgrown by a micritic-peloidal layer including sessile foraminifers (arrow lower right), which were finally overgrown by thin, irregular layers. Note the co-occurrence of tangential and radially oriented crystals. Scale bar is 20 mm long. (D) Oncoid consisting of homogeneous, micritic layers (dark) and sparitic laminae (white). The matrix is micritic and includes broken bioclasts. Scale bar is 10 mm long. (E) Detail of an irregular oncoid, showing the undulate flower shape around an algal fragment and the micritic matrix. As it occurs just above A and below the mounds, a decrease in energy may be postulated. Scale bar is 5 mm long.

minifers (*Nubecularia*) within thick micritic layers. These structures are similar to those described as "algal-foraminiferal consortium" by Johnson (1950), "algal-biscuits" by Toomey et al. (1988), and *Osagia* by Mamet et al. (1987). Algal fragments, fusulinids, gastropods, bivalves, brachiopods, and crinoid ossicles are the main non-coated grains. The matrix is generally micritic and includes peloids, sessile foraminifers, and bioclasts. Bowman (1983) described

in detail oncoids from the type locality of the San Emiliano Formation.

3.1.2. Interpretation

Ooids (which vary in size, composition, and are sometimes abraded) and the sparitic matrix suggest a wave-dominated, high-energy, shallow-water environment. Furthermore, ooids with few laminae, preferentially occurring in low-energy environments (Flügel,

1982), are absent. Quartz may indicate proximity to land. As the ooid-dominated beds (typically an unstable seabed) pass upward to oncoid-dominated, mud-rich beds (typically a more stable seabed), a decreasing energy regime and/or an establishment of soft bottoms is probable (Flügel, 1982, p. 137; Bowman, 1983). The occurrence of tangential (by far the dominant type) along with radial structures of ooids may indicate variation in salinity (cf. Flügel, 1982). From the oncolitic facies upward, the environment became more open, normal-marine as indicated by increasing biotic diversity. Some breaks in deposition may be reflected by the occurrence of common polyooids in certain horizons.

3.2. Mound facies

3.2.1. Description of the mounds

Mounds are generally 6–12 m thick and up to 20 m across. Most of the mounds are flat and lenticular, with slopes of less than 45°. They are isolated or aligned close to one another; no composite mound (that is one above another) has been observed in the area studied. This mode is similar to that described by Eichmüller (1985) from the adjacent Valdeteja Platform. Mound rocks are light gray, crudely bedded, massive limestone (Fig. 3), partly dolomitized.

Mound microfacies are characterized by skeletal–microbial boundstone, with intertwined growth of the septate, branching alga *Donezella* enclosing common peloidal and spar-filled cavities (Fig. 5). Based on the dominant biota, one can distinguish algal (*Donezella*)-dominated, agglutinated worm tube (*Thartharella*)-dominated, and sponge-dominated boundstone, respectively. Intermediate types are common; *Donezella* is commonly associated with both sponges and *Thartharella*. A peloidal-clotted matrix (Fig. 5) is typical and accounts for more than 30% of the mound volume. Most intraframe pores are mainly filled with
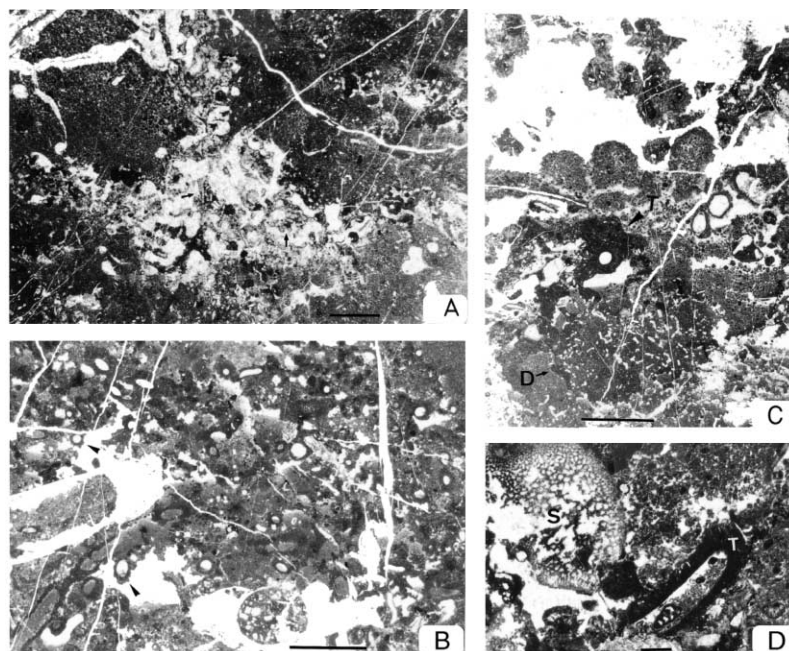

Fig. 5. Mound facies. Skeletal–microbial boundstone. A low-diversity association of algae (*Donezella*), agglutinated worm tubes (*Thartharella*) and calcisponges generally occurring in different parts of the mound characterizes this microfacies. No zonation can be recognized. (A) Patchy occurrence of *Donezella* (intertwined thalli, arrows) including voids (now cement-filled, white on photomicrographs). Space between patches consists of peloidal wackestone-packstone and dark, micritic cement. (B) Boundstone of agglutinated, gregarious worm tubes *Thartharella* (arrows). Tubes are very close to each other. The space between is filled with peloidal sediment and sparry cement. (C) *Donezella* (D) boundstone is here associated with *Thartharella* (T). (D) Calcisponge boundstone; calcisponge (S, upper) is here associated with *Thartharella* (T, lower) in transverse section. Note the overall low diversity of the respective boundstone types. Scale bar is 10 mm for all photomicrographs.

peloidal sediment and marine cement (Fig. 5). The accessory biota consists of small foraminifers (*Tuberitina*, and, rarely, *Climmacammina* and *Bradyina*, cf. Dingle and Schäfer, 1997), gastropods, and brachiopods. Boundstone fabrics are often diagenetically modified, being replaced by granular pseudospar (Fig. 5).

3.2.2. Description of intermound areas

Intermound strata are approximately one-third as thick as the mounds; these dimensions are similar to those measured by Riding (1979). Although mound fossils (algae, agglutinated worms, and sponges; see above) are commonly absent, intermound strata are generally more diverse than the mounds, containing fusulinids, gastropods, smaller foraminifers, and other bioclasts. Some of these fossils have micritic envelopes (Fig. 6). Fragments of donezellid algae from the mounds are conspicuously absent.

3.2.2.1. Interpretation. The microfacies of the mounds, consisting of mud-rich boundstone and delicate frameworks, suggests that the mounds grew below wave base at a depth greater than the mound substrate. This depositional setting is comparable to those inferred for most Late Paleozoic algal boundstone deposits elsewhere, e.g., Texas and New Mexico (Wahlman, 1988), the Canadian Archipelago (Beauchamp et al., 1989; Davies et al., 1989; Morin et al., 1994), and the Carnic Alps (Samankassou, 1998). Relief of the mounds indicates greater sediment accumulation in mounds than in the intermound areas. This is explained, in part, by the growth fabrics (indicating rapid growth), microbial sediment, early cementation observed in the mounds and the differences in biotic content of the two settings. Diagenesis was important, as shown by Hensen et al. (1995), but is of minor importance in explaining differences in thickness between mound and intermound areas. Stabilization of the edges of the mounds (e.g., Blendinger et al., 1997) may have contributed to maintenance of the relatively steep flanks.

3.3. Mound capping facies

3.3.1. Description

The capping facies is generally 3–6 m thick, 8 m in one section. The thickness is inversely proportional to
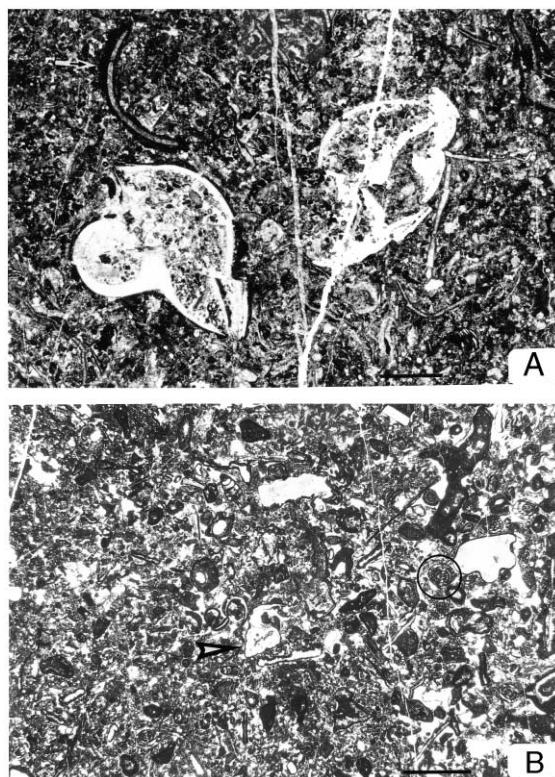

Fig. 6. Intermound facies. Bioclastic packstone. (A) Large brachiopods and fragments of algal thalli are the dominant bioclasts. Note coating of some grains (arrow, upper left) and common broken bioclasts. (B) Fusulinid-gastropod-dominated packstone (arrow for gastropod, circle for fusulinid). Most components have micritic envelopes. Scale bar is 5 mm for all photomicrographs.

mound relief. The capping facies is composed of bedded packstone and grainstone containing siliciclastics, fragments of the alga *Epimastopora*, fusulinids, rugose corals, and *Chaetetes* (Fig. 7). Bed thicknesses decrease upward, and siliciclastic content increases. Coated grains and ooids are uncommon. Ooids from the capping facies are smaller than those in the mound substrate. This facies passes upwards into shale and fine-grained sandstone.

3.3.2. Interpretation

The capping facies was deposited in very shallow water. Red beds overlie oolite in the Barrio de Tercia section and may represent an interval of subaerial exposure. Shallowing upward to a wave-
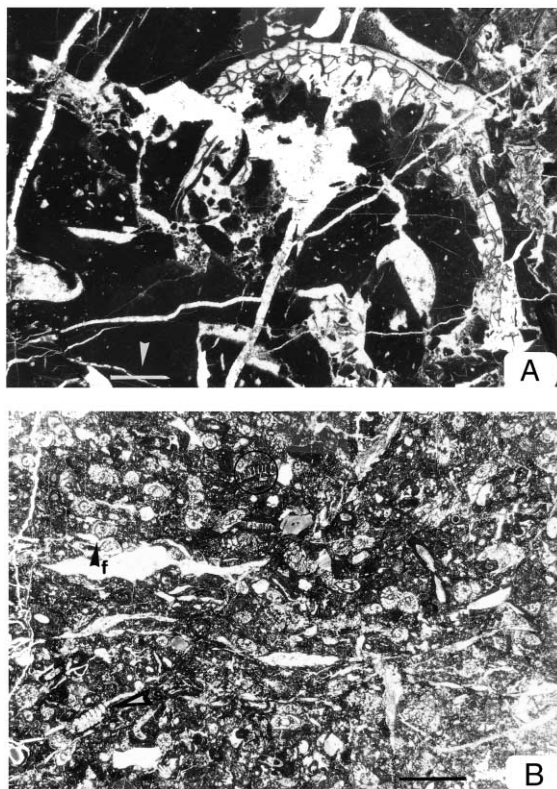
Fig. 7. Mound-capping facies. Packstone and, less common, grainstone including Chaetetid sponge, corals (A), fusulinids (f), smaller foraminifers (s, lower black−white arrow), and fragments of the dasyclad alga *Epimastopora* (B). Some beds of this facies are composed nearly entirely of *Epimastopora* (circle) packstone. Scale bar is 10 mm long for A and 5 mm for B.

dominated environment is a common feature in Late Paleozoic algal mounds (Wilson, 1975). Shallowing may have been coupled with regression, which favors siliciclastic input and inhibits mound growth (Chave, 1967).

4. Mound paleontology and paleoecology

Mound-forming fossils are briefly described in this section, and their relationships discussed. To better characterize mound biota, some fossils that are rare within the mound but common in rocks above, below, and in intermound areas are also considered.

4.1. Algae and related problematic taxa

4.1.1. Donezella

Generally two species of *Donezella* are widespread in Late Paleozoic sequences: *D. lunaensis* and *D. lutuginii*. *D. cespaeformis* is less common (Mamet, 1991).

D. lunaensis Rácz differs from *D. lutuginii* Maslov in having a greater thallus diameter, but both have a double-wall structure. These two species are not differentiated in this paper because of recrystallization in many cases and the systematic controversy (cf. Roux, 1985; Vachard et al., 1989; Mamet, 1991).

Donezella has been assigned to different groups: red algae (Maslov, referred in Rácz, 1964), possibly green algae (Pia, 1937; Johnson, 1963), codiacean (Rácz, 1964), sponges (Termier et al., 1977), algae incertae (Rich, 1967), foraminifera (Riding and Jansa, 1974; cf. Riding, 1977), and microproblematica (Riding, 1979).

The cylindrical thallus of *Donezella* is characterized by segmented tubes and dichotomous branching (Fig. 8A,B; cf. reconstruction in Mamet et al., 1987). The bases of branches are thicker in some species. Partitions are evenly spaced, and the wall structure is conspicuous, with a thick inner layer and a thinner outer layer. *Donezella* seems to grow upright, with closed and intertwined thalli, forming a delicate framework (Fig. 8) as indicated by the conspicuous cavities.

The diversity is low in areas covered by *Donezella* (Fig. 8), and fragments of *Donezella* are uncommon outside the mound core. Low diversity is common among Late Paleozoic algal-dominated mounds (Wilson, 1975, 1977; Flügel, 1979). For phylloid algae, Toomey (1991) postulated possible chemical poison produced by algae that prevented settlement of other organisms. Chemical defense used by algae is documented from studies of recent reefs (Hay, 1997; Paul, 1997) and other environments (G. Gerdes, personal communication, 1998). Indeed, only organisms able and adapted to live in cavities and/or on algal leaves occur within the *Donezella* boundstone. Gregarious sessile organisms, like corals and chaetetid sponges, that may compete with algae are found in bedded limestone above mounds only (see above).

Donezella is cosmopolitan in the Northern Hemisphere (Mamet, 1991), and mound-building *Done-*
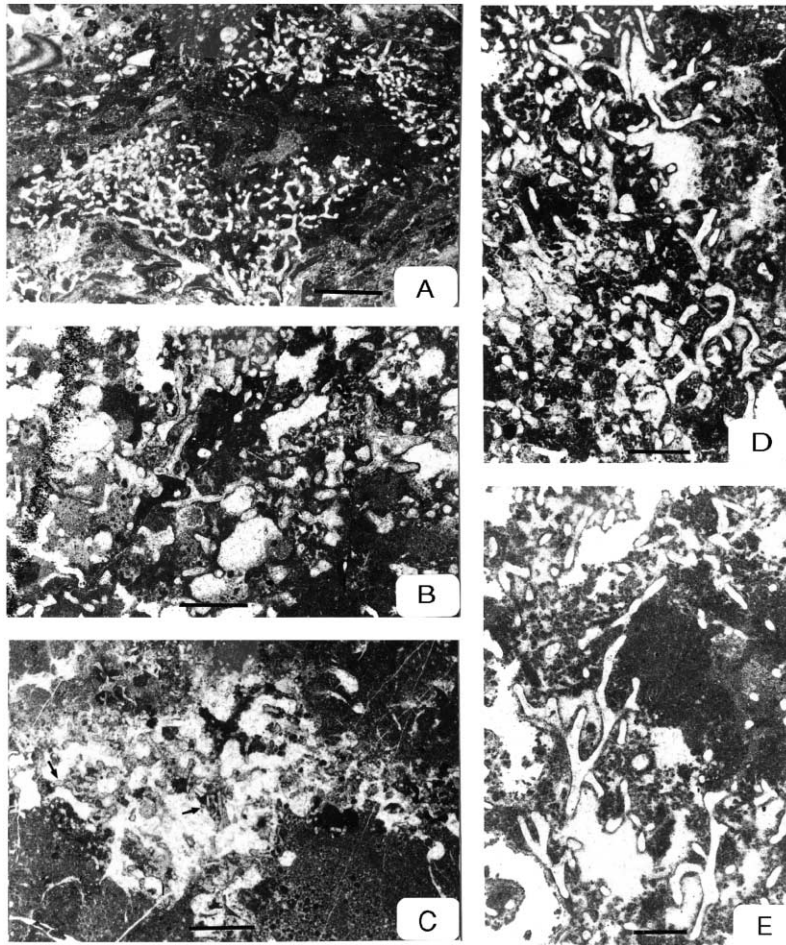
Fig. 8. *Donezella*. (A) Patchy distribution of *Donezella* within typical boundstone microfacies. (B) Detail of branched *Donezella* thalli, enclosing intraframework pores filled with sediment and cement. (C) Recrystallized areas with *Donezella*; peloidal areas retain more of primary texture. Note the dark micritic cement between thalli and around the recrystallized patch. (D, E) Detail of upright, branched, closely intertwined *Donezella* (arrows) thalli forming a delicate, unique framework. The framework pores are, as in B, filled with sediment and cement. Note pores around thalli, and peloidal sediment partly lining voids. *Donezella* thalli vary in their dimensions, which lead to classification into different species (see discussion in text). Scale bar is 10 mm long for A and C; 20 mm for B, D, E.

zella is reported from the Bashkirian and Moscovian of the Canadian Arctic Archipelago (*Donezella* bafflestone of Mamet et al., 1979). Illustrations therein lack the typical intertwined structures described above, but these have been noted in the text. Furthermore, the abundance of peloidal sediment is remarkably similar.

4.1.2. Rectangulina

Rectangulina consists of straight, angular, nonsegmented tubes, often grouped in bundles (Fig. 9A). A very thin micritic wall encloses a thin medulla (Fig. 9B). The systematic position is controversial due to the lack of useful morphological features (cf. discussion in Mamet and Roux, 1975, p. 143; Vachard, 1981).

This alga is associated with peloidal wackestone and packstone (Fig. 9), as reported by others (e.g., Mamet et al., 1987; Forke and Samankassou, 2000). Unlike the occurrences of *Rectangulina* reported in the two previously cited papers, *Rectangulina* did not build specific mounds in the Cármenes area. Instead,
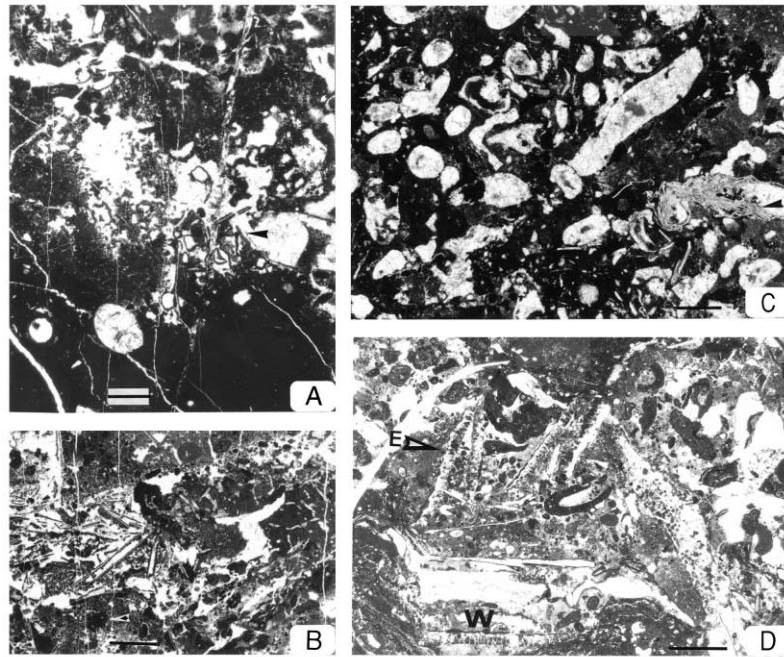
Fig. 9. *Rectangulina*. *Donezella*-dominated, mud-rich boundstone (A) including patches of the alga *Rectangulina* (arrow), recognizable through the typical straight, nonsegmented tubes. (B) *Rectangulina* commonly forms bundles. Note dark *Shamovella* in photo (B). (C) *Anthracoporella*-boundstone. This microfacies is nearly monospecific. Crusts of *Girvanella* (arrow, right) and other fossils do not exceed 5% of the biogenic components. As the thalli are entirely recrystallized, no further determination is possible. (D) *Epimastopora*. (E). *Epimastopora*-rich microfacies, along with *Tubiphytes* and other bioclasts. Fragments of slightly bent, cylindrical segments with pores aligned parallel to wall (W) are generally more common outside the mound. *Epimastopora* is one of the most widespread fossils in the investigated area. Scale bar is 10 mm long for all photomicrographs except for A (5 mm).

Rectangulina formed patches within *Donezella*-sponge-dominated facies. Most of the references to *Rectangulina* note only scarce occurrence; nevertheless, it has been reported, e.g., from the Russian Platform, Urals, Northern Africa, and North America (cf. Mamet, 1991).

4.1.3. Anthracoporella

The dasyclad alga *Anthracoporella* is characterized by branched thalli and a large medulla. Thalli are wholly recrystallized (Fig. 9C), and based on the diameter of the thalli, the specimens in the mounds considered here appear to be *A. spectabilis* Pia. As described from other localities, *Anthracoporella*-dominated facies are nearly monospecific, only rarely have encrustations of *Girvanella*, and occurrences of smaller foraminifera and fusulinids (less than 5% of the total fossil content) have been noted. Toomey's speculation regarding chemical defense mechanisms

in algae could also be postulated for *Anthracoporella* (see discussion in Section 4.1.1). There are no mounds built specifically by *Anthracoporella* in the Cármenes area. It occurs only locally within the mound complex described above.

Although *Anthracoporella* is common in Late Paleozoic sequences worldwide (cf. Mamet, 1991), *Anthracoporella* mounds have rarely been reported (Flügel, 1987; Krainer, 1995; Samankassou, 1998, all reporting occurrences in the Carnic Alps, Austria and Italy).

4.1.4. Archaeolithophyllum

Only *A. lamellosum* occurs in the samples studied. It consists of crusts of multiple sheets, typically on bioclasts (mostly as encrustation on fragments of phylloid algae). Generally, *Archaeolithophyllum* encrusts one side only, and differs in this from oncoid encrustations.

Archaeolithophyllum is considered a red alga (cf. Mamet et al., 1987) and is common in Middle Carboniferous to Early Permian deposits (Flügel, 1977; Mamet, 1991) worldwide. In the mounds of this study, its role in mound construction is secondary; it acts as an encruster rather than a constructor.

4.1.5. Epimastopora

As in all previous descriptions, only fragments of *Epimastopora* were found. They consist of straight to slightly bent, cylindrical segments a few mm long with pores aligned perpendicular to the wall (Fig. 9D). Because of the occurrence of fragments only, the characteristics and taxonomic affinities of *Epimastopora* remain controversial. *Epimastopora* is not conspicuous within the mounds; it is widespread in the mound substrate and intermound areas, commonly associated with coated grains and fusulinids. The typical "*Epimastopora* community", associated with *Gyroporella* and *Mizzia*, reported, e.g., from the Carnic Alps, the former Yugoslavia, and the Canadian Arctic Archipelago (see Flügel, 1977; Mamet et al., 1987), has not been found in this area.

In the Cármenes area, as in the other areas mentioned above, *Epimastopora* is uncommon in algal boundstone. It seems to grow in more agitated, very shallow environments; this fits well with its occurrence in oolitic–oncolithic facies and fusulinid packstone-grainstone, and its scarceness in boundstone.

Epimastopora is abundant in many Late Carboniferous–Permian deposits worldwide (Roux, 1979).

4.1.6. Komia

Komia is difficult to differentiate from the morphologically similar *Ungdarella*. Its thallus is irregular, ramose, or cylindrical (Fig. 10A). The wall is typically yellowish in thin sections (hyaline). *Komia* is very common in Carboniferous, but less abundant in Permian rocks of the Donbas, Urals, Northern Africa, North America, and Great Britain (see Mamet, 1991).

Komia occurs in boundstone of the present study, but is not a mound builder as reported from the Canadian Arctic Archipelago (Mamet et al., 1987, p. 53).

4.1.7. Eflugelia

Eflugelia (*Cuneiphycus*) has a tapering, generally encrusting thallus (Fig. 10B). The thallus could not be

differentiated. Cells are thin, regularly and hemispherically arranged. This form has been termed as "Pseudo-alga" by Termier et al. (1977) and is attributed to sponges. *Eflugelia* is an accessory in mound and bedded facies. It is stratigraphically long ranging from Viséan to Permian and is reported from many Late Paleozoic deposits (Mamet, 1991).

4.1.8. Shamovella (Tubiphytes)

Shamovella (commonly called *Tubiphytes*), a well-skeletonized tubular organism (Babcock, 1977, 1986; Riding and Guo, 1992; Senowbari-Daryan and Flügel, 1993; Vennin et al., 1997), is very common in Late Paleozoic reefs. *Shamovella* consists of segmented tubes, 0.5−3 mm in diameter and up to 10 mm long, that are cylindrical or elliptical or ovoid in cross-section, and occur as encrustations (on themselves, other skeletons, and/or syndepositional cements/crusts) or growing free on sedimentary substrates (Permian Hueco Mountains, USA; author observation, 2000). In shape, they may be rod- or worm-like, coiled or branched. *S. obscura* may have been a calcareous encruster, symbiotically surrounding an unknown organism (soft-bodied?, foraminifers?) that formed the internal cavity (Senowbari-Daryan and Flügel, 1993; Vennin et al., 1997).

Shamovella is common in boundstone, particularly associated with calcisponges and *Donezella* (Fig. 8). This is in agreement, in part, with reports from other areas (cf. overview in Vennin et al., 1997). The massive occurrence reported by Wahlman (1985, 1988), and occurrences associated with bryozoans (e.g., Vennin et al., 1997) have not been observed in the Cármenes area.

4.2. Agglutinated worm tubes

These are probably annelids and assigned to *Thartharella*.

4.2.1. Thartharella

Elliott (1962) originally described the agglutinated tube *Thartharella* as a microcoprolite from the Upper Jurassic of the Middle East, referring it to the genus *Prothocoprolithus*. He recognized two species, *P. centripetalus* and *P. cucumeriformis*. *Prothocoprolithus* was later revised by Elliott (1980), and renamed to the genus *Thartharella*, which he
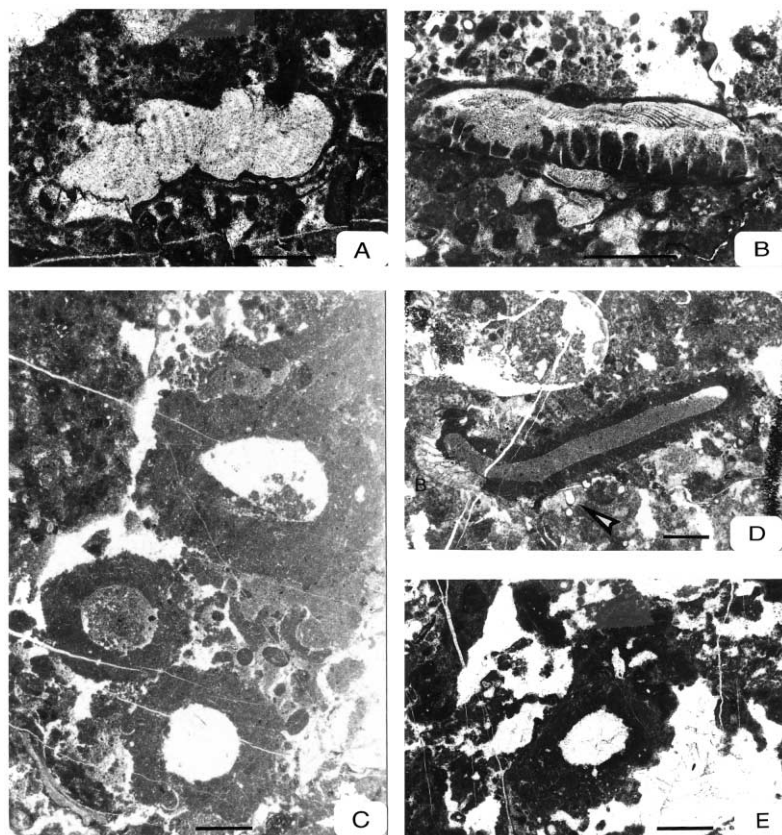
Fig. 10. (A) *Komia*: Irregular, ramose, cyclindrical thallus. It is accessory in boundstones, and has not been observed outside mounds. (B) *Eflugelia* commonly encrusts bioclasts, frequently algal thalli (here, a fragment of *Epimastopora*). Cells are closely spaced and the alga appears hemispherical. As in most previous descriptions, *Eflugelia* is ubiquitous, but in very reduced proportions in different facies. (C–E) *Thartharella* grew close to one another (C), with delicate framework enclosing peloidal sediment and cement-filled voids. (D) Transverse sections through *Thartharella* overgrown by bryozoans (B, left) and the small foraminifera *Tuberitina* (arrow, lower middle). (E) Radial section showing the diffuse contours, lined by micritic (dark) and spar (white) cements. Scale bar is 50 mm long for A; 20 for B, E; and 10 mm for C, D.

described as an annelid worm tube. The preserved part of *Thartharella* consists of thick, gregarious walls, very close to each other in thin sections (Fig. 10C,E). The outline of the inner face of an individual wall is diffuse. *Thartharella* is commonly associated with calcisponges (Fig. 10D), but not commonly with algae.

Similar structures have been interpreted, by Dingle et al. (1993), as *Aka*, a boring sponge. *Thartharella* is common in Carboniferous and Permian sequences. It commonly occurs in buildup facies (Wahlman, 1988; Choh and Kirkland, 2000; Kenter et al., 2000).

Thartharella seems to act principally as a delicate framebuilder (Fig. 10) and as a binder sensu Fager-

strom (1987), binding together fragments of algae and calcisponges into a clotted fabric. It represents a considerable part (>50%; Figs. 5B and 10) of some mound intervals (cf. boundstone descriptions above).

4.3. Foraminifers

Fusulinids (Fig. 11A) are the most common foraminifers in the San Emiliano deposits, particularly in bedded limestone in the mound substrate. Smaller foraminifers (mainly *Climmacammina* and *Paleotextularia*; Fig. 11B) are more common in the mound facies (Dingle and Schäfer, 1997), but never contribute much volumetrically as builders. Some problem-
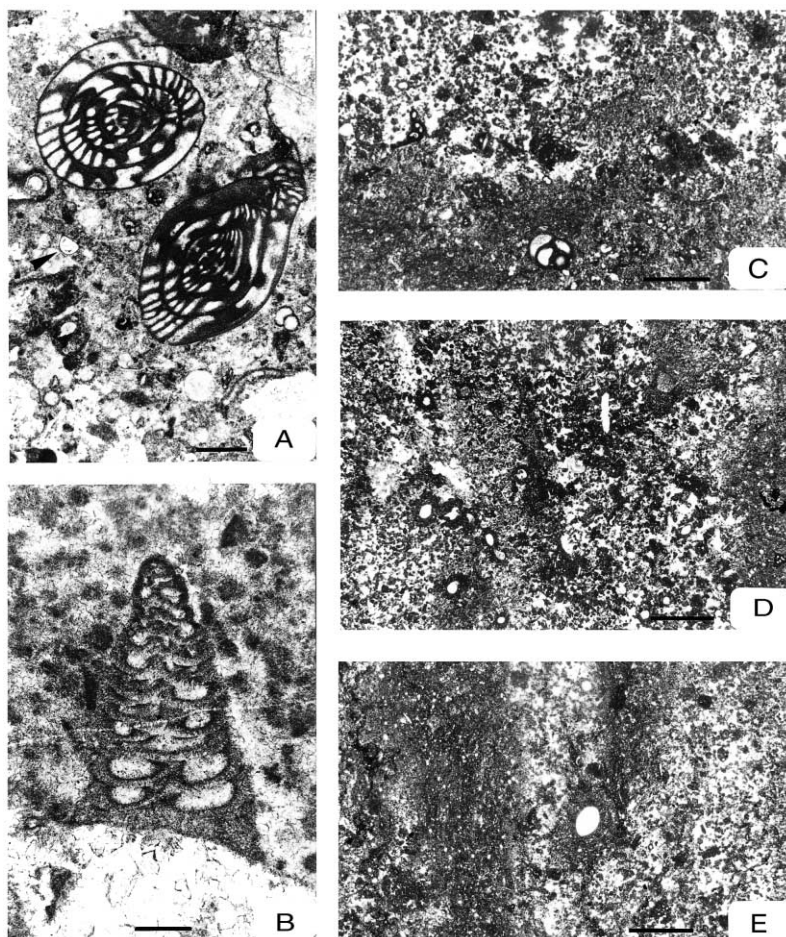
Fig. 11. (A) Fusulinids, the most common foraminifers in the studied area. Note *Tuberitina* (arrow, bulbous white circles) in the matrix. (B) Hat-like, conical smaller foraminifera *Tetrataxis* with numerous whorls. Various species occur generally attached to algal thalli in the mound facies. (D–E) Problematic smaller foraminifers (round–oval structures) are scattered in the peloidal sediment; the latter is commonly free of fossils. Scale bar is 20 mm long for A, C; 40 mm for B; and 10 mm for D, E.

atic sessile foraminifers occur in the peloidal matrix of boundstone (Fig. 11C,D,E).

4.4. Microbes

Indirect evidence of microbial activity exists in the presence of subrounded, irregular, clotted, and interconnected peloidal structures (Fig. 12). This is generally deduced from the interpretation of similar structures that are common in many Phanerozoic reefs and considered as microbial in origin (Chafetz, 1986; Chafetz and Buczynski, 1992; Guo and Riding, 1992; Reitner, 1993; Pratt, 1995; Webb, 1996). As

clotting contributed considerably to sediment accumulation and to the rigidity of the later mounds, the role of microbes is fundamental in mound interpretation.

4.5. Metazoans

Calcisponges (probably Inozoans, as they are not chambered), besides *Donezella* and *Thartharella*, are the principal mound builders. They act as constructors and binders. Solitary corals and chaetetid sponges occur in some of bedded limestone above the mounds. The latter do not play any role in mound construction.
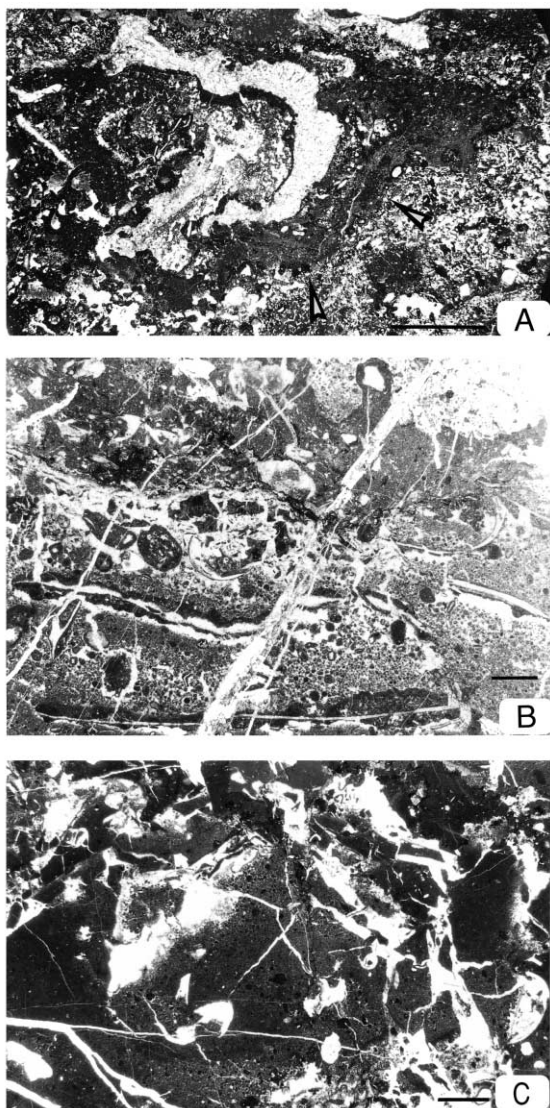
Fig. 12. Micritic cement (arrows) and peloidal sediment, which probably partly resulted from microbial activity, are abundant and obviously contributed to the rigidity of mounds. They are volumetrically important (up to 30%), overgrowing (A) and binding (B) bioclasts. The micritic cement and peloidal sediment seem to have been capable of constructing a framework as indicated by the numerous cement-filled voids lacking biota (C). Scale bar is 5 mm for all photomicrographs.

As suggested above, *Donezella*, the principal mound builder, may have excluded these other gregarious sessile metazoans and potential competitors from buildups.

4.6. Other fossils

Gastropods, ostracodes, bryozoans, and brachiopods are also present (Fig. 13). They are of secondary importance in mound construction. Bryozoans and brachiopods are conspicuous and diverse in the bedded limestone or capping facies (Bader, 1992).

5. Growth and demise of mounds, controlling factors

Ooids occur below the mounds, and as they are not continuous laterally, suggest the presence of ooids shoals/bars on which the mounds grew. Ooid shoals (unstable seabed; Flügel, 1982) were first stabilized, as indicated by the occurrence of coated grains (stable
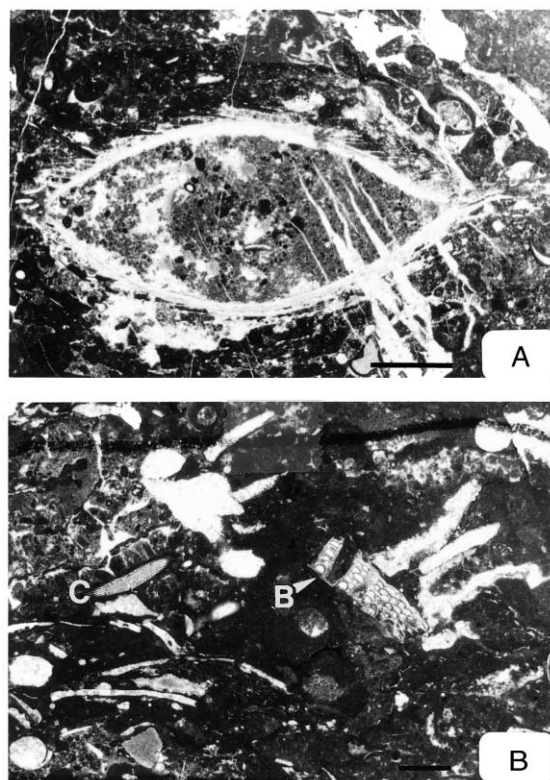

Fig. 13. Various fossils are common in the bedded rocks. These include brachiopods (A), bryozoans (B, arrow) and crinoids (C, left) (B). They only play a secondary role in mound construction, as they occur in intraframework voids and are not important volumetrically. Scale bar is 10 mm for all photomicrographs.

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seabed), before mound nucleation. Ooid bars and the oncolitic facies above these formed the *mound substrate facies*. In this siliciclastic–carbonate system, shoals built local highs, which seem to be the sites appropriated for growth initiation of mounds. Elias (1963) proposed a similar mode for mounds of the Paradox Basin, USA. This position protected the mound community from siliciclastic pollution. Boundstone, early cementation, and the resulting relief indicate that the mound-building community (algae, calcisponges, and worm tubes, along with microbes) colonized the substrate facies. Mound growth occurred below wave base as indicated by the delicate framework and the abundance of mud (Figs. 8 and 12). Hence, a transgressive event separated deposition of the mound substrate and mound facies. The *mound facies* is free of siliciclastic input. Mounds grew upward into a very shallow environment as indicated by the occurrence of ooids and grainstone (*capping facies*). The capping facies was slightly influenced by siliciclastic input. Mound growth was arrested, and the environment was locally colonized by corals and

chaetetid sponges. This capping facies was finally covered by siliciclastics (siltstone and sandstone). One can postulate a sea-level drop, combined with regression and siliciclastic input related to coastal erosion, to explain the upward increase in quartz content in the capping facies (Fig. 14).

The position of ooid shoals in this model differs from that proposed for the mounds of the Valdeteja Platform mounds. There, mounds seem to have grown in a lagoonal position behind, and protected by, ooid shoals (cf. Eichmüller, 1985, p. 84).

Relative sea-level fluctuations and differences in siliciclastic content among mound substrate, mound, and capping facies suggest allogenic controls on mound development, namely sea level and associated siliciclastic input. Facies changes reflect these variations, which are compatible with Late Paleozoic sealevel fluctuations (Heckel, 1994). Biotic changes are linked to these allogenic factors and do not reflect biogenic successions or zonation sensu stricto. Such variations have been reported in other Late Carboniferous sequences (cf. Heckel, 1994; Samankassou, 1997).

6. Comparison

Detailed reports of *Donezella*-dominated mounds are scarce. Data presented in this paper are compared only to that contained in a recent report of *Donezella*-dominated mounds by Choh and Kirkland (2000) from Oklahoma, USA.

• The mound substrates are similar in both areas, characterized by high-energy components.

• The boundstone facies of the mound intervals are similar in that both contain pores, encrustations, micritic cements, and *Archaeolithophyllum*. They differ in the abundance of siliceous sponges in Oklahoma, a rare component in the Cármenes area.

• Choh and Kirkland (2000) reported brachiopods, bryozoans, crinoids, and corals from the top of the mounds; thus, these fossils were part of the mound facies. In the Cármenes succession, these fossils are absent from the mound facies and occur only in the capping facies. Choh and Kirkland (2000) reported poor exposure conditions of the outcrops they investigated. A position of these fossils outside the mounds and, thus, identical to that of the Cármenes mounds, namely in the capping facies, is, therefore, probable.
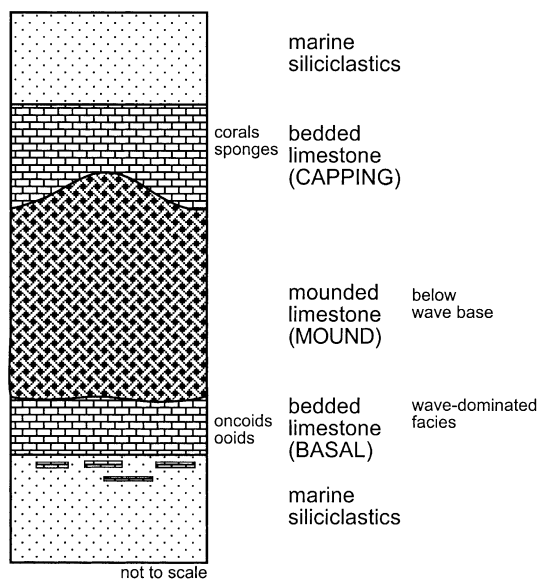

Fig. 14. Scheme of a typical sequence with siliciclastics, bedded limestone, including ooids and oncoids representing the mound substrate facies. Mounds built obvious relief and are overlain by bedded, siliciclastic-bearing limestone (capping facies) overlain, in turn, by siliciclastics. Mounds grew below wave base and their growth was probably arrested by shallowing and siliciclastic input.

The biotic association of the mound facies is similar to that of the Sierra de Cuera in Asturias, Spain, currently being studied (cf. short report in Kenter et al., 2000). These overall similarities in facies, depositional environment, and biotic association of known *Donezella*-dominated mounds point to a general mode of *Donezella*-dominated mound development.

7. Conclusions

The 6–12-m-thick mounds in the Cármenes area are characterized by skeletal–microbial boundstone. Donezellid algae, agglutinated worm tubes, and calcisponges are the dominant fossils. Accessory fossils are smaller foraminifers, gastropods, and brachiopods. A peloidal-clotted matrix is characteristic and accounts for more than 30% of mound volume. Most intraframe pores are filled with peloidal sediment and early marine cement. Mounds grew on stabilized ooid shoals as indicated by the occurrence of coated grains above the shoals and below the mounds.

Intermound strata are approximately one-third as thick as the mounds and lack mound fossils (algae, agglutinated worm tubes, and sponges). Intermound areas were generally more diverse, biotically, than mounds; they contain fusulinids, smaller foraminifers, bryozoans, gastropods, crinoids, and bioclasts.

Bedded packstone and grainstone, 3–6 m thick, with siliciclastics, rugose corals and chaetetid sponges characterize the capping facies. The presence of some coated grains and small ooids in the capping facies suggests a shallower water, higher energy environment and/or a higher input of siliciclastics, which may have arrested mound growth.

Mounds are interpreted to have accreted in quiet environments below wave base, at depths greater that those in which the mound substrate facies formed. Mound relief is explained by (1) accumulation of peloidal-clotted sediment that is limited to boundstone and probably related to microbial activities, (2) widespread marine cementation within this area, and (3) minimal transport of mound fossils into the intermound areas.

The position of the mounds within the sequence, and their initiation, size, and termination seem to be mainly controlled by sea-level fluctuations and siliciclastic input. Vertical biotic changes result from these fluctuations and do not represent ecological succession.

The main features (internal growth fabrics and repetition of facies and fossils) of these mounds in the Cármenes area, Spain are similar to those reported by Choh and Kirkland (2000) and Kenter et al. (2000) from *Donezella*-dominated mounds in Oklahoma, USA, and Spain, respectively. This implies a general rather than a local pattern. Future studies of *Donezella*-dominated mounds (e.g., from the well-exposed Sierra de Cuera Platform, Spain) at this detailed scale may provide more insights into and lead to further generalizations relative to this kind of mound.

References

Babcock, J.A., 1977. Calcareous algae, organic boundstones, and the genesis of the upper Capitan Limestone (Permian, Guadalupian), Guadalupe Mountains, west Texas and New Mexico. Hileman, M.E., Mazzullo, S.J. (Eds.), Upper Guadalupian Facies, Permian Reef Complex, Guadalupe Mountains, New Mexico and west Texas (1977 Field Conference Guidebook), vol. 77-16. Permian Basin Section-SEPM Publication, Tulsa, Oklahoma, pp. 3–44.

Babcock, J.A., 1986. The puzzle of alga-like problematica, or rummaging around in the algal wastebasket. In: Hoffman, A., Nitecki, M.H. (Eds.), Problematic Fossil Taxa. Oxford Univ. Press, New York, pp. 12–26.

Bader, B., 1992. Zur Geologie des südlichen Kantabrischen Gebirges westlich von Cármenes, NW Spanien mit einer systematischen Bearbeitung der oberkarbonischen Brachiopoden der Valdeteja Formation und der San Emiliano Formation. Diploma Thesis, Universität Kiel, Kiel, 120 pp.

Ball, S.M., Pollard, W.D., Robert, J.W., 1977. Importance of phylloid algae in development of depositional topography—reality or myth?. In: Frost, S.H., Weiss, M.P., Saunders, J.B. (Eds.), Reefs and Related Carbonates—Ecology and Sedimentology. American Association of Petroleum Geologists Studies in Geology vol. 4, 239–260.

Beauchamp, B., Davies, G.R., Nassichuk, W.W., 1989. Upper Carboniferous to Lower Permian *Palaeoaplysina*-phylloid algal buildups, Canadian Arctic Archipelago. In: Geldsetzer, H.H.J., James, N.P., Tebbutt, G.E. (Eds.), Reefs, Canada and Adjacent Areas. Canadian Society of Petroleum Geologists Memoir vol. 13, 590–599.

Blendinger, W., Bowlin, B., Zijp, F.R., Darke, G., Ekroll, M., 1997. Carbonate buildup flank deposits: an example from the Permian (Barents Sea, northern Norway) challenges classical facies models. Sedimentary Geology 112, 89–103.

Bowman, M.B.J., 1979. The depositional environment of a limestone unit from the San Emiliano Formation (Namurian/Westphalian), Cantabrian Mountains, NW-Spain. Sedimentary Geology 24, 25–43.

Bowman, M.B.J., 1983. The genesis of algal nodule limestones from the Upper Carboniferous (San Emiliano Formation) of N.W. Spain. In: Peryt, T.M. (Ed.), Coated Grains. Springer-Verlag, Berlin Heidelberg, New York, 409–423.

Brouwer, A., van Ginkel, A.C., 1964. La succession Carbonifère dans la partie méridionale des montagnes Cantabriques (Espagne Nord-Ouest). Comptes Rendus, 5ème Congrès sur le Carbonifère, Paris 1963 vol. 1, 307–319.

Chafetz, H.S., 1986. Marine peloids: a product of bacterially induced precipitation of calcite. Journal of Sedimentary Petrology 56, 812–817.

Chafetz, H.S., Buczynski, C., 1992. Bacterially induced lithification of microbial mats. Palaios 7, 277–293.

Chave, K.E., 1967. Recent carbonate sediments—an unconventional view. Journal of Geological Education 15, 200–204.

Choh, S.-J., Kirkland, B.L., 2000. Microfacies, biota, and depositional environment of an early Pennsylvanian (Morrowan) *Donezella*-siliceous sponge dominated bioherm, Frontal Ouachita Thrust Belt, Oklahoma, USA (abstract). SEPM-IAS Research Conference on Permo-Carboniferous Platforms and Reefs. El Paso, Texas, 15–16 May 2000, p. 37.

Dallmeyer, R.D., Martinez Garcia, E. (Eds.), 1990. Pre-Mesozoic Geology of Iberia. Springer, Berlin, 416 pp.

Davies, G.R., Richards, B.C., Beauchamp, B., Nassichuk, W.W., 1989. Carboniferous and Permian reefs in Canada and adjacent areas. In: Geldsetzer, H.J., James, N.P., Tebbutt, G.E. (Eds.), Reefs, Canada and Adjacent Areas. Canadian Society of Petroleum Geologists Memoir vol. 13, 565–574.

Dingle, P., Schäfer, P., 1997. Foraminifer associations and correlation between fusuline test and wall structure and water depth in Upper Carboniferous limestones of the Cantabrian Mountains (Northern Spain). Neues Jahrbuch für Geologie und Paläontologie Abhandlungen 206 (2), 197–221.

Dingle, P.S., Bader, B., Hensen, C., Minten, B., Schäfer, P., 1993. Sedimentology and paleoecology of Upper Carboniferous shallow-water carbonate complexes of the Carmenes Syncline (Cantabrian Mts., N-Spain). Zeitschrift der Deutschen Geologischen Gesellschaft 144, 370–395.

Eichmüller, K., 1985. Die Valdeteja Formation: Aufbau und Geschichte einer oberkarbonischen Karbonatplattform (Kantabrisches Gebirge, Nordspanien). Facies 13, 45–154.

Elias, G.K., 1963. Habitat of Pennsylvanian algal bioherms, Four Corners Area. In: Baas, R.O., Sharps, S.L. (Eds.), Shelf Carbonates, Paradox Basin (4th Field Conference Guidebook). Four Corners Geological Society, Durango, CO, pp. 185–203.

Elliott, G.F., 1962. More microproblematica from the Middle East. Micropaleontology 8 (1), 29–44.

Elliott, G.F., 1980. Revision of the microproblematicum *Prethocoprolithus* Elliott, 1962. Bulletin of the British Museum of Natural History (Geology) 34 (4), 251–254.

Fagerstrom, J.A., 1987. The Evolution of Reef Communities. Wiley, New York, 592 pp.

Flügel, E., 1977. Environmental models for Upper Paleozoic benthic algal communities. In: Flügel, E. (Ed.), Fossil Algae: Recent Results and Developments. Springer-Verlag, Berlin, Heidelberg, New York, pp. 314–343.

Flügel, E., 1979. Paleoecology and microfacies of Permian, Triassic and Jurassic algal communities of platform and reef carbonates from the Alps. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine 3 (2), 569–587.

Flügel, E., 1982. Microfacies Analysis of Limestones. Springer-Verlag, Berlin, Heidelberg, New York, 633 pp.

Flügel, E., 1987. Reef Mound-Entstehung: Algen-Mounds im Unterperm der Karnischen Alpen. Facies 17, 73–90.

Forke, H.C., Samankassou, E., 2000. Biostratigraphical correlation of Late Carboniferous (Kasimovian) sections in the Carnic Alps (Austria/Italy): integrated paleontological data, facies, and discussion. Facies 42, 177–210.

Guo, L., Riding, R., 1992. Microbial carbonates in uppermost Permian reefs, Sichuan basin, southern China: some similarities with Recent travertines. Sedimentology 39, 37–53.

Hay, M.E., 1997. Calcified seaweeds on coral reefs: complex defenses, trophic relationships, and value as habitats. Procedings of the 8th International Coral Reef Symposium (Panama) vol. I, 713–718.

Heckel, P.H., 1994. Evaluation of evidence for glacio-eustatic control over marine Pennsylvanian cyclothems in North America and consideration of possible tectonic effects. In: Dennison, J.M., Ettensohn, F.R. (Eds.), Tectonic and Eustatic Controls on Sedimentary Cycles. SEPM Concepts in Sedimentology and Paleontology vol. 4, 65–87.

Hensen, C., Dingle, P., Schäfer, P., 1995. Primary and diagenetic mud mound genesis in the San Emiliano Formation of the Cármenes syncline (Westphalian B/C, Cantabrian Mts, Spain). In: Reitner, J., Neuweiler, F. (Coordinators), Mud Mounds: A Poly-

genetic Spectrum of Fine-grained Carbonate Buildups. Facies 32, 31–36.

Johnson, H.J., 1950. A Permian algal–foraminiferal consortium from West Texas. Journal of Paleontology 24, 61–62.

Johnson, J.H., 1963. Pennsylvanian and Permian algae. Colorado School of Mines Quarterly 58, 1–211.

Julivert, M., 1971. Décollement tectonics in the Hercynian Cordillera of Northwest Spain. American Journal of Science 270, 1–29.

Kenter, J.A.M., Della Porta, G., Immenhauser, A., Bahamonde, J.R., 2000. Anatomy and lithofacies distribution across a Pennsylvanian inner platform transect (Sra de Cuera, Asturias, Spain) (abstract). SEPM-IAS Research Conference on Permo-Carboniferous Platforms and Reefs, El Paso, Texas, 15–16 May 2000, p. 89.

Kirkland, B.L., Dickson, J.A.D., Wood, R.A., Land, L.S., 1998. Microbialite and microstratigraphy: the origin of encrustations in the middle and upper Capitan Formation, Guadalupe Mountains, Texas and New Mexico, USA. Journal of Sedimentary Research 68 (5), 956–969.

Krainer, K., 1995. *Anthracoporella* mounds in the Late Carboniferous Auernig Group, Carnic Alps (Austria). Facies 32, 195–214.

Lotze, F., 1945. Zur Gliederung der Varisziden der Iberischen Meseta. Geotektonische Forschungen 6, 78–92.

Mamet, B., 1991. Carboniferous calcareous algae. In: Riding, R. (Ed.), Calcareous Algae and Stromatolites. Springer-Verlag, Berlin, Heidelberg, New York, pp. 370–451.

Mamet, B., Roux, A., 1975. Dasycladacees Dévoniennes et Carbonifères de la Tethys Occidentale. Revista Espanola de Paleontologia 7, 245–295.

Mamet, B., Nassichuk, W., Roux, A., 1979. Algues et stratigraphie du Paléozoïque supérieur de l'Arctique Canadien. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine 3 (2), 669–683.

Mamet, B.L., Roux, A., Nassichuk, W.W., 1987. Algues Carbonifères et Permiennes de l'Arctique Canadien. Geological Survey of Canada Bulletin 342, 1–143.

Martínez-Chacón, M.L., 1977. New carboniferous stenoscismatacean brachiopods from Oviedo and León, Spain. Palaeontology 20, 209–223.

Morin, J., Desrochers, A., Beauchamp, B., 1994. Facies analysis of Lower Permian platform carbonates, Sverdrup Basin, Canadian Arctic Archipelago. Facies 31, 105–130.

Paul, V.J., 1997. Secondary metabolites and calcium carbonate as defenses of calcareous algae on coral reefs. Proceedings of the 8th International Coral Reef Symposium (Panama) vol. I, 707–712.

Perez Estaun, A., 1990. Cantabrian and palentian zones, introduction. In: Dallmeyer, R.D., Martinez Garcia, E. (Eds.), Pre-Mesozoic Geology of Iberia. Springer, Berlin, pp. 7–9.

Perez Estaun, A., Bastida, F., Alonso, J.L., Marquínez, J., Aller, J., Alvarez Marrón, J.A., Marcos, A., Pulgar, J.A., 1988. A thin-skinned tectonic model for an arcuate and thrust belt: the Cantabrian Zone (Variscan Ibero–Armorican Arc). Tectonics 7, 517–537.

Pia, J., 1937. Die wichtigsten Kalkalgen des Jungpaläozoikums und ihre geologische Bedeutung. Compte rendu 2e Congrès international pour l'avancement de la stratigraphie du Carbonifère, Heelen 1935 vol. 2, 765–856.

Pratt, B.R., 1982. Stromatolitic framework of carbonate mud mounds. Journal of Sedimentary Petrology 52, 1203–1227.

Pratt, B.R., 1995. The origin, biota and evolution of deep-water mud-mounds. In: Monty, C.L.V., Bosence, D.V.J., Bridges, B.R., Pratt, B.R. (Eds.), Carbonate Mud-Mounds: Their Origin and Evolution. International Association of Sedimentologists Special Publication vol. 23, 49–123.

Rácz, L.G., 1964. Carboniferous calcareous algae and their associations in the San Emiliano and Lois-Ciguera Formations (prov León, NW Spain). Leidse Geologische Mededelingen 31, 1–112.

Reitner, J., 1993. Modern cryptic microbialite/Metazoan facies from Lizard Island (Great Barrier Reef, Australia): formation and concepts. Facies 29, 3–40.

Rich, M., 1967. *Donezella* and *Dvinella*, widespread algae in Lower and Middle Pennsylvanian rocks in eastern-central Nevada and west-central Utah. Journal of Paleontology 41, 973–980.

Riding, R., 1977. Reef concepts. In: Taylor, D.L. (Ed.), Proceedings of the Third International Coral Reef Symposium. University of Miami, Rosenstiel School of Marine and Atmospheric Science, Miami, FL, pp. 209–214.

Riding, R., 1979. *Donezella* bioherms in the Carboniferous of the southern Cantabrian Mountains, Spain. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine 3, 787–794.

Riding, R., Guo, L., 1992. Affinity of *Tubiphytes*. Palaeontology 35, 37–49.

Riding, R., Jansa, L.F., 1974. *Uraloporella* Korde in the Devonian of Alberta. Canadian Journal of Earth Sciences 11, 1414–1426.

Roux, A., 1979. Révision du genre *Epimastopora* "Pia 1922" (Dasycladaceae). Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine 3, 803–810.

Roux, A., 1985. Introduction à l'étude des algues fossiles paléozoïques (de la bactérie à la tectonique des plaques). Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine 9 (2), 465–699.

Samankassou, E., 1997. Palaeontological response to sea-level change: the distribution of fauna and flora in cyclothems from the Lower Pseudoschwagerina Limestone (Latest Carboniferous, Carnic Alps, Austria). Geobios 30, 785–796.

Samankassou, E., 1998. Skeletal framework mounds of dasycladalean alga *Anthracoporella*, Upper Paleozoic, Carnic Alps, Austria. Palaios 13, 297–300.

Samankassou, E., West, R., 2000. Construction versus accumulation in phylloid algal mounds: case study from the Pennsylvanian Frisbie Limestone Member, Kansas, USA. SEPM-IAS Research Conference on Permo-Carboniferous Platforms and Reefs, El Paso, Texas, 15–16 May 2000, p. 121.

Senowbari-Daryan, B., Flügel, E., 1993. *Tubiphytes* Maslov, an enigmatic fossil: classification, fossil record and significance through time: Part I. Discussion of Late Paleozoic material. In: Barattolo, F., De Castro, P., Parente, M. (eds.), Studies on Fossil Benthic AlgaeBolletino della Società Paleontologica Italiana Special vol. 1 Mucchi Editore, Modena, pp. 353–382.

Termier, H., Termier, G., Vachard, D., 1977. On Moravamminida and Aoujgaliida (Porifera, Ischyrospongia): Upper Paleozoic

"Pseudo Algae". In: Flügel, E. (ed.), Fossil Algae. Springer-Verlag, Berlin, pp. 215–219.

Toomey, D.F., 1991. Late Pennsylvanian phylloid-algal bioherms, Orogrande basin, south-central New Mexico and Texas. In: Barker, J.M., Kues, B.S., Austin, G.S., Lucas, S.G. (Eds.), Geology of the Sierra Blanca, Sacramento and Capitan Ranges, New Mexico. 42nd Annual Field Conference Guidebook. New Mexico Geological Society, Socorro, NM, pp. 213–220.

Toomey, D.F., Mitchell, R.W., Lowenstein, T.K., 1988. "Algal biscuits" from the Lower Permian Herington/Krider Limestones of southern Kansas–northern Oklahoma: paleoecology and paleodepositional setting. Palaios 3, 285–297.

Vachard, D., 1981. Téthys et Gondwana au Paléozoïque supérieur; les données afganes. Institut Géologique Albert de Lapparent, Documents et Travaux, 463 pp.

Vachard, D., Perret, M.F., Delvolvé, J.J., 1989. Algues, Pseudo-algues et foraminfères des niveaux Bachkiriens dans les secteurs d'Escarra et Aragon Subordan (Pyrénées aragonaises, Espagne). Geobios 22 (6), 697–723.

van den Bosch, W.J., 1969. Geology of the Luna-Sil region, Cantabrian Mountains (NW Spain). Leidse Geologische Mededelingen 44, 137–225.

van Ginkel, A.C., 1965. Carboniferous fusulunids from the Cantabrian Mountains (Spain). Leidse Geologische Mededelingen 34, 1–225.

van Ginkel, A.C., Villa, E., 1996. Palaeontological data of the San Emiliano Formation (Cantabrian Mountains, Spain) and their significance in the Carboniferous chronostratigraphy. Geobios 29 (2), 149–170.

Vennin, E., Vachard, D., Proust, J.-N., 1997. Taphonomie et synécologie du "Genre" *Tubiphytes* dans les bioconstructions de la Tratau et de Nizhni-Irginsk (Permien inférieur de l'Oural, Russie). Geobios 30 (5), 635–649.

Wagner, R.H., Bowman, M.B.J., 1983. The position of the Bashkirian/Moscovian boundary in West European chronostratigraphy. Newsletters on Stratigraphy 12 (3), 132–161.

Wahlman, G.P., 1985. Lower Permian (Wolfcampian) Archaeolithoporella–*Tubiphytes*–sponge boundstones from the subsurface of west Texas. In: Toomey, D.F., Nitecki, M.H. (eds.), Paleoalgology: Contemporary Research and Applications. Springer-Verlag, Berlin, Heidelberg, New York, pp. 208–215.

Wahlman, G.P., 1988. Subsurface Wolfcampian (Lower Permian) shelf-margin reefs in the Permian Basin of west Texas and southeastern New Mexico. In: Morgan, W.A., Babcock, J.A. (Eds.), Permian Rocks of the Midcontinent, vol. 1. Midcontinent Section-SEPM Special Publication, Tulsa, Oklahoma, pp. 177–204.

Webb, G.E., 1996. Was Phanerozoic reef history controlled by the distribution of non-enzymatically secreted reef carbonates (microbial carbonate and biologically induced cement)? Sedimentology 43, 947–971.

Wilson, J.L., 1975. Carbonate Facies in Geologic History. Springer-Verlag, Berlin, Heidelberg, New York, pp. 471.

Wilson, J.L., 1977. Regional distribution of phylloid algal mounds in Late Pennsylvanian and Wolfcampian strata of southern New Mexico. In: Butler, J.H. (ed.), Geology of the Sacramento Mountains, Otero County, New Mexico: vol. 77-68. West Texas Geological Society Publication, Midland, TX, pp. 1–7.

Winkler-Prins, C.F., 1968. Carboniferous Productina and Chonetidina of the Cantabrian Mountains (NW Spain): systematics, stratigraphy and paleoecology. Leidse Geologische Mededelingen 43, 41–126.