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Palynological age constraint of Les Vilelles unit, Catalan Coastal Chain, Spain

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ABSTRACT

Les Vilelles unit is a detrital sequence exposed at the southwestern margin of the Catalan Coastal Chain (CCC), NE Spain, below the Carboniferous turbiditic series. Based on the palynological content, the age of this unit was initially assigned to the Middle-Late Devonian (Eifelian to Famennian). Additional radiolarian and conodont findings were considered to be Early–Middle Mississippian (Tournaisian to early Visean). To clarify this age discrepancy a new and more comprehensive palynostratigraphic analysis has been conducted in the upper part of the section representative of Les Vilelles unit. This has provided an assemblage of miospores, acritarchs, prasinophyta phycomata and chitinozoans that can be confidently assigned to a latest Frasnian interval, in contact with the Frasnian–Famennian boundary. Therefore, the present analysis refines the Middle–Late Devonian age formerly assigned, establishes a latest Frasnian age for the top of the unit, and provides new insights to the better understanding of the unconformity and hiatus separating the pre-Carboniferous and Carboniferous CCC series in the Priorat Massif. The study also includes a systematic section with the description of three newly established miospore species: *Dibolisporites coniugatum*, *Dibolisporites prioratum* and *Rugospora spinosa*.

KEYWORDS **Les Vilelles unit. Catalonian Coastal Chains. Palynology. Late Devonian. Frasnian–Famennian.**

INTRODUCTION

The Catalan Coastal Chain (CCC) are a narrow NE-SW Alpine structure that runs parallel to the Mediterranean coast where some of the northeasternmost Variscan outcrops in the Iberian Peninsula occur. The Palaeozoic series of the CCC has been correlated with those of eastern Pyrenees, Montagne Noire, Menorca Island, Sadinia, Iberian Massif, French Central Massif and Chenous (Algeria) (Julivert and Martínez, 1983; Julivert et al., 1983; Julivert et al., 1985; Sáez abd Anadón, 1989; Julivert and Durán, 1990a,b; Raymond and Caridroit, 1993; Sanz López et al, 2000).

Classically, the Upper Palaeozoic of the CCC has been divided in pre-Carboniferous and Carboniferous series (*i.e.*, Julivert and Durán, 1990a). Whilst the Carboniferous series are relatively well constrained, the Devonian was attributed to disparate chronostratigraphies. The biostratigraphy of the Devonian successions exposed at the central and northern sectors of the CCC is well known (see, for example, Julivert *et al.*, 1985, 1987; García López *et al.*, 1990; Barnolas and García-Sansegundo, 1992; Ferrer *et al.*, 1992; Racheboeuf *et al.*, 1993; Valenzuela Ríos and García López, 1998; Sanz López *et al.*, 1998; Gutiérrez-Marco *et al.*, 1999; García-Alcalde *et al.*, 2002; Plusquellec *et al.*, 2007). By contrast, the age of the most significant Devonian sequence to the south, informally defined as Les Vilelles unit in the Priorat Massif (Sáez, 1982), is confusing.

On the basis of the palynological content of two closely collected shale samples, Colodrón *et al.* (1979) dated Les Vilelles unit as Middle to Late Devonian (Eifelian to Famennian). Since then, some authors considered that the age of Les Vilelles unit spans the entire Middle to Late Devonian interval (Sáez and Anadón, 1989; Villalba-Breva and Martín Closas, 2009) while some others select an arbitrarily age range within such interval (Anadón *et al.*, 1985b; García-Alcalde *et al.*, 2002; Carls *et al.*, 2004). The uncertainty about the age is enlarged with a second biostratigraphic study in the Priorat Massif. Raymond and Caridroit (1993) analyzed an assemblage of radiolarians and conodonts from two radiolaritic chert samples close to those analyzed by Colodrón *et al.* (1979) providing a Mississippian (Tournaisian to early Visean) age. Apart from being contradictory, the two biostratigraphic studies to date available at the "pre-Carboniferous" succession of the Priorat Massif are devoid of any taxonomic description or illustration and include a high number of species left in open nomenclature ("sp" and "cf"). In consequence, a detailed biostratigraphic study of this unit was required.

The present study analyzes palynologically the upper part of the most representative section of Les Vilelles unit, previously studied by Sáez (1982) to define it providing a more solid age constraint. It includes illustrations of most of the reported palynomorphs together with the systematic-descriptive analysis of the newly established species as well as those left in open nomenclature. Although biostratigraphically oriented in essence, the study also provides insights into the relation between the pre-Carboniferous and Carboniferous series of the CCC.

GEOLOGICAL SETTING

The CCC consists of two parallel mountain chains separated by an intermediate graben, located in NE Spain. They run NE-SW *circa* 250km from the southern margin of the Pyrenean belt to the linking zone with the Iberian Chain, west of the Ebro Delta, and extend transversally an average of 30km from the Mediterranean coast to the eastern border of the Ebro Basin. The chains, named Littoral and pre-Littoral, include numerous Palaeozoic/Mesozoic massifs and large upper Variscan batholith intrusions, mainly to the north. The graben between two chains, the Vallès-Penedès depression, consists essentially of upper Oligocene-Miocene detrital sediments (Fig. 1A).

The Palaeozoic stratigraphical record of the CCC has been traditionally divided into two series, pre-Carboniferous and Carboniferous, separated by a stratigraphical discontinuity (Julivert and Martínez, 1983; Julivert and Durán, 1990a). The pre-Carboniferous series are well exposed at the northern part of the CCC where they comprise large outcrops of Lower Cambrian to Lower Devonian detrital and carbonate rocks. To the south they are poorly represented. By contrast, the Carboniferous series, essentially turbiditic, are best exposed in the southern sector, particularly in the Priorat Massif, but are rare to the north. This distribution probably reflects the original palaeogeographic configuration of the CCC.

The stratigraphic gap separating the Carboniferous and pre-Carboniferous series, that may extend from Cambrian to Carboniferous in the northern sector of the CCC, is substantially smaller to the south. There, even in the absence of confirmatory chronostratigraphic studies, it is possible to assume that this unconformity could pass in some localities into its correlative conformity. In such cases the stratigraphic record, although continuous, must be represented by a condensed sequence.

In the Priorat Massif, where Les Vilelles unit is located, the pre-Carboniferous succession exhibits a patchy distribution, with series of siliciclastic rocks (shales and quartzites), carbonates (dolostones, limestones, and calcarenites), metaevaporites and black cherts that range from Early Cambrian to Devonian (Julivert, 1955; Solé Sabarís, 1973; Melgarejo and Martí, 1989; Julivert and Durán, 1990a; Melgarejo and Ayora, 1990; Melgarejo, 1993; Gutiérrez-Marco *et al.*, 2004). The Carboniferous series unconformably covering all these rocks is, by contrast, more widely exposed. It consists of three conformable thick sequences (Sáez, 1982): i) the Bassetes unit, a 400m thick sequence of graywackes, conglomerates, and shales in wildflysh facies with limestone lenses and chert olistostromes, dated as middle to late Visean (Sáez, 1982; Villalba-Breva and Martín-Closas, 2009); ii) the Scala Dei unit, a 400m thick turbidite sequence, of Serpukhovian age, representing a more distal deep sea fan facies and iii) the Poboleda unit, that includes more than 2000m of turbidites organized in megasequences attributed to the Bashkirian–early Moscovian (Colodrón *et al.*, 1976; 1978; Orche and Colodrón, 1977; Orche *et al.*, 1977; Maestro-Maideu *et al.*, 1998).

During the Variscan Orogeny the Palaeozoic rocks from the CCC were deformed and affected by high- to medium grade regional metamorphism in the northern domains, and only low grade regional metamorphism to the south (Julivert and Durán, 1990b). Postdating the deformation, large granodiorite batholiths (Enrique, 1990) intruded the Palaeozoic rocks and generated epizonal contact metamorphism halos that occasionally extend hundreds of meters (Gil Ibarguchi and Julivert, 1988). The Palaeozoic rocks were unconformably covered by

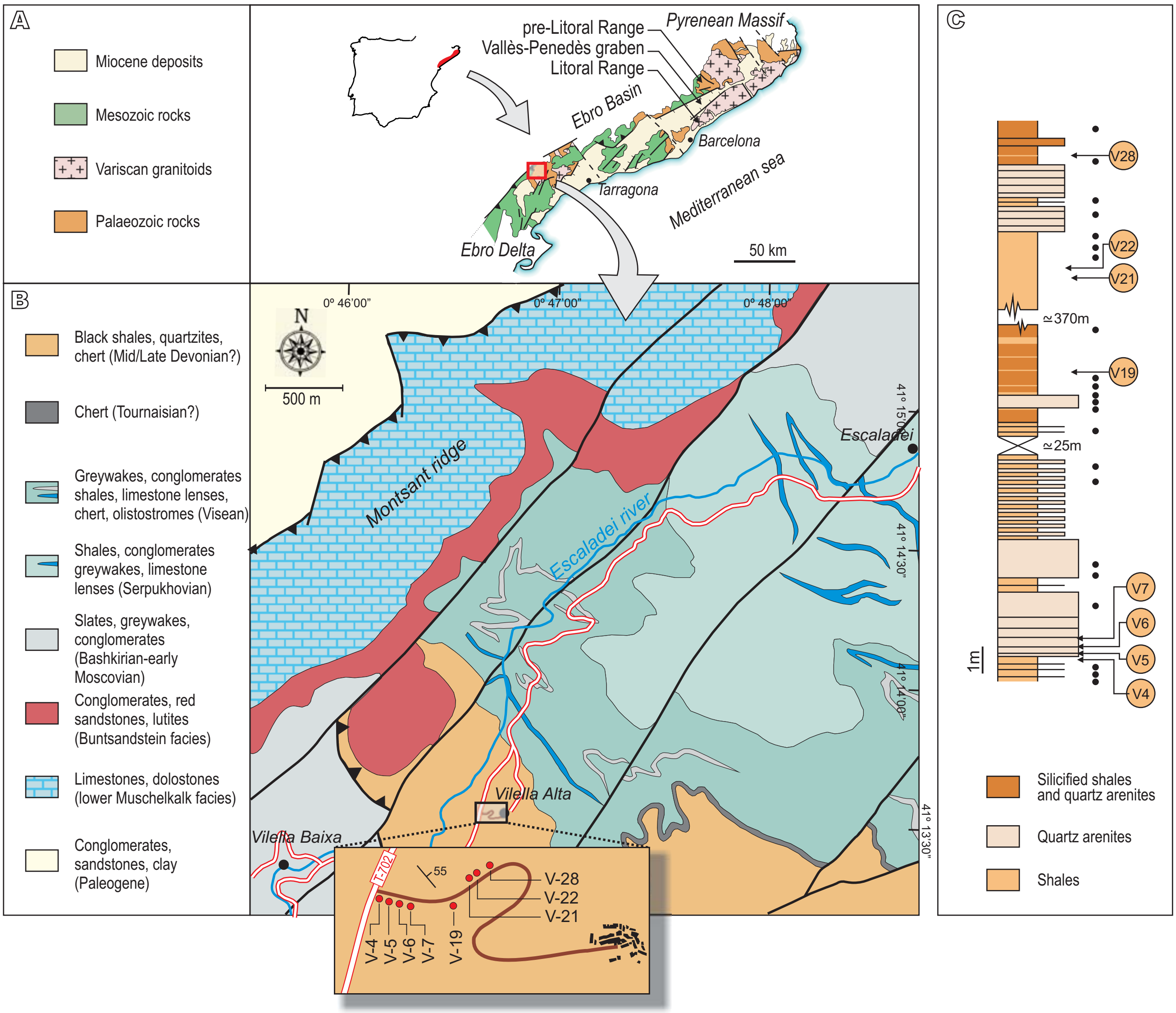

FIGURE 1. A) Geological sketch map of the Catalan Coastal Chain showing the location of the study area. B) Study area at the central Priorat Massif showing the location of palynologically productive samples; modified from Melgarejo (1987). C) Stratigraphic log showing the location of productive and unproductive samples (labelled circles and black dots, respectively).

detrital and carbonate Mesozoic sediments and deformed again during the Alpine Orogeny (Virgili, 1958; Calvet, 1986; Ortí, 2004; Sánchez Moya *et al.*, 2004a,b,c). During the Paleogene, the activity of NE-SW strike slip faults controlled the deposition of large amounts of syntectonic and post-tectonic series, mainly detrital (Anadón *et al.*, 1985a; Colombo, 1986). The reactivation of these faults during the Neogene extension produced the present-day configuration in horsts and grabens.

The studied Les Vilelles unit is located at the southern margin of the CCC. Although its cartographic significance at regional scale is limited, its stratigraphic position and age are pivotal in the understanding of the palaeogeography and, in general, the Palaeozoic record of the CCC.

Les Vilelles unit is cropping out at the core a NW-SE Variscan anticline whose axial plane dips gently to the NE. The inverted SW flank has been detached and the Devonian rocks overthrust the Carboniferous series. The intense deformation affecting the Devonian rocks precludes a detailed reconstruction of the whole stratigraphic log. The best outcrops of Les Vilelles unit are located between kms 16 and 17 of the road T-702, and particularly along the track connecting this road with La Vilella Alta (Fig. 1B). There, the stratigraphic record of Les Vilelles unit consists of a 250m alternating quartz arenites and grey/black shales (Melgarejo, 1993; Canet, 2001). The stratigraphic base level of this unit as well as the total thickness is unknown. Toward the top, the sequence exhibits strong silicification and is unconformably topped by the Carboniferous Bassetes unit (Julivert and Martínez, 1983; Sáez and Anadón, 1989; Julivert and Durán, 1990a).

MATERIAL AND METHODS

The shale samples of Les Vilelles unit constituting the basis of the present study were collected from a cutting along the track connecting the road T-702 with La Vilella Alta village (Fig. 1B). The section analyzed includes strongly tectonized intervals and was affected by moderate to intense weathering. For this reason the sample spacing was inevitably inconsistent (Fig. 1C). Virtually all the 30 samples analyzed resulted productive in terms of palynomorph content. However, their detrimental preservation state, manifested principally during the oxidation treatment, allowed the microscope analysis of only 8 samples.

Laboratory procedures employed for the extraction and concentration of palynomorphs were essentially those described by Wood *et al*. (1996). Approximately 30g of sample were disaggregated and subsequently immersed in hydrochloric acid (36%) to dissolve the carbonates. The silicates were removed with hot hydrofluoric acid (40%) and the fluorides and remaining carbonates with hot hydrochloric acid (36%). The remaining organic residue was oxidized with fuming Schulze solution for time interval varying from 1 to 5 minutes. Following the neutralization of the residue with distilled water, the palynomorphs were concentrated with the help of a 20µm sieve and a minimum of two slides per sample were permanently mounted, using "Cellosize" as dispersing agent and "Elvacite" as mounting medium.

The light microscopy was performed in the Department of Geology, University de Huelva with a Nikon Labaphot-2 microscope equipped with the digital camera Nikon DS-Fi1 (software NIS Elements, F Package, 3.22.00). The entire collection of specimens illustrated herein will be housed permanently in the Museo Geominero del Instituto Geológico y Minero de España, Madrid. Repository numbers, slide locations and additional curatorial details of type and other figured specimens are indicated in Appendix I.

SYSTEMATIC PALAEONTOLOGY

This systematic section includes three newly instituted species of miospores established on the basis of at least 10 well preserved specimens, one apparently new species sustained by fewer than 10 specimens, which has been informally designated with the letter "A", and another form uncertainly affiliated to a previously instituted species. This last taxon incorporates the abbreviation "cf." preceding the specific epithet. The miospores have been treated as fossil-taxa according to the provisions of the International Code of Nomenclature for algae, fungi and plants (McNeill *et al*., 2012), and are listed alphabetically. Regarding the morphological terminology, the descriptions accord with the glossaries provided by Dettmann (1963), Kremp (1965), Smith and Butterworth (1967), and Playford and Dettmann (1996). Dimension of miospores refers to the equatorial diameter (excluding projections) in polar compression and is given by the arithmetic mean bracketed between the lowest and highest values.

DESCRIPTIVE SYSTEMATICS

GENUS *Cymbosporites* ALLEN, 1965

Type species. *Cymbosporites magnificus* (MCGREGOR) MCGREGOR AND CAMFIELD, 1982; originally designated as C. *cyathus* ALLEN, 1965 (= junior synonym of *C. magnificus* according to MCGREGOR AND CAMFIELD, 1982, p. 32).

Cymbosporites sp. cf. *C. magnificus* (MCGREGOR) MCGREGOR AND CAMFIELD, 1982
Figures 2L, M

cf. 1960 *Lycospora magnifica* MCGREGOR, p. 35, pl. 13, figs. 2-4.

cf. 1965 *Emphanisporites cyathus* ALLEN, p.725, pl. 101, figs. 8-11.

cf. 1982 *Cymbosporites magnificus* ALLEN (MCGREGOR AND CAMFIELD), p. 32, pl. 6, figs. 4, 5; txt-fig. 42.

For extended synonymy see McGregor and Camfield (1982, p. 32).

Description. Spores radial, trilete. Amb subcircular to convexly subtriangular. Laesura simple, distinct, straight to somewhat sinuous, extending almost to equator; commonly accompanied by narrow lips, up to 1.5µm in overall width, terminating in curvature perfectae. Exoexine proximally laevigate to faintly scabrate, ca. 1µm thick; distally and equatorially patinate, 5-10µm thick. Patina sculptured with close-spaced, rarely fused verrucae, coni and minor mamillae up to 2.5µm high, 0.5-2µm (rarely up to 4µm) in basal diameter.

Dimensions. (9 specimens): equatorial diameter 45 (57.5) 63µm.

Comparison. Sculpture and overall width in the Priorat specimens are somewhat smaller than is usual for

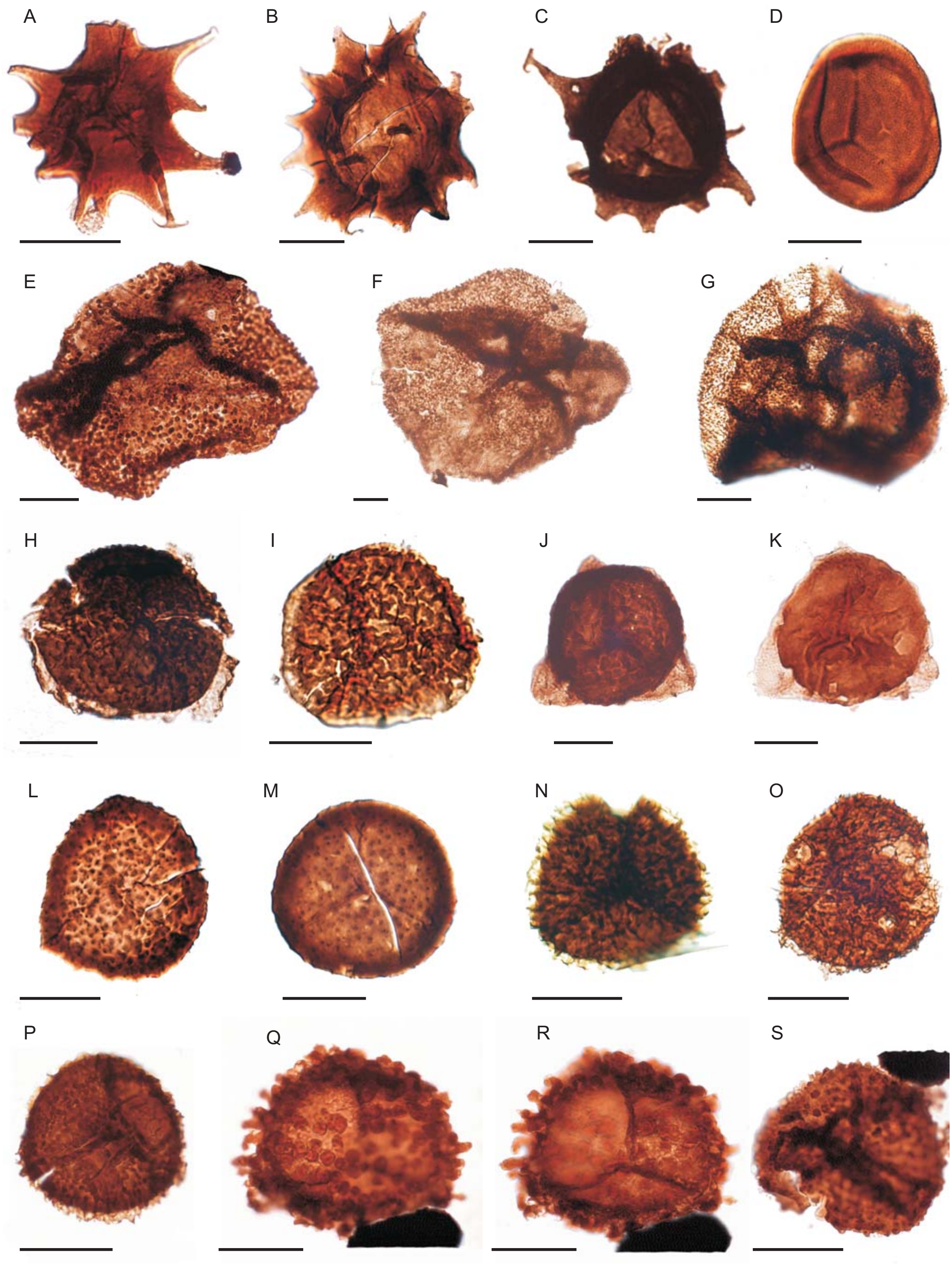

FIGURE 2. A-C) *Ancyrospora melvillensis* Owens, 1971; distal foci. D) *Aneurospora gregsii* (McGregor) Streel in Becker, Bless, Streel and Thorez, 1974; median focus. E-G) *Apiculatasporites adevalensis* (de Jersey) Grey, 1992; median foci. H, I) *Cristatisporites inusitatus* (Allen) McGregor and Camfield, 1982; median foci. J, K) *Cristatisporites triangulatus* (Allen) McGregor and Camfield, 1982; median foci. L, M) *Cymbosporites* sp. cf. *C. magnificus* (McGrergor) McGregor and Camfield, 1982; median foci. N-P) *Dibolisporites coniugatum* sp. nov. N (holotype). O, distal foci, P, median foci. Q-S) *Dibolisporites prioratum* sp. nov.; Q, R, distal and proximal foci of the same specimen (holotype), S, distal focus. Scale bars represent 25μm.

Cymbosporites magnificus (McGregor) McGregor and Camfield, 1982, but are otherwise closely comparable with the type species. *C. catillus* Allen, 1965 (p.727, pl. 100, figs. 11, 12) has similar equatorial diameter but differs in having smaller and more closely spaced sculptural projections (mainly grana and verrucae).

Previous records (of *C. magnificus per se*). Richardson and McGregor (1986) defined this species as index for the *lemurata-magnificus* assemblage Zone of the Old Red Sandstones and adjacent regions, suggesting a middle Givetian–early Famennian? stratigraphic age range. Although known widely from strata of such age range, younger occurrences (late Famennian–late Tournaisian) have been also described in England (Higgs and Clayton, 1984) and Ireland (Higgs *et al*., 1988).

GENUS *Dibolisporites* Richardson emend. Playford, 1976

Type species. *Dibolisporites echinaceus* (Eisenack) Richardson, 1965; by original designation.

Dibolisporites coniugatum sp. nov.
Figure 2N, O, P

Diagnosis. Spores radial, trilete. Amb convexly subtriangular. Laesurae distinct, straight, extending nearly to equatorial margin; associated with membranous labra, up to 5µm high at pole, tapering toward the equator. Exine 1.5-2µm thick, distally and proximo-equatorially sculptured with densely packed coni, spinae and bacula, 2.5-4.5µm high, 1-2.5µm in basal diameter, 1-3.5µm apart. Sculptural elements generally surmounted by one, rarely two, slender minute coni, up to 0.5µm high; occasionally fused at bases to form short, narrow, sinuous, freely terminating rugulae, up to 6µm long. Contact areas bearing sparser and finer sculptural elements.

Dimensions. (14 specimens): 42 (52) 79µm.

Holotype (MGM-3361D-3). Preparation V-28/a, England Finder E44/3, Figure 2N. Amb subcircular, 51µm in diameter. Leasurae distinct, lipped, reaching equator. Exine 2µm thick, sculptured distally and proximo-equatorially with coni, spinae and bacula, 2.5-4µm high, 1-2µm in basal diameter, up to 2µm apart, surmounted by minute coni. Some sculptural element basely fused, defining short, narrow rugulae. Contact areas with minor sculpture.

Paratypes. Figures 2O (MGM-3361D-4), 2P (MGM-3361D-5).

Name derivation. Latin, *coniugatum*, mixed, joined.

Remarks and comparison. This species is assignable to *Dibolisporites* on accounts of its biform sculpture, and the dominance of coni, spinae and bacula at the basal portion of the projections. *Dibolisporites coniugatum* sp. nov. appears similar to *D. farraginis* McGregor and Camfield, 1982 (p. 38, pl. 8, figs. 3, 4; txt-fig. 54), but the latter is somewhat larger and possesses sculptural elements discrete, not basely fused. *Rugospora explicata* González, Playford and Moreno, 2005 (p. 33, pl. 7, figs. 14-18; pl. 8, figs. 1-3) displays also short, narrow rugulae and apiculate distal sculpture, but this species is cavate and the apiculate sculpture, conformed by broad-based coni, bacula and minor pila, surmounts the rugulae.

Dibolisporites perioratum sp. nov.
Figures 2Q-R, S, 3A

Diagnosis. Spore radial trilete. Amb rounded subtriangular to broadly subcircular. Laesurae distinct to obscure, bordered by narrow labra 3-4µm in overall width, tapering to equator and extending at least three quarters of distance to equatorial margin. Exine 2-4.5µm thick equatorially and distally sculptured with discrete to rarely fused, unevenly distributed pilate, verrucate and bulbous baculate projections, usually surmounted by a subsidiary apiculate element. Projections circular to irregularly rounded at bases, 2-7µm in overall width, 4-10µm long, 1-10µm apart. Apiculate surmounted elements consist of coni and spinae up to 1.5µm in maximum dimension. Processes near equator are normally larger and more densely packed. Contact areas and non-sculptured distal exine scabrate.

Dimensions. (10 specimens): 42 (52) 75µm.

Holotype (MGM-3354D-3). Preparation V-5/c, England Finder U35/0, Figures 2Q, R. Amb rounded subtriangular; overall diameter, including sculpture, 75µm. Laesurae straight, accompanied by narrow lips (3.5µm high) reaching equatorial margin. Equatorial and distal exine sculptured with biform elements consisting of major pila, verrucae and bulbous bacula, circular to irregularly rounded in basal diameter (3-6µm basally, 4-10µm high), surmounted by one thin spina or conus (up to 1.5µm in overall dimension). Sculpture normally discrete, 2-10 µm apart, most densely distributed near equator. Non-sculptured exoexine, including contact areas, scabrate.

Paratypes. Figures 2S (MGM-3353D-3), 3A (MGM-3352D-1).

Name derivation. From Priorat, the name of the study area.

Comparison. *Dibolisporites prioratum* sp. nov. is comparable with *D. bullatus* (Allen) Riegel, 1973 (p.

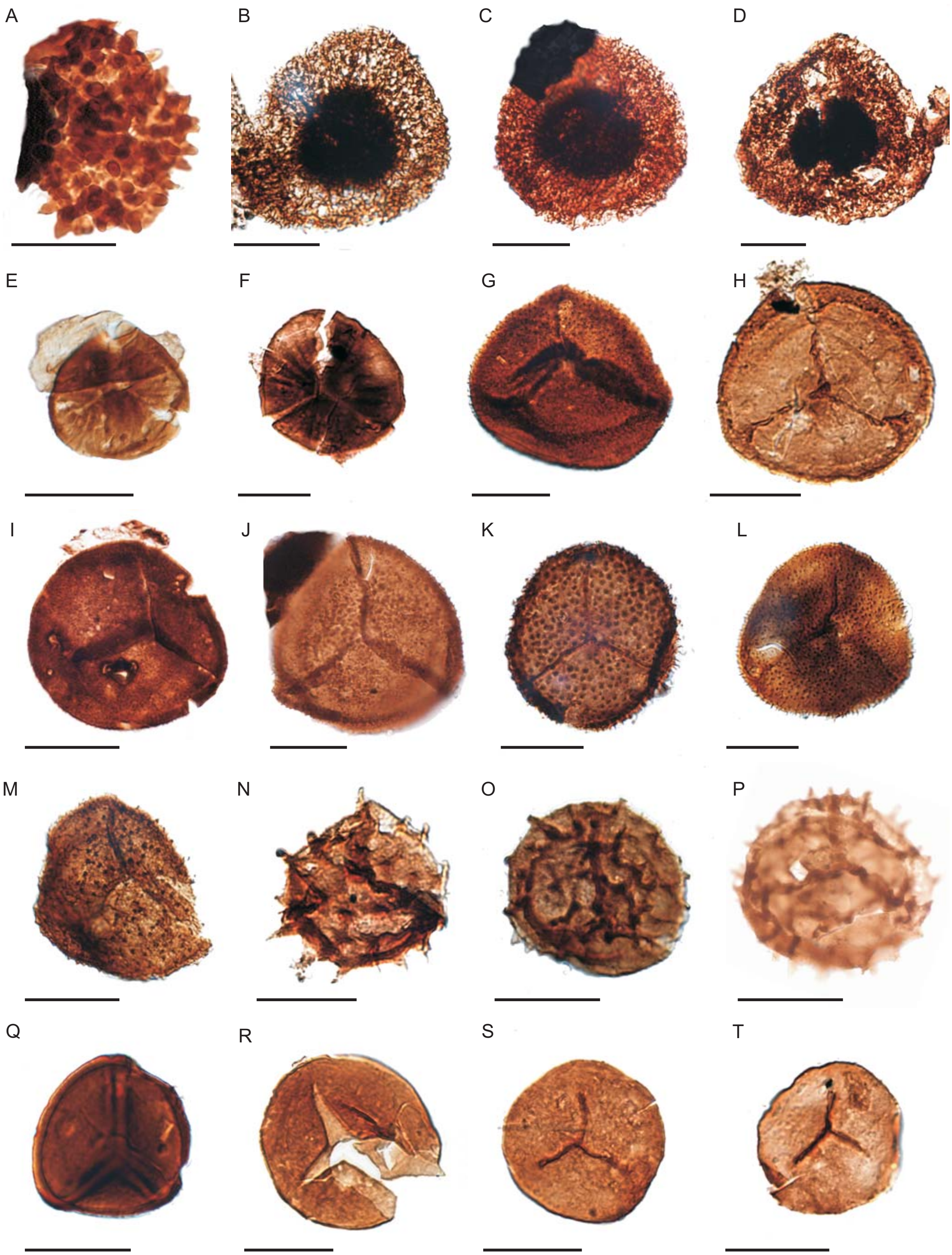

FIGURE 3. A) *Dibolisporites prioratum* sp. nov., distal focus. B-D) *Diducites mucronatus* (KEDO) emend. VAN VEEN, 1981; distal foci. E) *Emphanisporites hibernicus* CLAYTON, HIGGS AND KEEGAN, 1977; median focus. F) *Emphanisporites rotatus* MCGREGOR emend. MCGREGOR, 1973; median focus. G-J) *Geminospora lemurata* BALME emend. PLAYFORD, 1983; proximal foci. K-M) *Grandispora gracilis* HIGGS, 1975; K) median focus, L, M) distal foci. N-P) *Hystricosporites?* sp. A; N, P) proximal foci; O) distal focus. Q) *Leiotriletes ornatus* ISHCHENKO, 1956; proximal focus. R, S) *Punctatisporites debilis* HACQUEBARD, 1957; proximal foci. T) *Punctatisporites minutus* KOSANKE, 1950; proximal focus. Scale bars represent 25μm.

84, pl. 10, figs. 10-12; pl. 11, figs. 1, 2), but the latter is somewhat larger, being sculptured with thinner elements, more evenly and densely distributed. *Acinosporites hirsutus* (Brideaux and Radforth) McGregor and Camfield, 1982 (p.11, pl. 1, figs. 7, 8, 12, 13; text-fig. 9) resembles D. *prioratum*, but its distal and equatorial sculptural elements are said to be joined to form ridges. *Raistrickia baculata* Filipiak, 1996 (p. 171, pl. 1, figs. 1, 2, 4, 5) differs from this form in having exclusively baculate sculpture frequently fused at bases. Bacula in this species are irregularly shaped but never exhibit the multiform pattern characterizing *Dibolisporites*.

GENUS *Hystricosporites* McGregor emend. Owens, 1971

Type species. *Hystricosporites delectabilis* McGregor, 1960; by original designation.

Hystricosporites? sp. A
Figures 3N, O, P

Description. Spores radial, trilete. Amb subcircular to convexly subtriangular. Laesurae distinct, slightly sinuous, extending almost to equatorial margin, accompanied by narrow lips 2-4.5µm high, tapering toward the equator. Exine two-layered, cavate. Intexine distict, laevigate, thin (0.5µm thick), closely appressed to exoexine, length ca. four-fifth of spore radius; outline (in polar view) conformable with amb. Exoexine 1.5-2µm thick, distally and equatorially sculptured with tapering processes, bearing minute bifurcate terminations. Processes 3-6µm high, 2-4µm in basal diameter, commonly fused at bases to form ill-defined rugulae. Non-sculptured distal exoexine slightly scabrate, contact areas laevigate.

Dimensions. (7 specimens): 40 (44) 51µm.

Remarks. This species has been tentatively assigned to *Hystricosporites* on the basis of the bifurcate sculptural elements at the distal exoexine, and the absence of the equatorial flange characterizing *Ancyrospora* Richardson emend. Richardson, 1962. The common occurrence of basally fused elements to form weakly defined rugulae is a feature apparently undescribed for *Hystricosporites*.

GENUS *Rugospora* Neves and Owens, 1966

Type species. *Rugospora corporata* Neves and Owens, 1966; by original designation.

Rugospora spinosa sp. nov.
Figures 4I, J, K, L, P

Diagnosis. Spore radial, trilete. Amb rounded subtriangular. Laesurae distinct to obscure, extending almost to equator; simple or accompanied by narrow labra up to 5µm high at pole, diminishing toward equator. Exine two-layered, cavate. Intexine 1.5-2µm thick, laevigate, closely appressed to exoexine, occupying 90-95% of spore diameter. Exoexine thin, 0.5-1µm thick, proximally laevigate, proximo-equatorially and distally sculptured with very narrow, sinuous, rarely branching rugulae, 0.5-1µm wide, 0.5-3µm high, up to 14µm long. Rugulae surmounted by very thin spinae, 0.2-2µm high; contact areas with greatly reduced sculpture.

Dimensions. (14 specimens): Overall equatorial diameter 38 (48) 60µm.

Holotype (MGM-3362D-8). Preparation V-28/b, England Finder M48/2, Figure 4P. Amb rounded subtriangular, 55µm in diameter. Laesurae obscure, straight, extending almost to equatorial margin. Intexine 1.5µm thick, laevigate, closely appresed to exoexine. Proximo-equarorial and distal exoexine with sinuous rugulae (1-2.5µm high, 1µm wide, up to 7µm long) bearing thin spinae 0.5-1.5µm high. Contact areas with minor sculpture.

Paratypes. Figures 4I (MGM-3362D-7), 4J (MGM-3350D-3), 4K (MGM-3352D-5), 4L (MGM-3361D-11).

Name derivation. Latin, spinae, spine.

Remarks and comparison. *Rugospora explicata* González, Playford and Moreno, 2005 (p. 33, pl. 7, figs. 14-18; pl. 8, figs. 1-3) closely resembles *R. spinosa* sp. nov., but the former has regulae surmounted by more robust apiculate sculpture, *i.e.*, low, broad-based coni, bacula and minor pila. Priorat specimens of *R. spinosa* showing short rugulae and closely appressed spore walls superficially resemble *Dibolisporites coniugatum* sp. nov. (described above), but the apiculate sculpture in this species is characteristically biform and arises, not from the rugulae like *R. spinosa*, but directly from the exoexine.

COMPOSITION OF THE PALYNOFLORA

The palynoflora recovered from the 8 samples contained the best preserved material and is illustrated in Figures 2 to 5, comprises both terrestrial and marine palynomorphs. The terrestrial compound, the most abundant and diverse, consists mainly of trilete miospores and minor phytoclasts, whereas the subsidiary marine palynoflora is dominated by organic-walled microphytoplankton, rare chitinozoans and undifferentiated scolecodonts. In detail, the inventory of the palynomorphs identified in Les Vilelles unit section includes 24 miospore species, 9 acritarchs, 3 prasinophyte phycomata (including non-segregated *Leiosphaeridia*

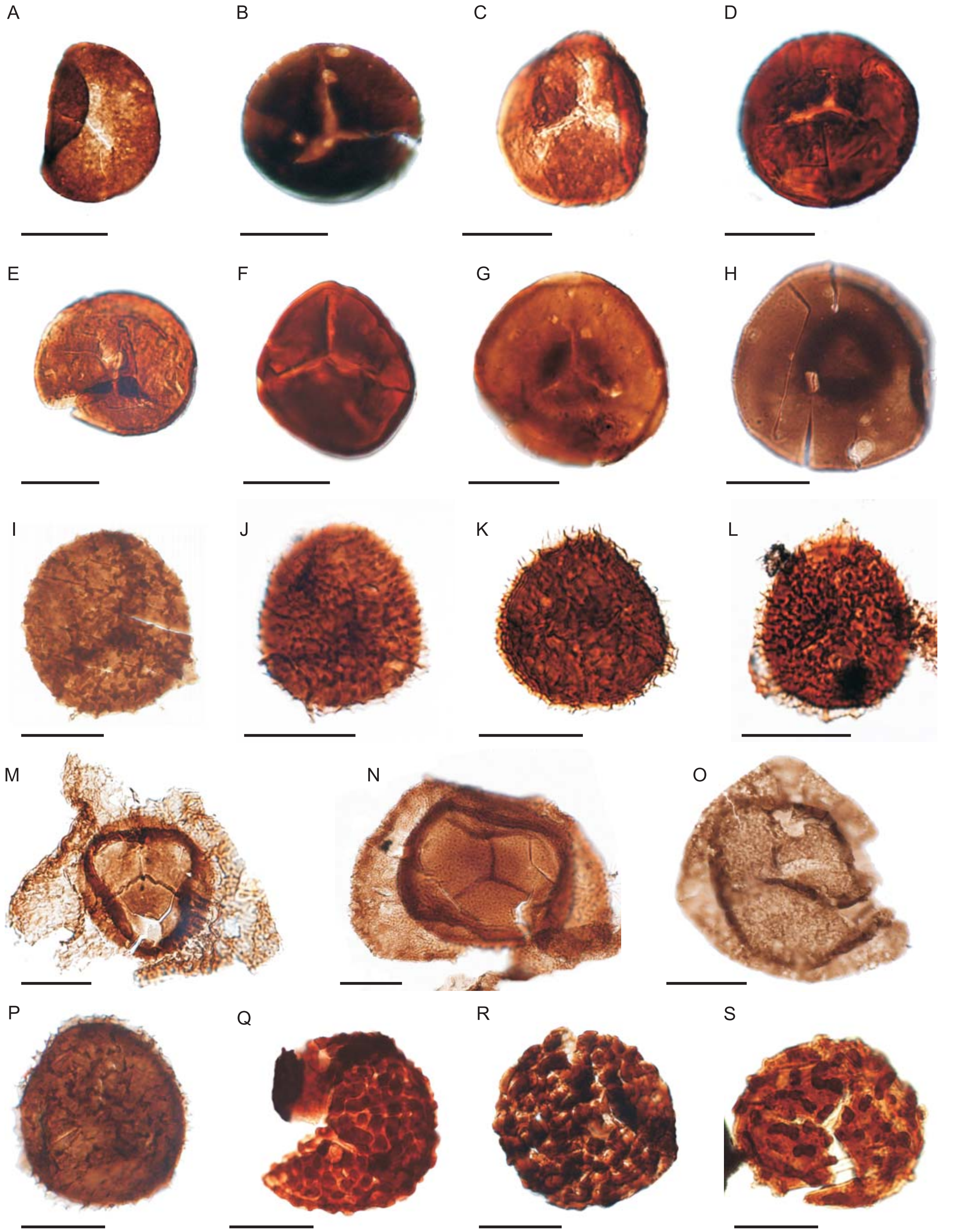

FIGURE 4. A-C) *Punctatisporites planus* Hacquebard, 1957; A, B) median foci, C) proximal focus. D-F) *Punctatisporites solidus* Hacquebard, 1957; proximal foci. G-H) *Retusotriletes rotundus* (Streel) Streel, 1967; median foci. I-L, P) *Rugospora spinosa* sp. nov.; distal foci, P, holotype. M, N) *Teichertospora torquata (*Higgs) McGregor and Playford, 1990; median foci. Q-S) *Verrucosisporites scurrus* (Naumova) McGregor and Camfield, 1982; distal foci. Scale bars represent 25µm.

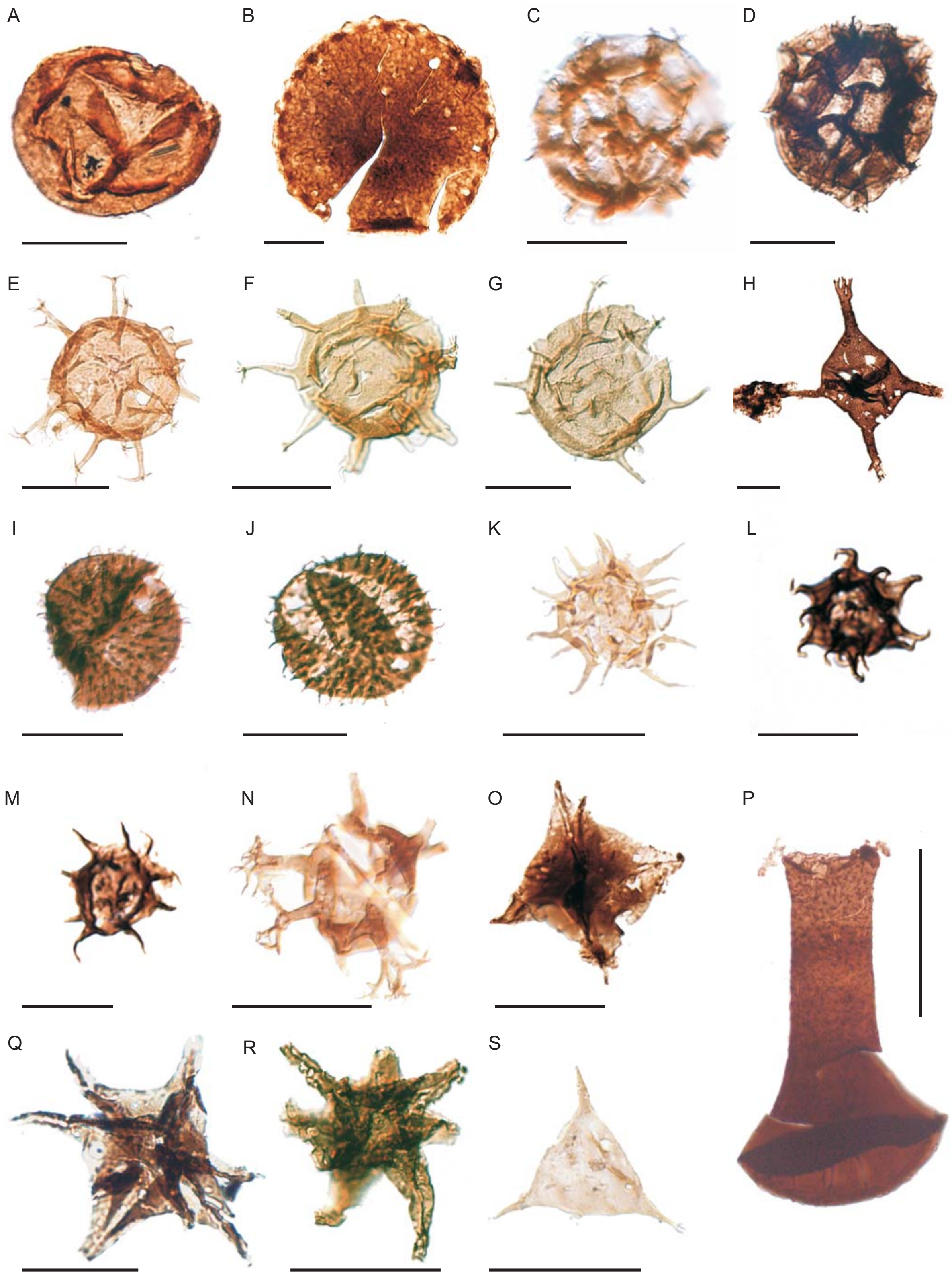

FIGURE 5. A) *Leiosphaeridia* sp. B) *Maranhites mosesii* (Sommer) emend. González, 2009. C, D) *Dictyotidium fairfieldense* Playford, 1978. E-G) *Craterisphaeridium sprucegrovense* (Staplin) Turner, 1986. H) *Evittia geometrica* Playford in Playford and Dring, 1981. I, J) *Gorgonisphaeridium inflatum* Wicander and Wood, 1981. K, L) *Micrhystridium erugatum* Wicander, 1974. M) *Micrhystridium stellatum* Deflandre, 1945. N) *Multiplicisphaeridium ramispinosum* Staplin, 1961. O) *Stellinium micropolygonale* (Stockmans and Willière) Playford, 1977. P) *Fungochitina pilosa* (Collinson and Scott, 1958). Q, R) *Stellinium octoaster* (Staplin) Jardiné, Combaz, Magloire, Peniguel and Vachey, 1972. S) *Veryhachium trispinosum* (Eisenack) Stockmans and Willière, 1962 “complex”. Scale bars represent 25μm except of P which is 100μm.

MIOSPORE SPECIES	V-4	V-5	V-6	V-7	V-19	V-21	V-22	V-28
Ancyrospora melvillensis Owens, 1971	•	•	•	•	•	•	•	
Aneurospora gregsii (McGregor) Streel in Becker *et al.,* 1974			•				•	
Apiculatasporites adevalensis (de Jersey) Grey, 1992					•		•	•
Cristatisporrites inusitatus (Allen) McGregor & Camfield, 1982	•	•	•	•	•	•	•	•
Cristatisporites triangulatus (Allen) McGregor & Camfield, 1982	•	•	•					•
Cymbosporites sp. cf. C. magnificus (McGrergor) McGregor and Camfield, 1982	•	•		•	•	•		•
Dibolisporites coniogatum sp. nov.		•			•			•
Dibolisporites prioratum sp. nov.	•	•						•
Diducites mucronatus (Kedo) emend. Van Veen, 1981		•	•					•
Emphanisporites annulatus McGregor, 1961		•				•		
Emphanisporites hibernicus Clayton, Higgs & Keegan, 1977								•
Emphanisporites rotatus McGregor emend. McGregor, 1973				•				
Geminospora lemurata Balme emend. Playford, 1983	•	•	•			•	•	•
Grandispora gracilis (Kedo) Streel in Becker *et al.,* 1974		•			•		•	
Hystricosporites? sp. A	•	•			•			
Leiotriletes ornatus Ishchenko, 1956	•	•						
Punctatisporites debilis Hacquebard, 1957	•	•			•			
Punctatisporites minutus Kosanke, 1950						•		•
Punctatisporites planus Hacquebard, 1957	•			•			•	•
Punctatisporites solidus Hacquebard, 1957		•			•		•	
Retusotriletes rotundus (Streel) Streel, 1967		•			•		•	•
Rugospora spinosa sp. nov.		•			•			•
Teichertospora torquata (Higgs) McGregor & Playford, 1990	•	•			•			•
Verrucosisporites scurrus (Naumova) McGregor & Camfield, 1982	•		•	•		•	•	•
MICROPHYTOPLANKTON SPECIES								
Craterisphaeridium sprucegrovense (Staplin) Turner, 1986	•	•	•		•	•		•
Dictyotidium fairfieldense Playford, 1978		•						•
Evittia geometrica Playford in Playford & Dring, 1981	•							
Gorgonisphaeridium inflatum Wicander & Wood, 1981	•	•	•	•		•	•	•
Leiosphaeridia spp.	•	•	•	•		•	•	
Maranhites mosesii (Sommer) emend. González, 2009	•	•	•				•	
Micrhystridium erugatum Wicander, 1974		•						•
Micrhystridium stellatum Deflandre, 1945			•					
Multiplicisphaeridium ramispinosum Staplin, 1961			•					
Stellinium micropolygonale (Stockmans & Willière) Playford, 1977	•		•			•		
Stellinium octoaster (Staplin) Jardiné *et al.,* 1972		•						•
Veryhachium trispinosum (Eisenak) Stockmans & Willière, 1962 "complex"		•	•					•
CHITINOZOA SPECIES								
Fungochitina pilosa (Collinson & Scott, 1958)	•	•	•	•	•	•		•

FIGURE 6. Distribution of miospore organic-walled microphytoplankton, and chitinozoan species in the palyniferous samples from the studied section at Les Vilelles unit.

species) and 1 chitinozoan (Fig. 6). Among the miospore taxa, 3 newly instituted species and 2 left in open nomenclature have been described in detail in the preceding systematic section.

Most of the analyzed assemblages are dominated by *Ancyrospora melvillensis* Owens, 1971, *Cristatisporites inusitatus* (Allen) McGregor and Camfield, 1982, *Cymbosporites* sp. cf. *C. magnificus* (McGregor) McGregor and Camfield, 1982, *Geminospora lemurata* Balme emend. Playford, 1983, and *Verrucosisporites scurrus* (Naumova) McGregor and Camfield, 1982. Other species also representative but more discontinuously represented throughout the analyzed section are *Cristatisporites triangulatus* (Allen) McGregor and Camfield, 1982, *Grandispora gracilis* (Kedo) Streel in Becker *et al.*, 1974, *Punctatisporites planus* Hacquebard, 1957, *Retusotriletes rotundus* (Streel) Lele and Streel, 1969, and *Teichertospora torquata* (Higgs) McGregor and Playford, 1990. The remaining miospore list includes less abundant and unevenly distributed species; see Figure 6 for more details.

The marine palynoflora is dominated by the acritarchs *Craterisphaeridium sprucegrovense* (Staplin) Turner, 1986 and *Gorgonisphaeridium inflatum* Wicander and Wood, 1981, together with undifferentiated species of the prasinophyte phycomata genus *Leiosphaerida* Eisenack, 1958. Most of the remaining organic walled microphytoplanckton species occur in the sample V-5, which is exceptionally more diverse than the rest of analyzed samples in terms of marine palynofora. Regarding the chitinozoan content, the only species recovered is *Fungochitina pilosa* (Collinson and Scott, 1958), which is represented in all but one analyzed sample.

BIOSTRATIGRAPHIC SIGNIFICANCE AND DISCUSSION

In biostratigraphic terms Les Vilelles unit section analyzed is characterized by a set of miospores widely reported in many Middle–Upper Devonian localities from Laurentia and Gondwana (see, for example, Loboziak and Streel, 1988; McGregor and Camfield, 1982; Richardson and McGregor; 1986; Streel *et al*., 1987; McGregor and Playford, 1992). Apart from long-ranging species such *Emphanisporites annulatus* McGeegor, 1961, E. *rotatus* McGregor emend. McGregor, 1973, *Leiotriletes ornatus* Ishchenko, 1956, *Retusotriletes rotundus*, *Verrucosisporites scurrus* and *Punctatisporites* spp., the reported assemblages include characteristic Middle to Upper Devonian (occasionally Lower Mississippian) miospore species such *Ancyrospora melvillensis*, *Cristatisporites inusitatus*, *Cristatisporites triangulatus* and *Geminospora lemurata*. Nevertheless, the biostratigraphically most relevant miospores at Les Vilelles section were *Teichertospora torquata*, *Grandispora gracilis* and Diducites *mucronatus* (Kedo) emend. Van Veen, 1981. According to Richardson and McGregor (1986) the common occurrence of the first two species defines the Old Red Sandstone and adjacent regions the *torquata-gracilis* assemblage Zone. In Western Europe, the first occurrence of *G. gracilis* is used by Streel (2009) to define the Zone BA grac., the intermediate of the three interval zones subdividing the *Rugospora bricei-Cymbosporites acanthaceus* (BA) oppel Zone. This BA grac. Zone corresponds to the former (IV) Cα phase Zone defined by Streel *et al*. (1987) in the Ardenne-Rhenish regions.

The bases of the *torquata-gracilis* and BA grac. zones are virtually coincident and fit well into the conodont Zone 13 MN of Klapper (1989) and the Upper *rhenana* and *linguiformis* zones of Ziegler and Sandberg (1990). Accordingly, the oldest age of the analyzed Les Vilelles unit section can be firmly established as late Frasnian (Fig. 7). This age is also corroborated by the occurrence in Les Vilelles of *D. mucronatus*, a species characteristically reported in the Famennian–lower Tournaisian of Europe, Russia, Saudi Arabia and Brazil (see references in González *et al*., 2005), but whose first inception apparently falls within the late Frasnian (Obukhovskaya *et al*., 2000; Streel, 2009). The youngest possible age for the studied section is somewhat more controversial as the tops of these two miospore biozones are noticeably different. The top of the BA Zone, and more specifically the base of the succeeding *Knoxisporites dedaleus-Diducites versabilis* (DV) oppel Zone falls within the lower Famennian *triangluaris* conodont Zone according to Streel (2009), while the base of the *flexuosa-cornuta* assemblage Zone, the one succeeding the *torquata-gracilis* biozone in the scheme of Richardson and McGregor (1986), falls more imprecisely within a range comprising the middle to early late Famennian (Upper *rhomboidea* to Lower *trachytera* conodont zones of Ziegler and Sandberg, 1990). Les Vilelles assemblage includes nevertheless a chitinozoan species that permits a noticeable and solid constraint of the upper age limit. *Fungochitina pilosa* is a worldwide known species characteristically reported in Middle and Upper Devonian assemblages (Grahn and Melo, 2005 and references therein) whose top age range apparently coincides with the Frasnian–Famennian boundary. Consequently, on the basis of the miospore and chitinozoan content, the age of Les Vilelles unit section analyzed in this study can be confidently assigned to the latest Frasnian (Fig. 7), in the near vicinity of the Frasnian–Famennian boundary. Given the extraordinary relevance of the Late Devonian events, and particularly of the one defined at the Frasnian–Famennian boundary (Kellwasser Event), it would be desirable to undertake a more comprehensive study of this unit.

From a regional perspective, the latest Frasnian age assumed for the stratigraphic section analyzed at the upper part of Les Vilelles unit is not only in agreement with, but drastically constraints the most commonly accepted Middle to Late Devonian age proposed by Colodrón *et al*. (1979). The complete absence of palynomorphs exclusively Carboniferous in any of the assemblages reported here precludes the possible interpretation that the Devonian palynomorphs were reworked and redeposited in deeper marine settings during Mississippian time. On the other hand, neither the palynological dating presented here nor that in Colodrón *et al*. (1979) supports the radiolarian-based Mississippian age suggested by Raymond and Caridroit (1993). Most likely, the cherts dated by these authors belong to the radiolaritic cherts at the base of the unconformably succeeding Bassetes unit (Fig. 1B).

In consequence, the data presented in this study are in agreement with the accepted hypothesis that the contact between the Carboniferous and the pre-Carboniferous successions at the CCC is a disconformity, or possibly an angular unconformity (see Julivert and Martínez, 1983

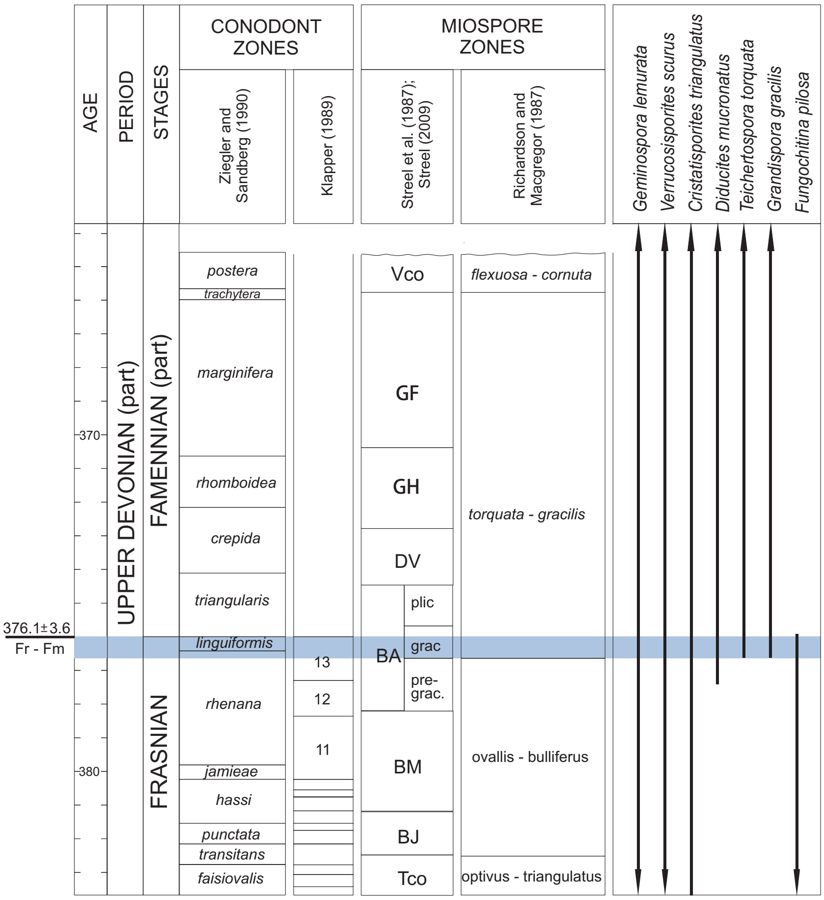

FIGURE 7. Stratigraphic ranges of selected palynomorphs recorded in the studied section at Les Vielles unit, with reference to the miospore zonal schemes of Streel *et al.* (1987), Streel (2009), and Richardson and McGregor (1986), and the conodont zonal schemes of Ziegler and Sandberg (1990) and Klapper (1989). Geochronological data extracted from Kaufmann (2006). The stratigraphic age range assigned to the recovered assemblage is represented by the blue colour interval.

and references therein). Taking in consideration the latest Frasnian age provided for the top of Les Vilelles unit, the hiatus separating both successions in the Priorat Massif spans at least the entire Famennian stage. Together with the Famennian succession dated with conodonts at El Papiol (Puschmann, 1968), Les Vilelles unit represents the youngest pre-Carboniferous rocks in the CCC.

CONCLUSIONS

The biostratigraphic analysis of Les Vilelles unit here presented provides a palynological assemblage containing both terrestrial and marine palynomorphs. The terrestrial component is dominated by miospores while the marine palynoflora, distinctly subsidiary, consists of microphytoplankton and, in a lesser extent, chitinozoan and undifferentiated scolecodonts. Compositionally, the identified palynoflora consists of 24 miospore species (3 newly instituted herein), 9 species of acritarchs, 2 prasinophyte phycomata (plus one undifferentiated species grouping) and 1 chitinozoan species. This palynological assemblage is indicative of a marine environment highly influenced by terrestrial input, possibly in the near vicinity of an emerged landmass. In biostratigraphic term, the miospore assemblage corresponds to the West European *Rugospora bricei-Cymbosporites acanthaceus* (BA) oppel Zone or the *torquata-gracilis* assemblage Zone from the Old Red Sandstone and adjacent regions. Taking in conjunction this biozonal assignment and the vertical range of the chitinozoan species recovered, the assemblage studied at Les Vilelles unit can be confidently assigned to a latest Frasnian interval, in contact with the Frasnian–Famennian boundary. Consequently, the hiatus between the Carboniferous and pre-Carboniferous series in the study area spans at least the Famennian stage.

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ELECTRONIC APPENDIX I

TABLE I. Register of illustrated specimens from Les Vilelles unit. Abbreviations are as follow, H: holotype; P: paratype; MGM: Museo Geológico Minero. England Finder coordinates have been calculated using the software EFC (González, 2012)

Species	Type	Figure	Sample	Prep/slide	Eng. Find.	Type nº
Ancyrospora melvillensis		2A	V-5	k759/b	R65/0	MGM-3353D-1
“” “”		2B	V-4	k891/b	Q45/0	MGM-3350D-1
“” “”		2C	V-5	k759/c	X39/0	MGM-3354D-1
Aneurospora gregsii		2D	V-6	k892/a	Q50/0	MGM-3355D-1
Apiculatasporites adevalensis		2E	V-28	k764/a	K31/1	MGM-3361D-1
“” “”		2F	V-28	k764/b	H33/0	MGM-3362D-1
“” “”		2G	V-28	k764/b	T48/0	MGM-3362D-2
Cristatisporites inusitatus		2H	V-5	k759/c	040/0	MGM-3354D-2
“” “”		2I	V-4	k891/c	O45/4	MGM-3351D-1
Cristatisporites triangulatus		2J	V-28	k764/a	U37/1	MGM-3361D-2
“” “”		2K	V-6	k892/a	V40/1	MGM-3355D-2
Cymbosporites sp. cf. C. magnificus		2L	V-5	k759/b	S34/3	MGM-3353D-2
“” “”		2M	V-7	k893/b	N36/3	MGM-3358D-1
Dibolisporites coniugatum	H	2N	V-28	k764/a	E44/3	MGM-3361D-3
“” “”	P	2O	V-28	k764/a	J33/2	MGM-3361D-4
“” “”	P	2P	V-28	k764/a	W34/0	MGM-3361D-5
Dibolisporites prioratum	H	2Q, R	V-5	k759/c	U35/0	MGM-3354D-3
“” “”	P	2S	V-5	k759/b	P44/3	MGM-3353D-3
“” “”	P	3A	V-5	k759/a	U49/3	MGM-3352D-1
Diducites mucronatus		3B	V-28	k764/b	S33/1	MGM-3362D-3
“” “”		3C	V-28	k764/a	R65/4	MGM-3361D-6
“” “”		3D	V-28	k764/b	F51/3	MGM-3362D-4
Emphanisporites hibernicus		3E	V-28	k764/a	Q37/0	MGM-3361D-7
Emphanisporites rotatus		3F	V-7	k893/a	H58/3	MGM-3357D-1
Geminospora lemurata		3G	V-5	k759/c	Q64/3	MGM-3354D-4
“” “”		3H	V-5	k759/b	P51/1	MGM-3353D-4
“” “”		3I	V-6	k892/c	S68/0	MGM-3356D-1
“” “”		3J	V-5	k759/b	F66/0	MGM-3353D-5
Grandispora gracilis		3K	V-5	k759/b	E35/0	MGM-3353D-6
“” “”		3L	V-7	k893/a	K31/3	MGM-3357D-2
“” “”		3M	V-28	k764/b	R37/3	MGM-3362D-5
Hystricosporites? sp. A		3N	V-5	k759/b	V66/0	MGM-3353D-7
“” “”		3O	V-5	k759/b	J41/4	MGM-3353D-8
“” “”		3P	V-5	k759/b	E51/3	MGM-3353D-9
Leiotriletes ornatus		3Q	V-5	k759/b	X65/2	MGM-3353D-10
Punctatisporites debilis		3R	V-5	k759/a	Q39/4	MGM-3352D-2
“” “”		3S	V-4	k891/b	Q49/0	MGM-3350D-2
Punctatisporites minutus		3T	V-5	k759/b	H44/2	MGM-3353D-11
Punctatisporites planus		4A	V-21	k895/b	F41/4	MGM-3360D-1
“” “”		4B	V-28	k764/a	T31/4	MGM-3361D-8
“” “”		4C	V-28	k764/a	M31/0	MGM-3361D-9
Punctatisporites solidus		4D	V-28	k764/a	Q48/3	MGM-3361D-10
“” “”		4E	V-5	k759/a	S45/4	MGM-3352D-3
“” “”		4F	V-5	k759/a	V61/0	MGM-3352D-4
Retusotriletes rotundus		4G	V-5	k759/b	L40/0	MGM-3353D-12
“” “”		4H	V-28	k764/b	N52/0	MGM-3362D-6
Rugospora spinosa	P	4I	V-28	k764/b	H52/0	MGM-3362D-7
“” “”	P	4J	V-4	k891/b	E69/1	MGM-3350D-3
“” “”	P	4K	V-5	k759/a	W69/1	MGM-3352D-5
“” “”	P	4L	V-28	k764/a	S45/4	MGM-3361D-11
“” “”	H	4P	V-28	k764/b	M48/2	MGM-3362D-8
Teichertospora torquata		4M	V-28	k764/a	Q61/0	MGM-3361D-12
“” “”		4N	V-28	k764/a	K58/0	MGM-3361D-13
“” “”		4O	V-28	k764/b	M31/0	MGM-3362D-9
Verrucosisporites scurrus		4Q	V-28	k764/a	L63/0	MGM-3361D-14
“” “”		4R	V-28	k764/a	L52/0	MGM-3361D-15
“” “”		4S	V-28	k764/a	H46/2	MGM-3361D-16
Leiotriletes sp.		5A	V-28	k764/a	R39/1	MGM-3361D-17
Maranhites mosesii		5B	V-6	k892/c	G59/0	MGM-3356D-2
Dictyotidium fairfieldense		5C	V-5	k759/a	H48/0	MGM-3352D-6
“” “”		5D	V-28	k764/a	L62/0	MGM-3361D-18
Craterisphaeridium sprucegrovense		5E	V-5	k759/a	Q/40/0	MGM-3352D-7
“” “”		5F	V-5	k759/a	O/41/0	MGM-3352D-8
“” “”		5G	V-5	k759/b	R51/1	MGM-3353D-13
Evitia geometrica		5H	V-6	k892/c	R39/1	MGM-3356D-3
Gorgonisphaeridium inflatum		5I	V-5	k759/b	J39/0	MGM-3353D-14
“” “”		5J	V-5	k759/b	L65/1	MGM-3353D-15
Micrhystridium erugatum		5K	V-5	k759/a	N33/4	MGM-3352D-9
“” “”		5L	V-28	k764/a	P48/3	MGM-3361D-19
Micrhystridium stellatum		5M	V-28	k764/a	L59/0	MGM-3361D-20
Multiplicisphaeridium ramispinosum		5N	V-19	k774/a	G67/2	MGM-3359D-1
Stellinium micropolygonale		5O	V-6	k892/c	F47/1	MGM-3356D-4
Fungochitina pilosa		5P	V-5	k759/c	O61/2	MGM-3354D-5
Stellinium octoaster		5Q	V-28	k764/b	R60/0	MGM-3362D-10
“” “”		5R	V-28	k764/a	M63/0	MGM-3361D-21
Veryhachium trispinosum		5S	V-5	k759/b	J41/4	MGM-3353D-16