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

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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*.


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, 2000; 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 flysch 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 Pobleda 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 Ibaruguchi and Julivert, 1988). The Palaeozoic rocks were unconformably covered by
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 silification and is unconformably topped by the Carboniferous Bassetes

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).
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-taxon 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 mammillae 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...
**Cymbosporites magnificus** (McGregor) McGregor and Campfield, 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** (MG-3361D-3). Preparation V-28/a, England Finder E44/3, Figure 2N. Amb subcircular, 51μm in diameter. Laesurae distinct, lipped, reaching equator. Exine 2μm thick, sculptured distally and proximo-equatorially with coni, spinae and bacula, 2.5-4.5μm 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 (MG-3361D-4), 2P (MG-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 Campfield, 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, conforming by broad-based coni, bacula and minor pila, surmounts the rugulae.

**Dibolisporites prioratum** sp. nov. Figures 2Q–R, S, 3A

**Diagnosis.** Spores 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** (MG-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, 2-10μm apart, most densely distributed near equator. Non-sculptured exoexine, including contact areas, scabrate.

**Paratypes.** Figures 2S (MG-3353D-3), 3A (MG-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.
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 distinct, laevigate, thin (0.5μm thick), closely appressed to exoexine, occupying 90-95% of spore diameter. Exoexine thin, 0.5-1μm thick, proximally laevigate, proximo-equatorial 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.** (41 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 appressed to exoexine. Proximo-equatorial 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.


**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 scolicodonts. In detail, the inventory of the palynomorphs identified in Les Villes unit section includes 24 miospore species, 9 acritarchs, 3 prasinophyte phycomata (including non-segregated *Leiosphaeridia*...
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 Verrucosissporites sccurus (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 infatum* Wicander and Wood, 1981, together with undifferentiated species of the prasinophyte phycotoma genus *Leiosphaeridia Eischenk*, 1958. Most of the remaining organic walled microphytoplankton species occur in the sample V-5, which is exceptionally more diverse than the rest of analyzed samples in terms of marine palynoflora. 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, Loboziaik and Streele, 1988; McGregor and Camfield, 1982; Richardson and McGregor; 1986; Streele et al., 1987; McGregor and Playford, 1992). Apart from long-ranging species such *Emphantisporites annulatus* McGregor, 1961, *E. rotatus* McGregor emend. McGregor, 1973, *Leiotritelites ornatus* Isichenko, 1956, *Retusotritelites rotundus*, *Verrucosispores scurru* 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 *Geminispora lemura*. 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 Streele (2009) to define the Zone BA grac., the intermediate of the three interval zones subdividing the *Bricei-Cymbosporites acanthalus* (BA) oppel Zone. This BA grac. Zone corresponds to the former (IV) Ct phase Zone defined by Streele 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 Tourmaisian 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; Streele, 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 *triangularis* conodont Zone according to Streele (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 constrains 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 Caradroit (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).
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.

ACKNOWLEDGMENTS

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Richardson, J.B., 1965. Middle Old Red Sandstone spore assemblages from the Orcadian Basin, northeast Scotland. Palaeontology, 7, 559-605.


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

<table>
<thead>
<tr>
<th>Species Type</th>
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<th>Sample</th>
<th>Pre/slide</th>
<th>Eng. Find.</th>
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