

Palynological studies of the boundary marls unit (Albian-Cenomanian) from northeastern Spain. Paleophytogeographical implications

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ABSTRACT

Detailed records of spore-pollen assemblages from four sites located in the Aliaga and Oliete Sub-basins provide new insights into the palaeoclimatic and palaeogeographic settings during the Albian-Cenomanian transition in the Maestrazgo Basin (northeastern Spain). Palynological taxa such as *Afropollis jardinus* Doyle, Jardiné & Doerenkamp, 1982, *Elaterosporites klaszii*

KEY WORDS

Palynology,
Lower Cretaceous,
Albian-Cenomanian
boundary,
paleophytogeography.

(Jardiné & Magloire) Jardiné, 1967, *Equisetosporites ambiguus* (Hedlund 1966) Singh, 1983, *Gabonispuris pseudoreticulatus* Boltenhagen, 1967, *Senectotetradites varireticulatus* Dettmann, 1973, *Stellatopollis barghoornii* Doyle, 1975, and the dinoflagellate cyst *Cyclonephelium chabaca* Below, 1981 indicate a latest Albian age for this unit. Abundance of Gondwanan elements such as *Afropollis* Doyle, Jardiné & Doerenkamp, 1982, *Elaterosporites* Jardiné, 1967 and *Stellatopollis* Doyle, 1975 indicates a northward extension of the paleogeographic distributions of those taxa during this time. Comparison between the studied microflora of the Iberian Range and microfloras from Tethyan and Gondwanan realms allows better understanding of the Tethyan paleogeographic setting.

RÉSUMÉ

Études palynologiques de l'Unité Marnes de Transition (Albien-Cénomanien) du Nord-Est de l'Espagne. Implications paléophytogéographiques.

Les enregistrements détaillés d'assemblages palynologiques, obtenus à partir de quatre gisements situés dans les sous-bassins d'Aliaga et d'Oliete, fournissent des données nouvelles sur les paramètres paléoclimatiques et paléogéographiques à la transition Albien-Cénomanien dans le bassin du Maestrazgo (nord-est de l'Espagne). Certains taxons tels que *Afropollis jardinus* Doyle, Jardiné & Doerenkamp, 1982, *Elaterosporites klaszii* (Jardiné & Magloire) Jardiné, 1967, *Equisetosporites ambiguus* (Hedlund 1966) Singh, 1983, *Gabonispuris pseudoreticulatus* Boltenhagen, 1967, *Senectotetradites varireticulatus* Dettmann, 1973, *Stellatopollis barghoornii* Doyle, 1975 et le dinoflagellé *Cyclonephelium chabaca* Below, 1981 permettent de proposer un âge Albien terminal aux « Marnes de transition ». La présence et l'abondance des éléments gondwaniens, observés dans les assemblages indiquent l'extension vers le nord de leurs aires de répartition pendant cette période. Une comparaison entre la microflore étudiée et celles des domaines téthysien et gondwanien permet une meilleure compréhension du cadre paléogéographique.

MOTS CLÉS

Palynologie,
Crétacé inférieur,
limite Albien-
Cénomanien,
paléophytogéographie.

INTRODUCTION

In the late Albian pulses of relative sea-level rise are known reaching a maximum eustatic level seen in the early Turonian (Haq *et al.* 1988). At the base of the sedimentary succession and to the northeast of the Bajo Aragón (northeastern Spain) detrital material of coastal river environments represented by the Utrillas Formation was deposited, followed by shallow carbonate platform environments with subtidal bars that recorded a shallowing-upward trend. During the latest Albian-early Cenomanian transition a drop in sea level occurred that favoured the deposition of marls restricted to coastal environ-

ments, represented by the so-called Boundary Marls Unit (named as the "Margas de Transición" Unit by Aguilar *et al.* 1971) in the study area. An eustatic fall was followed by a worldwide rise in sea level during the early Cenomanian, which led to the installation of a carbonate platform dominated by tidal facies or even continental deposits of lacustrine facies at the uppermost part of the series.

The correlation of the successions corresponding to the latest Albian-Cenomanian boundary is difficult due to numerous lateral facies changes. In this context, the Capa de Chera Unit has been identified by Segura *et al.* (1994) in the Puerto de San Just section and also dated in the vicinity of

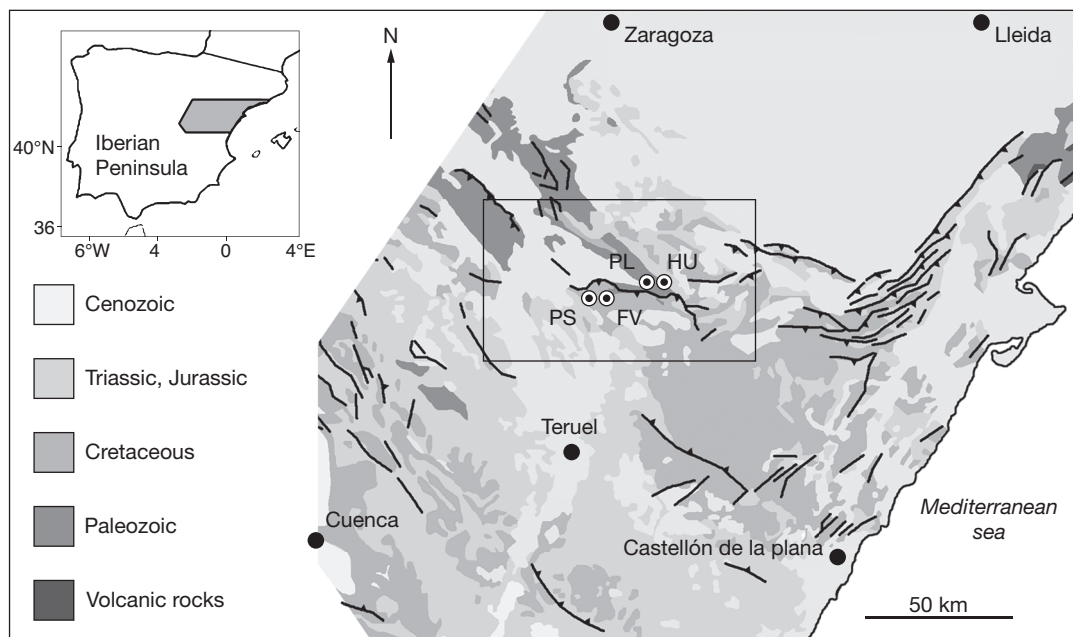


FIG. 1. — Geological map of the Aragonese Branch of the Iberian Chain from Teruel, Spain, with placement of the sections marked as circles with inner dots: **FV**, Fuente del Vaso; **HU**, Huesa del Común; **PL**, Plou; **PS**, Puerto de San Just.

Huesa del Común village (both places located in Teruel province, northeastern Spain) as early-middle Cenomanian. In the area of Huesa del Común the succession consists of green marls with abundant ostracids, nodular limestones and laminated limestones and dolomites with tractive structures, where marls are more abundant towards the base while the dolomites predominate at the top of the succession (Figs 1; 2).

The base of the Capa de Chera unit changes laterally into the Utrillas Formation (Vilas *et al.* 1982), the top to the Dolomías de Alatoz Formation and the Calizas de Losa Member of the Aras de Alpuente Formation (Gil *et al.* 2004). In addition, it presents great similarities with the informal Margas de Pinarueco unit of the Mosqueruela Formation (Canérot *et al.* 1982). Due to the difficulty of correlating the numerous lateral facies changes of the Capa de Chera unit, we have followed the work of Aguilar *et al.* (1971) in the Puerto de San Just area, using the informally defined Boundary Marls unit for this study.

The Mosqueruela Formation, overlying the Boundary Marls unit, has been dated as early Cenomanian with orbitolinids (Neumann & Schröder 1985; Calonge 1989; García *et al.* 1989). Moreover, sediments representing the Boundary Marls Unit have been assigned to the late Albian by the presence of the ammonoid *Knemiceras ubligi* Choffat, 1886 northeast of the Arroyofrío locality, province of Teruel (Geyer 1995). However, the exact stratigraphic level where Geyer found this species is not clear; hence, these cannot be used to provide a reliable age for this unit. More integrated approaches using palynomorphs and marine fauna (ammonoids and foraminifers) are needed in future high-resolution study to confirm this age.

GEOLOGICAL SETTING

The Boundary Marls Unit at the Aragonese Branch of the Iberian Range is placed between the Utrillas (Aguilar *et al.* 1971) and the Mosqueruela forma-

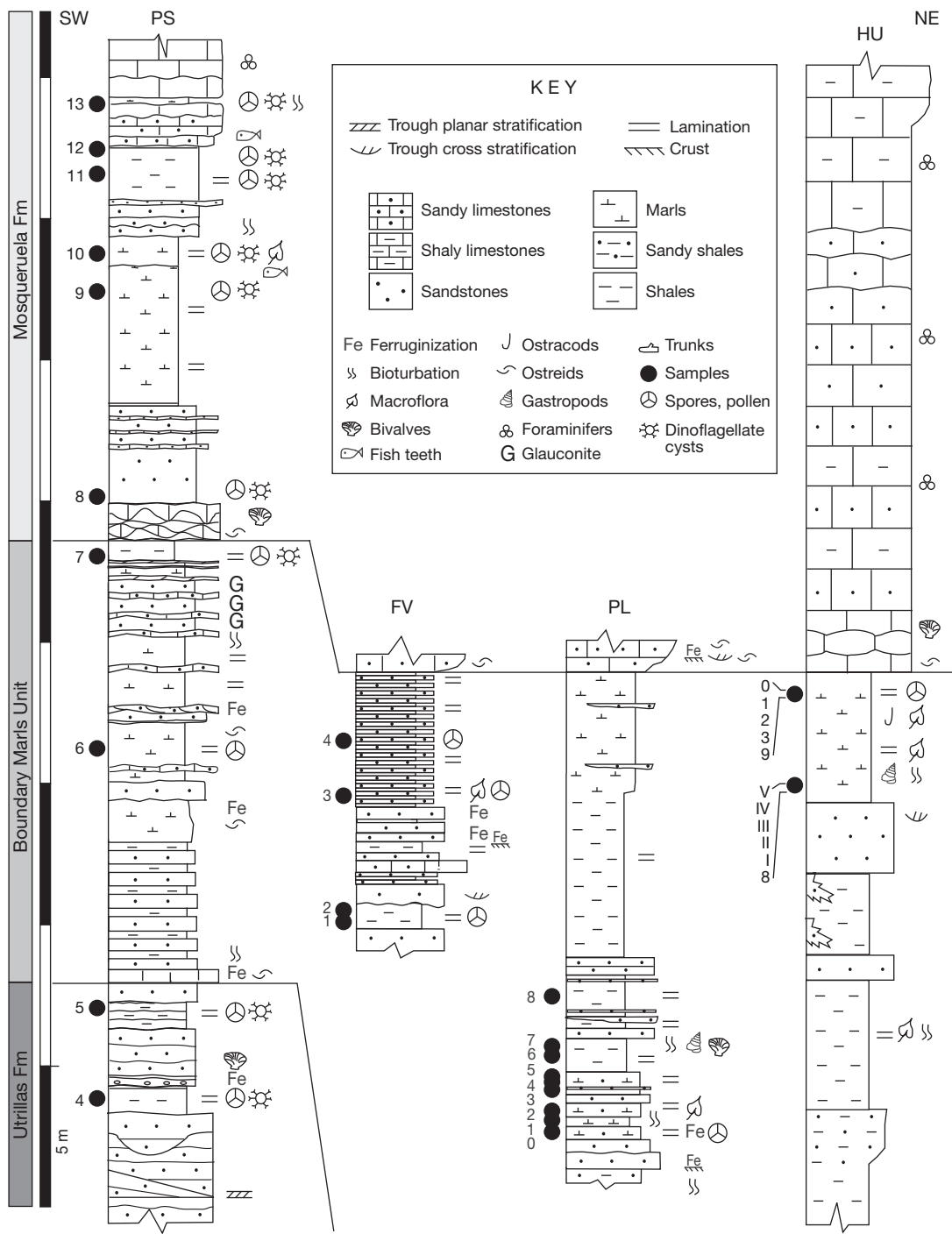


Fig. 2. — Correlation of the four sections studied. Abbreviations: **PS**, Puerto de San Just; **FV**, Fuente del Vaso; **PL**, Plou; **HU**, Huesa del Común.

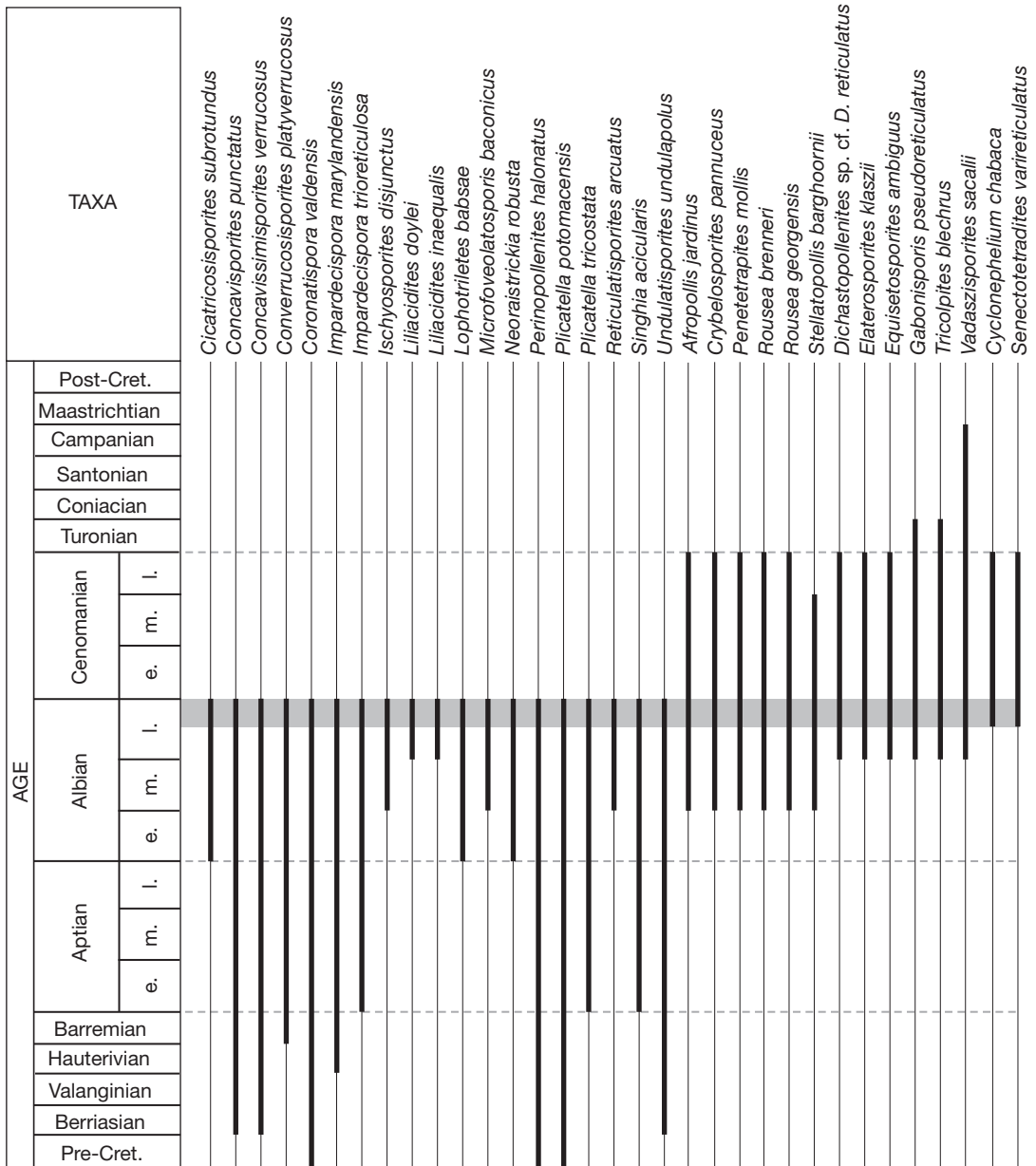


FIG. 3. — The palynostratigraphic distribution, for the presence of the individual spores and pollen grains identified within the positive 21 samples, based on the previous available literature.

tions (Canérot *et al.* 1982). The underlying Utrillas Formation, late Albian in age (Villanueva-Amadoz *et al.* in press), has been interpreted as fluvial deposits with the presence of sequences of point bars

and flood plains. The Boundary Marls Unit is an informal unit, showing a transition from fluvial to marine environments. The overlying Mosqueruela Formation consists of limestones and marls with

ostreids and orbitolinids, which has been interpreted as shallow marine deposit.

The Boundary Marls Unit constitutes the base of the depositional sequence K2.2 of the late Albian-early Cenomanian (Querol 1990). This deposition is the result of the second post-rifting process of latest Albian to early Cenomanian age related to rotation of the Iberian plate and Tethyan and Central Atlantic spreading (Salas 1987; Salas & Casas 1993).

This unit is composed of greyish to green laminated marls intercalated with marly limestones and dolomitic limestones with ostracods, plant remains and lamellibranchs. This informal unit together with the lower part of the calcareous Upper Cretaceous succession were interpreted as deposited in a lagoon complex with possible estuary-type transitional deposits according to Pardo & Villena (1979).

Four sections were studied (Fig. 1) in the Maestrat Basin of the Aragonese Branch of the Iberian Range (Eastern Iberian Chain), two corresponding to the Aliaga Sub-basin (Puerto de San Just, PS; Fuente del Vaso, FV) and two to the Oliete Sub-basin (Plou, PL; Huesa del Común, HU). Below we present a brief summary of some of the relevant lithological and paleophytogeographical aspects of the sections sampled in this study (Fig. 2).

PUERTO DE SAN JUST SECTION (PS)

The Boundary Marls Unit is represented in this section by a 7 m thick succession of laminated green marlstones with occasional levels containing unidentifiable macrofloral remains, intercalated with limestones. The overlying Mosqueruela Formation consists of 2 m of yellowish limestones with ostreids. The underlying Utrillas Formation

in the same section has been previously described by Villanueva-Amadoz *et al.* (2009).

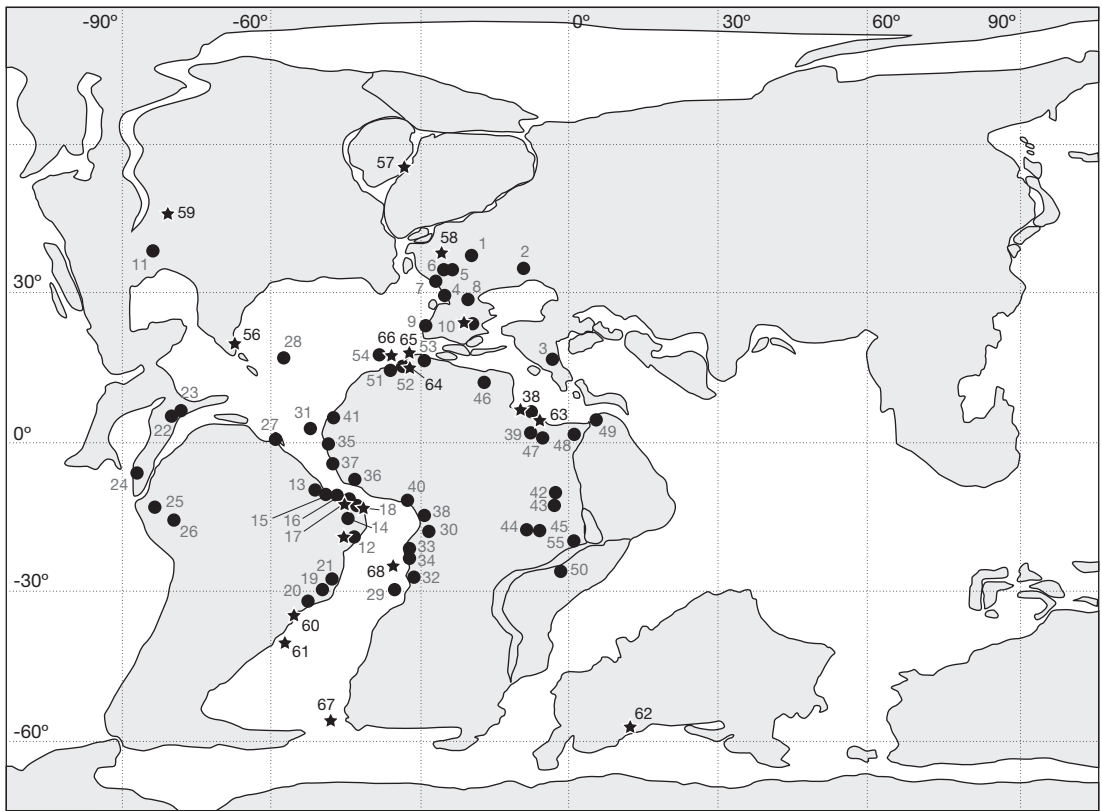
FUENTE DEL VASO SECTION (FV)

The stratigraphic succession of the Boundary Marls Unit at Fuente del Vaso shows three distinct intervals (Fig. 2). The lowest, about 10 m thick, consists at the base of a white, channelled, medium-grained sandstone alternating with grey claystone that changes upward into a succession composed mainly of white, medium-grained sandstone with interbedded grey claystones and sandy shales. The next interval, about 10 m thick, is formed by a succession of finely laminated white sandstone and grey claystone with macroflora remains. The upper interval, 1 m thick, is represented by yellowish sandy limestones with ostreids of the Mosqueruela Formation, which may correspond to a tidal channel deposit.

PLOU SECTION (PL)

The stratigraphic succession of the Boundary Marls Unit at Plou shows two distinct intervals (Fig. 2). The lowest, about 7 m thick and overlying the Utrillas Formation, consists of finely laminated marlstone and claystone alternating with fine-grained sandstone, representing sedimentation in a shallow freshwater lake with occasional clastic input. Levels from the lowest interval provided the aquatic angiosperm macrofossils *Klitzschophyllites choffatii* (Saporta *sensu* Teixeira) Gomez, Coiffard, Sender, Martín-Closas, Villanueva-Amadoz & Ferrer, 2009 (Gomez *et al.* 2009) and *Ploufolia cerciforme* Sender, Gomez, Diez, Coiffard, Martín-Closas, Villanueva-Amadoz & Ferrer, 2010 (Sender *et al.* 2010). The upper interval, up to 10 m thick, is a monotonous succession of massive claystone and sandy channels, interpreted to

FIG. 4. — Distribution of *Afropollis jardinus* Doyle, Jardín & Doerenkamp, 1982 (●) and *Cyclonephelium chabaca* Below, 1981 (★). The palaeogeographic map was created using the ODSN Plate Tectonic Reconstruction Service (Hay *et al.* 1999) back to 100 My (late Albian) in an orthographic projection: **Afropollis jardinus**: **1**, Mons Basin (Yans *et al.* 2007), Belgium; **2**, Bohemia (Pacltová & Lashin 1998), Czech Republic; **3**, Marches-Ombrie Basin (Fiet 1999; Fiet & Pons 1998), Italy; **4**, Charentes, Île Madame (Dejax & Masure 2005; SNEA[P]; Doyle *et al.* 1982), France; **5**, Ecommoy (Azéma *et al.* 1972), France; **6**, Neau (Azéma *et al.* 1972), France; **7**, La Bironnière (Azéma *et al.* 1972), France; **8**, Anjou (Yans *et al.* 2007), France; **9**, between Lisbon and Foz da Felcao and on both sides of the Serra de Sintra (Hasenboehler 1981), Portugal; **10**, Iberian Chain (this study), Spain; **North America**: **11**, Lake Texoma, Oklahoma (Wingate 1980), USA; **Gondwana, South America**: **12**, Sergipe and Alagoas Basins (Müller 1966; Regali *et al.* 1974a, b; Herngreen 1975), Brazil; **13**, Maranhão Basin (Müller 1966; Regali *et al.* 1974a, b; Lima 1982), Brazil; **14**, Ararape Basin (Pons *et al.* 1996), Brazil; **15**, Barreirinhas Basin (Herngreen 1973, 1975; Regali *et al.* 1974a, b), Brazil; **16**, northern Piauí Basin (Regali *et al.* 1974a, b), Brazil; **17**, Ceará Basin (Regali *et al.* 1974a, b; Lima 1979), Brazil; **18**, North R.G. and Potiguar Basins (Regali *et al.* 1974a, b; Campos *et al.* 1994), Brazil; **19**, Espírito Santo, Brazil; **20**, Rio de Janeiro, Brazil; **21**, Jequitinhonha/Cumuruxaliba Basins; **19-21**, (Regali *et al.* 1974a, b), Brazil; **22**, San Luis de Gaceno (Dueñas Jiménez 1989; Herngreen & Dueñas Jiménez 1990), Colombia; **23**, Pamplona (Dueñas



Jiménez 1989), Colombia; **24**, Oriental Basin (Jaillard 1997), Ecuador; **25**, Montaña region (Brenner 1968), Peru; **26**, Oriente Basin (Robertson Research 1990), Peru; **27**, (Belsky *et al.* 1975), Suriname; **28**, DSDP sites 418A/core10, 418B/core 28 and 417D/core 19 (Hochuli & Kelts 1980), southwestern North Atlantic; **West Africa**: **29**, offshore, DSDP Site 364 (Morgan 1978; Doyle *et al.* 1982), Angola; **30**, Douala Basin (SNEA[P]; Doyle *et al.* 1982), Cameroon; **31**, DSDP Site 367, cores 21 and 23, 150 km west of Guinea Bissau (Kotova 1978; Doyle *et al.* 1982), Cape Verde; **32**, SNEA(P); Doyle *et al.* 1982, Congo; **33**, North Gabon (SNEA[P]; Doyle *et al.* 1982), Gabon; **34**, Doukaga 1980, north of Mayumba; **35**, SNEA(P); Doyle *et al.* 1982, Guinea-Bissau; **36**, Bérour I, Port Bouet I, and Groguida 1 deep wells (SNEA[P]; Doyle *et al.* 1982), Ivory Coast; **37**, SNEA(P); Doyle *et al.* 1982, Liberia; **38**, wells A1-28 core 3, A1-36, B1-36, Bla-18 and A1-45, North Cyrenaica (Thusu & Van der Eem 1985; Thusu *et al.* 1988; Uwins & Batten 1988), Libya; **39**, wells A1a-117, Ai-NC-92, B1-2, between Benghazi and Tobruk, flanks of the Abakaliki Anticlinorium and flanks of the Lamurde Anticline and the Dadyia Syncline (Legoux 1978; Allix 1982; SNEA[P] Doyle *et al.* 1982; Uwins & Batten 1988), Libya; **40**, borehole Ojo-1, 25 km west of Lagos, Benin Basin (Jan du Chêne *et al.* 1978; Klsz & Jan du Chêne 1978), Nigeria; **41**, M'Bour 1 well (Jardiné & Magloire 1965), Senegal; **42**, Dongola-Wadi Muqaddam area (Schrank 1990), Sudan; **43**, west of Umm Badda (Awad 1994), Sudan; **44**, Muglad, Sudan; **45**, Melut (Kaska 1989), Sudan; **North Africa-Middle East**: **46**, SNEA(P); Doyle *et al.* 1982, Algeria; **47**, Qattara Depression and surroundings (Saad 1978; Schrank & Ibrahim 1995; Ibrahim 1995; Ibrahim 1996, 2002a; Mahmoud & Moawad 2000; Zobaa *et al.* 2008; Atawy 2009; El-Beialy *et al.* 2010), Egypt; **48**, Kabrit-1 and Abu Hammad-1 wells, near Ismailia (Ibrahim *et al.* 2001) and Tahrir well, Western Desert (Sultan 1978), Egypt; **49**, Sample Ramon Maále Haázamát (SNEA[P]; Herngreen 1975; Doyle *et al.* 1982), Israel; **50**, Majunja Basin [SNEA(P); Doyle *et al.* 1982], Madagascar; **51**, Tantan-Tarfaya and Tamaloukte localities (Bettar & Méon 2001, 2006), Morocco; **52**, samples TSK02 to TSK43 (Tiskatine), samples AOR15 to AOR40 (Aouerga), and samples ADZ07 and ADZ10 (Adouz), Agadir-Essaouira Basin (Bettar & Méon 2006), Morocco; **53**, core G 503 (Tisirène) and core G 488 (Meloussa) (Hochuli 1981), Morocco; **54**, DSDP Hole 370 (Kotova 1978; Doyle *et al.* 1982), Morocco; **55**, SNEA(P); Doyle *et al.* 1982, Somalia. **Cyclonephelium chabaca**, **Laurasia**: **56**, DSDP Holes 627B and 635B (Masure 1988), Bahamas; **57**, offshore (Williams 1975), Canada; **58**, Isle of Wight (Clarke & Verdier 1967), Great Britain; **10**, Iberian Chain (this study), Spain; **59**, central and southern Kansas (Bint 1986), USA; **Gondwana**: **12**, Sergipe Basin (Masure & Vrielynck 2009), Brazil; **17**, Ceará Basin (Lana & Roesner 2002; Arai 2005), Brazil; **18**, Potiguar Basin (Masure & Vrielynck 2009), Brazil; **60**, 1-SPS-14A well, Santos Basin (Masure & Arai 2003; Arai 2005), Brazil; **61**, offshore site 203 (Masure & Vrielynck 2009), Brazil; **62**, Cauvery Basin (Khowaja-Ateequzzaman & Garg 2002), India; **63**, site 15 (Masure & Vrielynck 2009), Libya; **38**, well A1-45 core 1 (Uwins & Batten 1988), Libya; **64**, KV-Blätter Tamri and Tarhazoute, Chichaoua I and Timinoun sections (Below 1981), Morocco; **65**, sites 18 and 19 (Masure & Vrielynck 2009), Morocco; **66**, DSDP Holes 545 and 547A, Mazagan Plateau (Below 1984), Morocco; **67**, offshore, DSDP Leg 40 site 361 (Davey 1978), South Africa; **68**, offshore Cabinda (Nelson 2008), Angola.

reflect deposition in distal alluvial fans. The top of the succession is overlain by the sandy limestone of the Mosqueruela Formation. These beds contain abundant bioclasts of marine molluscs such as oysters, and are interpreted as a near-shore high-energy marine deposit (Canérot *et al.* 1982).

HUESA DEL COMÚN SECTION (HU)

In the Huesa del Común section (HU) the Boundary Marls Unit consists of 5 m of finely laminated grey marls with ostracods, gastropods and plant remains. It has been interpreted as a shallow freshwater lake with occasional clastic input. At the top, the Mosqueruela Formation includes a thick succession (23 m) of nodulose limestones with ostreids at the base which passes into sandy limestones and shaly limestones toward the top.

MATERIAL AND METHODS

A total of 34 samples were processed following the standard processing technique used in palynology, employing an acid digestion with HCl, HF and HNO₃. Finally, the residue was filtered through a 100 µm mesh sieve. Only 21 samples proved to be positive (Appendix).

The slides were analysed at the Muséum national d'Histoire naturelle (Paris) under a Nikon Eclipse 80i light microscope using a differential interference contrast objective and equipped with a Nikon Coolpix 5400. Palynomorphs were photographed at a magnification of × 750, except for pollen grains photographed at × 1000. Several separate optical

section pictures were taken for each palynomorph and depth of field was then reconstructed using the free image stacking program CombineZM (Bercovici *et al.* 2009). Scanning electron micrographs were taken at Vigo University using a SEM Phillips XL 30.

Each pollen grain is designated first with the acronym of the section and its stratigraphic level, followed by the slide number and finally the England Finder coordinates.

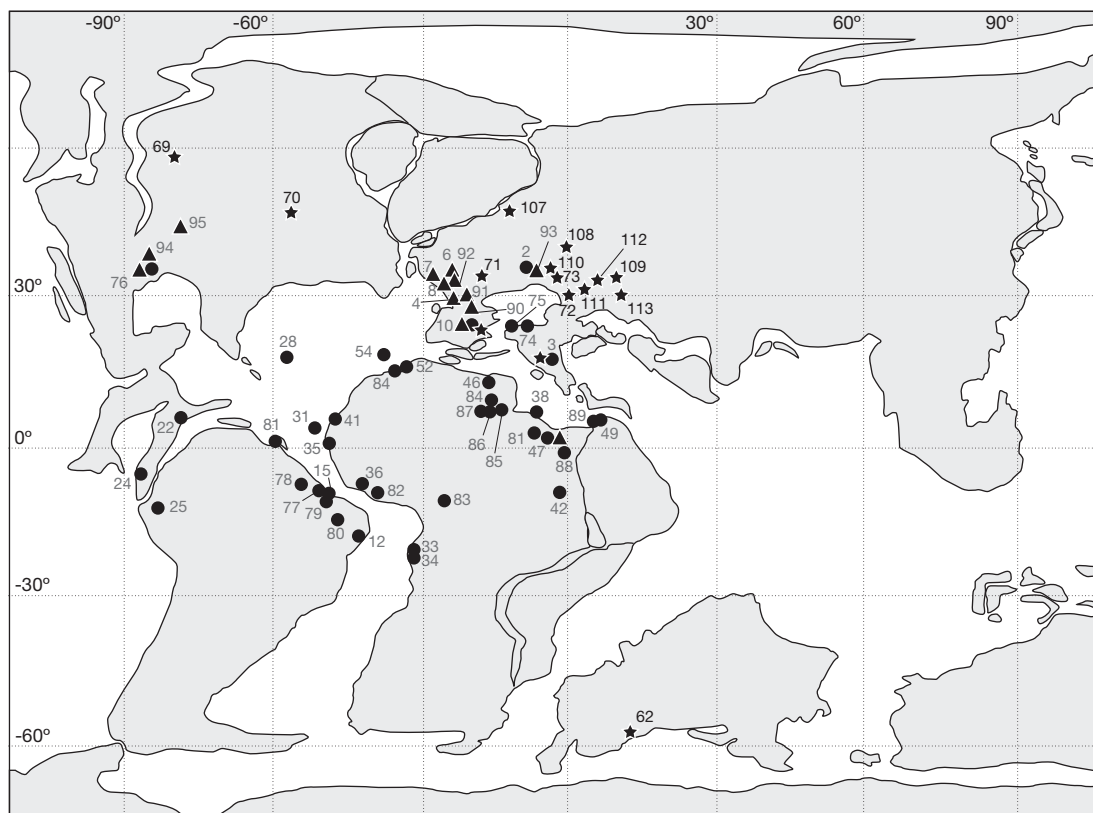
COMPOSITION OF PALYNOLOGICAL ASSEMBLAGES

The four studied sections yielded very rich palynological assemblages with a high diversity of species (Appendix; Figs 8-16).

The most noteworthy aspect of this study concerns the variability of the palynological assemblages, which may be explained in part by facies control. It is evident that the taphonomic (biostratigraphical) processes involved in the particular sedimentological setting within this lagoon complex determined the composition of the palynological assemblage.

It ought to be noted that in the present paper *Afropollis* has been described as angiosperm pollen grain as there is not yet any consistent data that relate to any known group. However, the interpretation of *Afropollis* as an angiosperm has been questioned based on the finding of this pollen in microsporangia of uncertain but probably non-angiospermous affinities (Friis *et al.* 1999) and its gymnosperm-like laminated endexine structure (Doyle 2000).

FIG. 5. — Distribution of *Asbeckiasporites* Von der Brelie, 1964 (★), *Elaterosporites klaszii* (Jardiné & Magloire) Jardiné, 1967 (●) and *Vadaszsporites sacalii* Deák & Combaz, 1967 (▲). The palaeogeographic map was created using the ODSN Plate Tectonic Reconstruction Service (Hay *et al.* 1999) back to 100 My (late Albian) in an orthographic projection. **Asbeckiasporites**, **Laurasia**: 69, Peace River, Alberta (Singh 1971), Canada; 70, Saskatchewan and Manitoba (Playford 1971), Canada; 71, Sauerland (von der Brelie 1964), Germany; 3, Marches-Ombrie Basin (Fiet & Pons 1998; Fiet 1999), Italy; 72, Caucase, Russia; 73, Donetz; 107, Southern Baltic Sea; 108, Russian platform; 109, Dniepr-Donetz depression; 110, pre-Black Sea depression; 111, eastern Caucase; 112, pre-Caspian depression; 113, western Kazakhstan; 72, 73, 107-113, Bolkhovitina 1966; Voronova 1971; Herrngreen & Chlonova 1981, Russia; 10, Iberian Chain (this study), Spain; **Gondwana**: 62, borehole RKK-1, Damodar Basin (Vijaya 2011), India. **Elaterosporites klaszii**, **Laurasia**: 28, DSDP Hole 417 (Hochuli & Kelts 1980), Bermudas; 2, Bohemia (Paclitová & Lashin 1999), Czech Republic; 74, Cismon section (Hochuli 1981), Italy; 3, Marches-Ombrie Basin (Fiet & Pons 1998; Fiet 1999), Italy; 10, Iberian Chain (this study), Spain; 75, Breggia section (Hochuli 1981), Switzerland; 76, recycled palynomorph, Ragley Lumber D1 well, Louisiana (Gregory & Hart 1992), USA; **Gondwana**, **South America**: 12, Calumbi (Ca-1-Se) borehole and sample 9704593 (137.7 m) GTP-17-SE, Sergipe Basin (Boer *et al.* 1965; Herrngreen 1975; Carvalho 2001), Brazil; 15, 1-QS-1-MA, Mandacaru (I-MU-I-MA), Humberto de Campos (2-HCst-I-MA) and Barreirinhas (2-BAst-I-MA) boreholes, Barreirinhas Basin (Boer *et al.* 1965; Herrngreen 1973, 1975; Regali *et al.* 1974a, b; Dino *et al.* 1999), Brazil; 77, continental platform of Maranhão and São Luis Basin (Regali *et al.* 1974a, b; Ferreira *et al.* 2008), Brazil; 78, core



16 of borehole Bj-I-PA, Marajó/Badajós Basin (Boer *et al.* 1965; Herrgreen 1975), Brazil; **79**, Parnaíba Basin (Dino *et al.* 1999), Brazil; **80**, GTP-24-SE, Taquari/Vassouras, Piauí Basin (Carvalho 2001), Brazil; **22**, San Luis de Gaceno (Dueñas Jiménez 1989) and between Bogotá and Villavicencio (Pons 1988; Herrgreen & Dueñas Jiménez 1990), Colombia; **24**, Rio Misahualli and Rio Chapiza, Oriental Basin (Jaillard 1997; Dino *et al.* 1999), Ecuador; **25**, Peru Mountains, Cerros Contamana, Cushabatay and Campanquiz (Brenner 1968, 1976; Müller & Aliaga 1981; Vara 2003), Peru; **81**, DSDP site 144 leg 14 (Habib 1972), Suriname; **West Africa**: **31**, DSDP Site 367, cores 21 and 23, 150 km west of Guinea Bissau (Kotova 1978), Cape Verde; **33**, Boltenhagen 1965; Jardiné 1967; Klasz & Micholet 1972, Gabon; **34**, north of Mayumba (Doukaga 1980), Gabon; **82**, Tano 1-1 and 1S-3AX wells, Tano Basin (Atta Petters & Salami 2006), Ghana; **35**, SNEA(P); Doyle *et al.* 1982, Guinea Bissau; **36**, wells Gr1, Gt, Tt1, Bt1, Bu1 and Bérou 1, Lahou-Abidjan localities (Vachey & Jardiné 1962; Jardiné & Magloire 1965; Jardiné *et al.* 1974; SNEA(P); Doyle *et al.* 1982), Ivory Coast; **38**, A1-28 core 3, A1-36, B1-36, Bla-18, Ala-117, Ai-NC-92, B1-2and A1-45 wells, North Cyrenaica (Thusu & Van der Eem 1985; Uwins & Batten 1988), Libya; **83**, Upper Benue Graben (Allix 1983; Abubakar *et al.* 2006), Nigeria; **84**, Septentrional Province (ZB 1 well), southern Tunisian area, Sahara; **85**, Te 1 and Sb 1 wells, Gassi-Touil area, Sahara; **86**, Ar 101, GT 3, Mf 101 and Aa 1 wells, Tinnhert area and Occidental area, Sahara; **87**, St 1 and Df 1 wells (Reyre 1973), Sahara; **41**, Bb1, DN1, DN2, DN5, 3, 4, 7, 6, 8, Sa1, Do.1, Do.2, Do.3, Mb.1, DS1, Po.1, Ye.3 wells, east of Dakar (Stover 1963; Jardiné & Magloire 1965; Jardiné 1967), Senegal; **42**, Dongola-Wadi Muqaddam area (Schrank 1990, 1994), Sudan; **44**, Muglad, Sudan; **45**, Melut (Kaska 1989), Sudan; **North Africa-Middle East**: **46**, SNEA(P); Doyle *et al.* 1982, Algeria; **88**, well Umbarka IX, Kharga, Nile Delta area (Saad 1978), Egypt; **47**, Qattara Depression and surroundings (Sultan 1978, 1987; Penny 1991, 1992; Schrank & Ibrahim 1995; Ibrahim 1996, 2002a; Mahmoud & Moawad 2000; Atawy 2009; El-Beialy *et al.* 2010), Egypt; **89**, north of Negev (Horowitz 1970), Israel; **49**, Sample Ramon Ma'ale Haazamaut [SNEA(P); Herrgreen 1975; Doyle *et al.* 1982], Israel; **51**, Tantan-Tarfaya and Tamaloukte localities (Bettar & Méon 2001, 2006), Morocco; **52**, samples TSK04 to TSK43 (Tiskatine), samples AOR27 and AOR38 (Aouerga), Agadir-Essaouira Basin (Bettar & Méon 2006), Morocco; **54**, DSDP Hole 370 (Kotova 1978), Morocco. **Vadaszsporites sacalii**, **Laurasia**: **4**, Saint-Romain-de-Benêt and Archingey quarry, Charente-Maritime (Deák & Combaz 1967; Dejax & Masure 2005), France; **6**, Neau (Azéma & Ters 1971), France; **7**, La Bironnière, La Bloire, La Laiterie, Les Gaucherries, Bois-Soleil and Vendée (Azéma & Ters 1971), France; **8**, Anjou (Pons, unpublished observations), France; **90**, Laudun, Montloux and Col des Robines (Médus & Triat 1969; Médus 1970), France; **91**, Simeyrols, La Malvie (Azéma & Ters 1971), France; **92**, Le Revest (Azéma & Ters 1971), France; **93**, Transdanubia (Juhász 1975, 1983; Góczán & Siegl-Farkas 1990); Uppony Mountains, south part of the Great Hungarian Plain and the Trans-Tisza Region (Góczán & Siegl-Farkas 1990), Hungary; **10**, Iberian Chain (this study), Spain; **76**, Louisiana, USA; **94**, Mississippi, USA; **95**, near Sargeant Bluff in Iowa (Ravn 1986; Ludvigson *et al.* 2010), USA; **Gondwana (Turonian-Coniacian)**: **47**, well GPTSW-7, north Western Desert (El-Beialy *et al.* 2010), Egypt.

In the Puerto de San Just section (PS) there is a more marked marine influence than in other sections, evidenced by green marls with an interbedding of nodular bioclastic limestones with ostracods. The palynological results also attest this increasing marine input by a gradual increase of dinoflagellate cysts, mainly composed of *Cyclonephelium chabaca*, which is the dominant palynomorph at PS 13, and, to a lesser extent, by *Oligosphaeridium pulcherrimum*, *Florentinia* sp. and other indeterminate cysts. This trend is also associated with an upward decrease of gymnosperm and angiosperm pollen grains and also of spores. The gymnosperm pollen grains, which are abundant at the base of the unit, consist mainly of *Classopollis* spp. followed in abundance by *Exesipollenites tumulus*, *Taxodiaceapollenites hiatus*, *Araucariacites australis*, *Spheripollenites psilatus*, *Alisporites grandis*, *Applanopsis* spp., *Podocarpidites bififormis*, *Balmeiopsis limbata*, *Singhia* spp., *Cycadopites* spp., *Cedripites canadensis* and *Perinopollenites halonatus*. The second most abundant group is that of pteridophyte spores, which are mainly composed of *Cyathidites* spp., *Patellasporites* spp., and, in lower proportions, *Gleicheniidites senonicus*, *Gabonisorites* spp., *Matonisorites equixinus*, *Deltoidospora psilotoma*, *Dictyophyllidites harrisii*, *Laevigatosporites haardtii*, *Polycingulatisporites reduncus*, *Taurocusporites segmentatus*, *Cicatricosisporites* spp., *Camarozonosporites insignis*, *Asbeckiasporites* sp., *Crybelosporites pannuceus*, *Plicatella* spp., *Ruffordiaspora australiensis*, *Anapiculatisporites* sp., *Cibotiumspora juncta*, *Concavisporites punctatus*, *Concavissimisporites verrucosus*, *Convverrucosisporites platyverrucosus*, *Coronatispora* spp., *Costatoperforosporites foveolatus*, *Fisciniasporites breviaesuratus*, *Leptolepidites verrucatus*, *Neoraistrickia truncata*, *Peromonolites* spp., *Reticulatisporites arcuatus*, *Undulatisporites undulapulus*, *Asbeckiasporites* sp., *Camarozonosporites* spp., *Anapiculatisporites* sp. and *Heliosporites* sp. Angiosperm pollen grains are also quite abundantly represented by *Transitoripollis* sp. cf. *T. similis*, *Clavatipollenites* spp., *Afropollis jardinus*, *Monosulcites chaloneri*, *Pennipollis* spp., *Retimonocolpites dividuus*, *Stellatopollis barghoornii*, *Retitricolpites virgeus*, aff. *Tricolpites crassimurus* and *Rousea* sp. B.

At very low proportions, bryophyte spores are represented by *Aequitriradites spinulosus*, *Triporoletes*

cenomanianus and *T. reticulatus*, and there are also spores of algae such as *Pterospermella aristotelesii*.

The other studied sections (FV, PL, HU) are more generally lacustrine. At the Plou section (PL), the lacustrine character of the deposits is inferred from sedimentological evidence and the aquatic angiosperm macrofossil content. However, the palynological assemblage provides no evidence, due to the scarcity of specimens possibly due to a high clastic input. It is mainly composed of angiosperm pollen grains, which are represented in decreasing order of abundance by *Stellatopollis barghoornii*, *Rousea* spp., *Tricolpites crassimurus*, *Afropollis jardinus*, *Asteropollis* sp. cf. *A. asteroides*, *Transitoripollis* sp. cf. *T. similis*, *Clavatipollenites* spp., *Retimonocolpites textus* and *Similipollis* spp. Gymnosperm pollen grains are represented to a lesser extent by *Araucariacites australis*, *Alisporites grandis*, *Cycadopites* spp., *Taxodiaceapollenites hiatus*, *Balmeiopsis limbata*, *Equisetosporites ambiguus* and *Spheripollenites psilatus*. Finally pteridophyte spores are characterized by the presence of *Cyathidites* spp. and *Peromonolites* sp.

The most lacustrine deposits are recorded from Fuente del Vaso (FV) and Huesa del Común (HU) sections, coinciding with abundant macrofloral remains and high values of *Afropollis jardinus*.

At the Fuente del Vaso section (FV) there is very low marine influence with the highest abundance of dinoflagellate cysts (represented by undetermined dinoflagellate cysts, *Cyclonephelium chabaca*, *Florentinia* sp. and *Oligosphaeridium pulcherrimum*) being 2.2% of the total palynological assemblage.

Angiosperm pollen grains are abundant, consisting mainly of *Afropollis jardinus*, and, to a lesser extent, *Clavatipollenites* spp., *Stellatopollis barghoornii*, *Penetetrapites mollis*, *Tricolpites* spp., *Pennipollis* spp., *Senectotetradites varireticulatus*, *Transitoripollis* sp. cf. *T. similis*, *Dichastopollenites* spp., *Echimonocolpites* sp. and *Sriatopollis paraneus*. The next most abundant group is the gymnosperm pollen grains, mainly represented by *Taxodiaceapollenites hiatus*, followed by *Araucariacites* spp., *Balmeiopsis limbata*, *Classopollis classoides*, *Exesipollenites tumulus*, *Spheripollenites psilatus*, *Podocarpidites* spp., *Perinopollenites halonatus*, *Applanopsis* spp., *Eucommiidites* spp., *Alisporites grandis*, *Cedripites canadensis*, *Elaeterosporites*

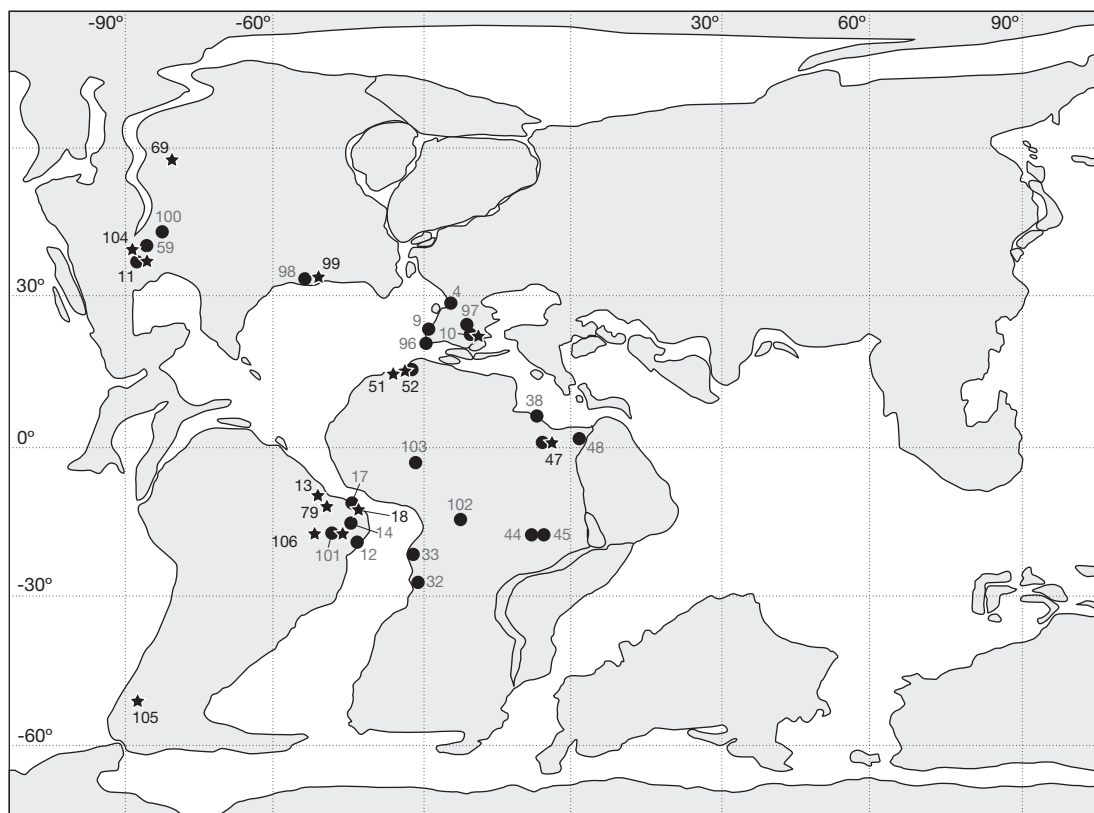


Fig. 6. — Distribution of *Penetetrapites mollis* Hedlund & Norris, 1968 (★) and *Stelletapollis barghoornii* Doyle, 1975 (●). The paleogeographic map was created using the ODSN Plate Tectonic Reconstruction Service (Hay *et al.* 1999) back to 100 My (late Albian) in an orthographic projection. ***Stelletapollis barghoornii*, Laurasia:** 4, Charentes (Dejax & Masure 2005), France; 9, Folcao-Magoito, Baforeira Rana, Barrigudo, Casal da Cova and Magoito-Aguda, near Nazaré (Hasenboehler 1981; Heimhofer *et al.* 2007), Portugal; 96, Luz (Heimhofer *et al.* 2007), Portugal; 97, Peñacerrada, Basque-Cantabrian Basin (Barrón *et al.* 2001), Spain; 10, Iberian Chain (present study), Spain; 11, Oklahoma (Hedlund & Norris 1968), USA; 98, Virginia, USA; 99, Maryland and Delaware (Doyle *et al.* 1975; Doyle & Robbins 1977; Walker & Walker 1984), USA; 59, Kansas (Ward 1986), USA; 100, Nebraska (Ludvigson *et al.* 2010), USA; **Gondwana:** 12, Sergipe Basin (Carvalho 2001), Brazil; 14, Araripe Basin (Pons *et al.* 1996), Brazil; 17, Pernambuco-Ceará Basin (Lima 1976), Brazil; 18, Potiguar Basin (Campos *et al.* 1994), Brazil; 101, Chapada do Araripe (Martill *et al.* 2007), Brazil; 102, Doba Graben (Doyle *et al.* 1982), Chad; 32, borehole K8, south of Tchiboula (Boltenhagen & Salard-Chebaldoeff 1987), Congo; 47, Ghazalat-1 (GTX-1) well, Qattara Depression (Penny 1991; Schrank & Ibrahim 1995; Ibrahim 1996, 2002b; Atawy 2009), Egypt; 48, Kabrit-1 well, Bitter Lake (Ibrahim *et al.* 2001), Egypt; 33, Libreville (Doyle *et al.* 1977, 1982), Gabon; 38, northern Cyrenaica (Thusu & van der Eem 1985); well VV1-80/GGG1-59 (Thusu *et al.* 1988), Libya; 103, Ansongo 1 well, Gao Graben (SNEA[P]; Doyle *et al.* 1982), Mali; 52, Tiskatine, Agadir-Essaouira Basin (Bettar & Méon 2006), Morocco; 44, Muglad, Sudan; 45, Melut (Kaska 1989), Sudan; ***Penetetrapites mollis*, Laurasia:** 69, southern Alberta (Braman 2001), Canada; 10, Iberian Chain (present study), Spain; 11, Lake Texoma, Bokchito Creek and Marshall County, Oklahoma (Hedlund & Norris 1968; Srivastava 1975; Wingate 1980), USA; 59, central Kansas (Ward 1986), USA; 99, Delaware (Doyle & Robbins 1977), USA; 104, Dallas and Waco Texas (Brown & Pierce 1962), USA; **Gondwana:** 105, Rio Turbio, Santa Cruz province (De Baldis 1995), Argentina; 13, Maranhão Basin (Lima 1982), Brazil; 18, Potiguar Basin (Dino 1992), Brazil; 79, Parnaíba Basin (Campos *et al.* 1994), Brazil; 101, Chapada do Araripe (Martill *et al.* 2007), Brazil; 106, Fazenda Muzinho, Florianópolis (Lima & Campos 1980), Piauí, Brazil; 47, Mersa Matruh borehole, North West Desert (Penny 1991), Egypt; 51, Tamaloukte, Morocco; 52, Tiskatine and Aouerga in Agadir-Essaouira Basin (Bettar & Méon 2001, 2006), Morocco.

klaszii, *Cycadopites* spp., *Parvisaccites radiatus*, *Ephedripites multicostatus*, *Equisetosporites ambiguus* and *Singhia acicularis*. The assemblage also presents a

high abundance of pteridophyte spores, mainly *Cyathidites* spp., *Peromonolites* sp., *Matonisporites equiexinus*, *Gabonisoris* spp., *Gleicheniidites senonicus*

and, in lower proportions, *Dictyophyllidites harrisii*, *Deltoidospora* spp., *Ruffordiaspora australiensis*, *Concavissimisporites verrucosus*, *Laevigatosporites haardtii*, *Cicatricosisporites* spp., *Plicatella* spp., *Impardecispora* spp., *Patellasporites* spp., *Biretisporites potoniaei*, *Camarozonosporites* spp., *Neoraistrickia robusta*, *Todisporites* spp., *Crybelosporites* spp., *Nodosisporites* spp., *Ischyosporites disjunctus*, *Klukisporites* sp. cf. *K. foveolatus*, *Microreticulatisporites crassiexinuous*, *Vinculisporites flexus*, *Cibotiumspora juncta*, *Concavisporites punctatus*, *Distaltriangulisporites* sp., *Leptolepidites verrucatus*, *Lophotriletes babsae*, *Microfoveolatosporis baconicus*, *Perinomonoletes* sp., *Reticulisporites* sp. and *Undulatisporites undulapolus*. Less frequently, spores of freshwater algae are also present (*Schizophacus parvus*, *Schizosporis* spp., *Pterospermella aristotelesii*), together with bryophyte spores (*Aequitriradites spinulosus*, *Antulsporites varigranulatus*, *Stereisporites antiquasporites*, *Triporoletes laevigatus*).

The palynological assemblage of the Huesa del Común section (HU) also shows very low proportions of dinoflagellate cysts. However, there is a clear predominance of angiosperm pollen grains consisting mainly of *Afropollis jardinus*, with lower quantities, listed in decreasing abundance, of *Clavatipollenites* spp., *Tricolpites* spp., *Retimonocolpites fragilis*, *Stellatopollis barghoornii*, *Transitoripollis* sp. cf. *T. similis*, *Liliacidites* spp., *Pennipollis* spp., *Dichastopollenites dunveganensis*, *Penetetrapites mollis*, *Rousea* sp., *Monosulcites minimus* and *Hammenia fredericksburgensis*. In addition the gymnosperm pollen grains are represented in low proportions in decreasing abundance by *Araucariacites australis*, *Spheripollenites psilatus*, *Alisporites grandis*, *Taxodiaceapollenites hiatus*, *Ephedripites multicostatus*, *Eucommiidites troedssonii*, *Applanopsis* spp., *Classopollis classoides*, *Cycadopites* sp. and *Podocarpidites ornatus*. Algae spores are also found represented by *Schizophacus* spp. and *Pterospermella aristotelesii*, while pteridophytes are characterized by terrestrial *Cyathidites* spp., *Camarozonosporites insignis*, *Peromonolites* sp. and freshwater *Crybelosporites pannuceus*.

PALYNOSTRATIGRAPHY

The palynostratigraphic distribution, based on the previous available literature, for the presence of the individual spores and pollen grains identified within

the 21 samples is shown in Figure 3. The Boundary Marls Unit includes some taxa that are not known to extend above the Albian-Cenomanian boundary such as: *Cicatricosisporites subrotundus*, *Concavisporites punctatus*, *Concavissimisporites verrucosus*, *Converrucosisporites platyverrucosus*, *Coronatispora valdensis*, *Impardecispora marylandensis*, *I. trioreticulosa*, *Ischyosporites disjunctus*, *Liliacidites doylei*, *L. inaequalis*, *Lophotriletes babsae*, *Microfoveolatosporis baconicus*, *Neoraistrickia robusta*, *Perinopolitenites halonatus*, *Plicatella potomacensis*, *P. tricostata*, *Reticulatisporites arcuatus*, *Singhia acicularis* and *Undulatisporites undulapolus*.

Some other taxa are widely distributed above the early-middle Albian boundary, such as *Afropollis jardinus*, *Crybelosporites pannuceus*, *Penetetrapites mollis*, *Rousea brenneri*, *R. georgensis* distributed from the middle Albian to Cenomanian and *Stellatopollis barghoornii* from the middle Albian to middle Cenomanian. Moreover, there are abundant taxa distributed above the middle-late Albian boundary, such as *Dichastopollenites* sp. cf. *D. reticulatus*, *Elaterosporites klaszii* and *Equisetosporites ambiguus* present through the late Albian to Cenomanian, *Tricolpites blechrus* from late Albian to Turonian, *Vadaszispites sacalii* from late Albian to early Campanian, and *Gabonispis pseudoreticulatus* from late Albian to earliest Turonian. Taxa restricted to the latest Albian-Cenomanian interval in Laurasia include *Cyclonephelium chabaca* and *Senectotetradites varireticulatus*.

The presence of the palynomorphs cited above allows us to establish a latest Albian age for this unit (shaded rectangle in the Figure 3).

PALAEOPHYTOGEOGRAPHICAL AND PALAEOECOLOGICAL IMPLICATIONS

PALAEOPHYTOGEOGRAPHY

The rapid diversification of early angiosperms after a phase of pronounced environmental instability was favoured by the extensive marine transgressions of the early Aptian and latest Albian-Cenomanian (Haq *et al.* 1988) permitting ecological strategies of early angiosperms and their dominance in coastal disturbed habitats (Doyle *et al.* 1982). The upper-

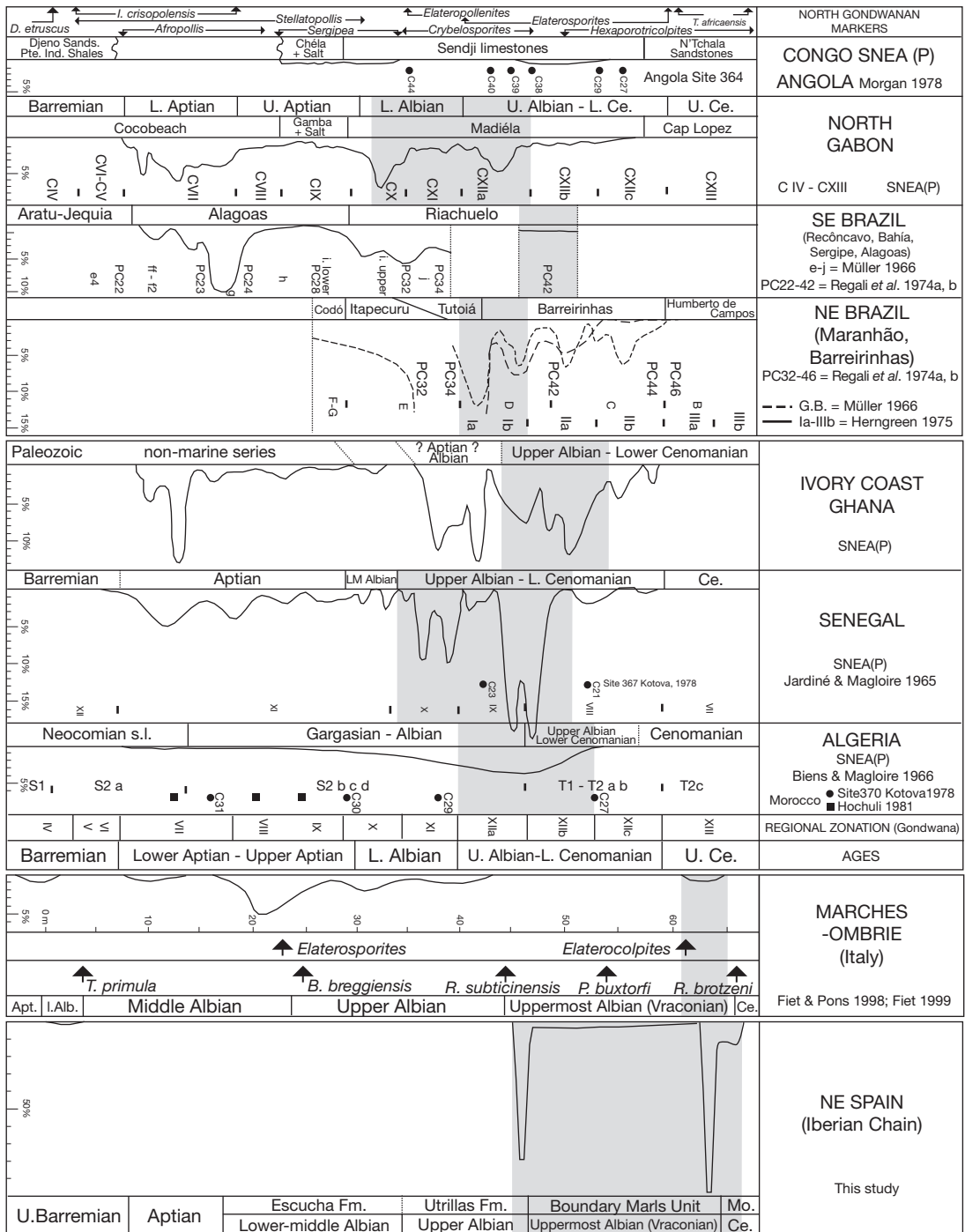


Fig. 7. — Quantitative distribution of the genus *Afropollis* Doyle, Jardíné & Doerenkamp, 1982 in Gondwana and southern Laurasia (modified after Doyle *et al.* 1982).

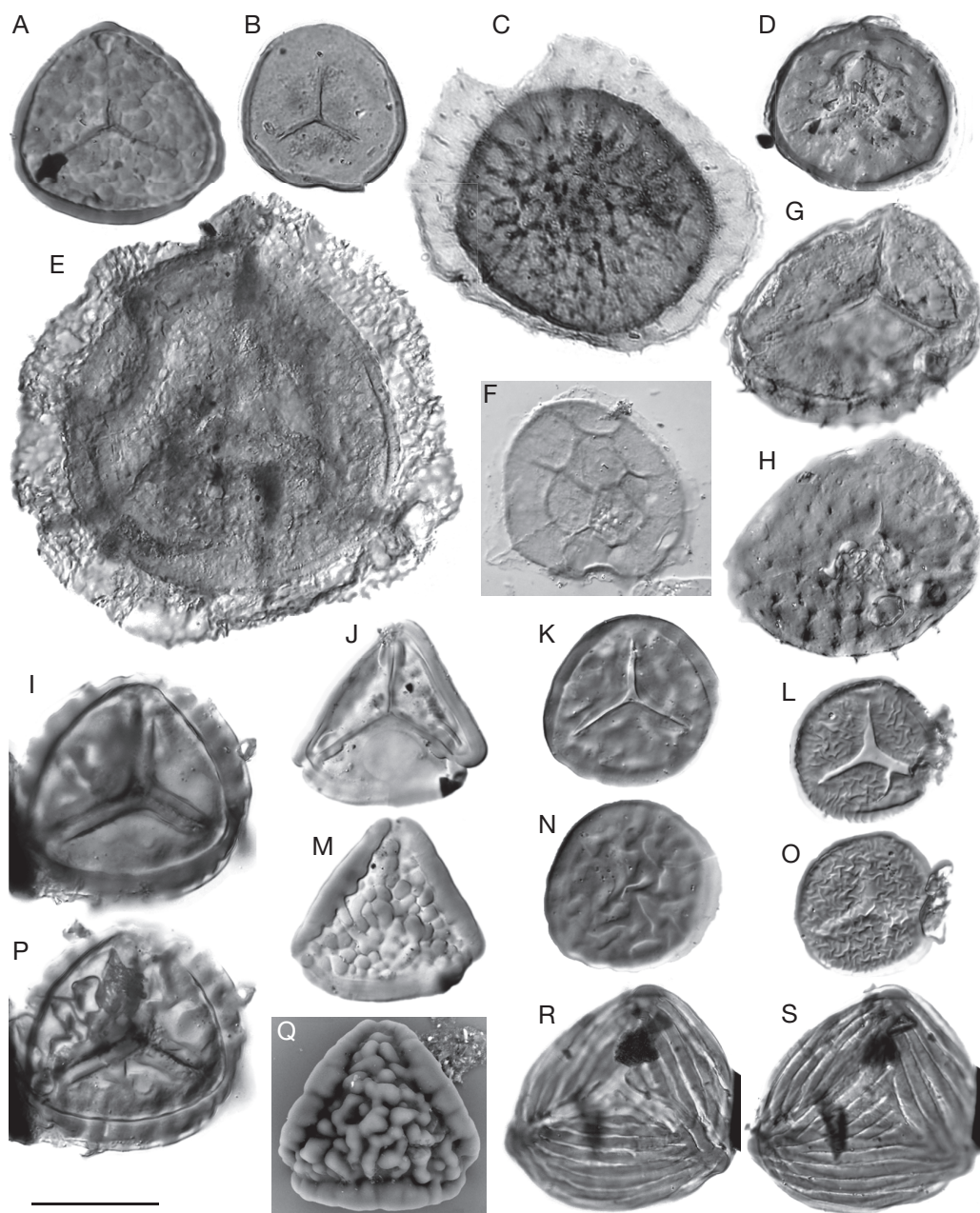


FIG. 8. — **A**, *Antulsporites varigranulatus* in proximal face (VA2B4Q524); **B**, *Stereisporites antiquasporites* in proximal view (VA2A3H44); **C**, *Aequitriaradites spinulosus* in distal view (FV2A1K19); **D**, *Triporoletes laevigatus* in proximal view (FV4 3_3R4); **E**, *Aequitriaradites* sp. 2 in distal view (PS8a2_5F424); **F**, *Triporoletes cenomanianus* in proximal view (PS8bA3T573); **G**, **H**, *Anapiculatiporites* sp. in proximal (**G**) and distal (**H**) views (PS126P414); **I**, **P**, *Camarozonosporites* sp. 2 in proximal (**I**) and distal (**P**) views (FV3 3_3M352); **J**, **M**, *Asbeckiasporites* sp. in proximal (**J**) and distal (**M**) views (PS121X291); **K**, **N**, *Camarozonosporites* sp. 1 in proximal (**K**) and distal (**N**) views (PS124S56); **L**, **O**, *Camarozonosporites insignis* in proximal (**L**) and distal (**O**) views (PS10c4M523); **Q**, *Asbeckiasporites* sp. in distal view (PS10); **R**, **S**, *Cicatricosisporites* sp. cf. *Anemia exiloides* in proximal (**R**) and distal (**S**) views (FV4B1F58). Scale bar: A-E, G-P, R, S, 20 μ m; F, Q, 10 μ m.

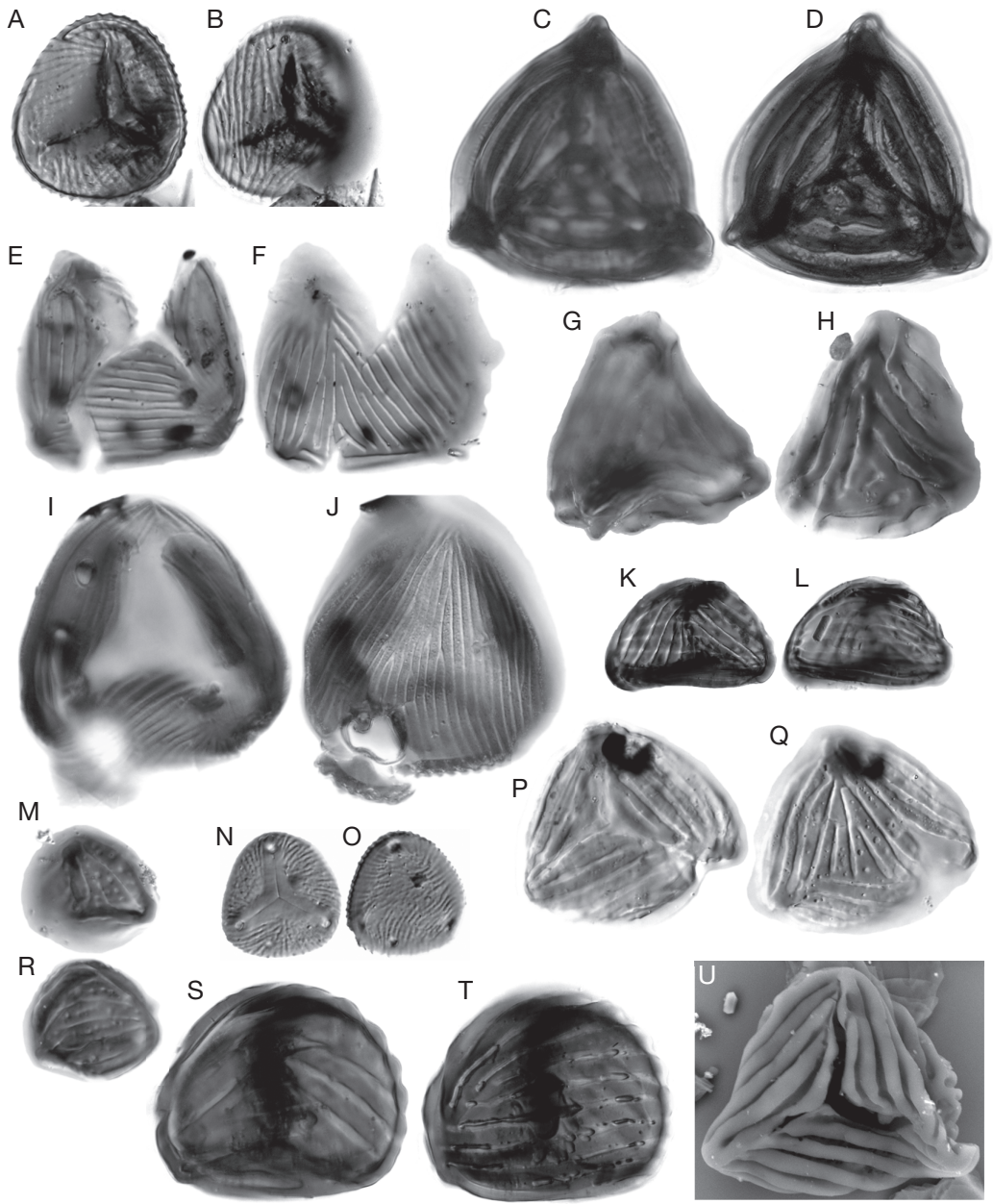


FIG. 9. — A, B, *Cicatricosisporites hallei* in proximal (A) and distal (B) views (FV3_3N382); C, D, *Cicatricosisporites hughesii* in proximal (C) and distal (D) views (FV1B2G433); E, F, *Cicatricosisporites imbricatus* in proximal (E) and distal (F) views (PS121R37); G, H, *Cicatricosisporites* sp. cf. *C. imbricatus* in proximal (G) and distal (H) views (PS132O343); I, J, *Cicatricosisporites minutaestriatus* in proximal (I) and distal (J) views (PS8bB2O532); K, L, *Cicatricosisporites myrtellii* in proximal (K) and distal (L) views (PS121L254); M, R, *Cicatricosisporites perforatus* in proximal (M) and distal (R) views (PS7c3O402); N, O, *Cicatricosisporites venustus* in proximal (N) and distal (O) views (PS10b3bS504); P, Q, *Cicatricosisporites pseudotripartitus* in proximal (P) and distal (Q) views (PS10A2S383); S, T, *Cicatricosisporites subrotundus* in proximal (S) and distal (T) views (FV3_3_N384); U, *Cicatricosisporites pseudotripartitus* in proximal view (PS10a), SEM. Scale bars: A-T, 20 μ m; U: 30 μ m.

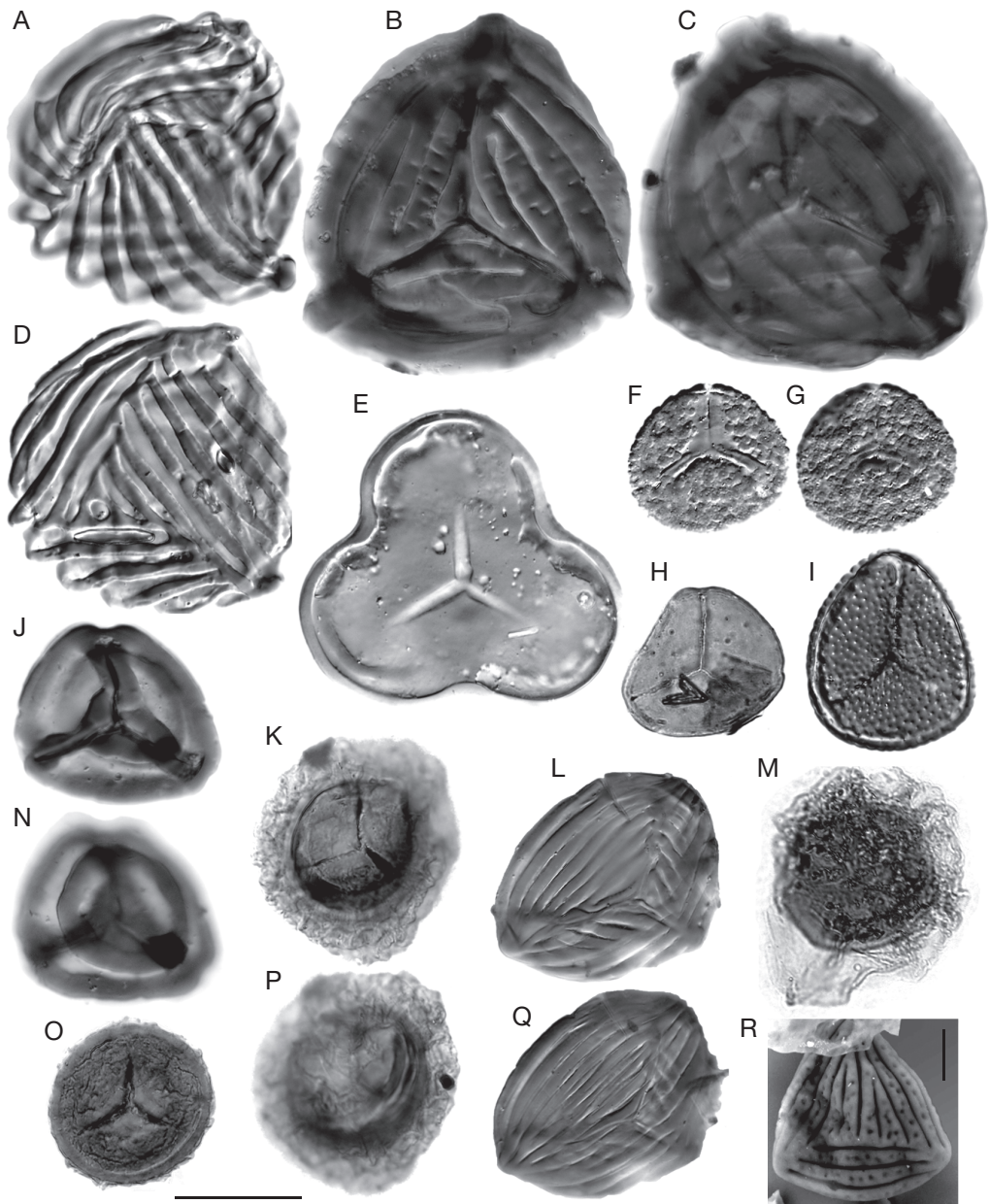


FIG. 10. — **A, D**, *Cicatricosisporites* sp. 3 in proximal (**A**) and distal (**D**) views (PS10c6U42); **B, C**, *Cicatricosisporites* sp. 4 in proximal (**B**) and distal (**C**) views (PS8bB3C37); **E**, *Concavisorites punctatus* in proximal view (PS7c3O412); **F, G**, *Converrucosisporites platyverrucosus* in proximal (**F**) and distal (**G**) views (PS10a6K27); **H**, *Deltoidospora* sp. in proximal view (FV1A2H372); **I**, *Foveosporites subtriangularis* in proximal view (PS7c3X291); **J, N**, *Coronatispora* sp. in proximal (**J**) and distal (**N**) views (PS10c2N312); **K, P**, *Gabonispors pseudoreticulatus* in proximal (**K**) and distal (**P**) views (FV2A3Z414); **L, Q**, *Fisciniasporites brevilaeuratus* in proximal (**L**) and distal (**Q**) views (PS10a3Y39); **M**, *Crybelosporites pannuceus*, high focus (VA1A2G49); **O**, *Crybelosporites* sp. in proximal view (FV2A4M402); **R**, *Costatoperforosporites foveolatus* in distal view (PS10a). Scale bars: A-Q, 20 µm; R: 10 µm.

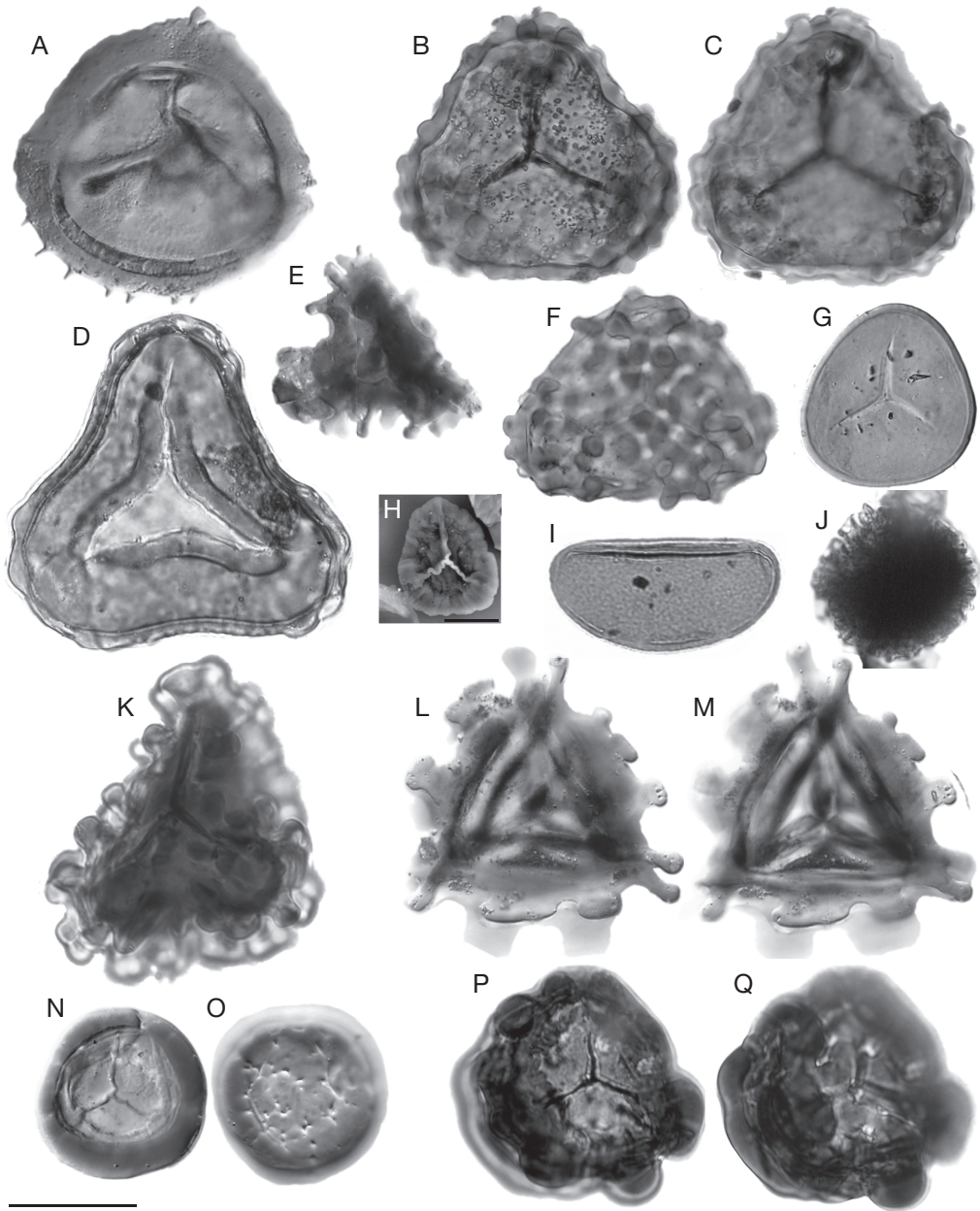


FIG. 11. — **A**, *Heliosporites* sp. in proximal view (PS122E52); **B**, **C**, *Impardecispora marylandensis* in proximal (**B**) and distal (**C**) views (FV4B4T33); **D**, *Impardecispora trioreticulosa* in proximal view (FV1B2O333); **E**, *Neoraistrickia truncata* in distal view (PS10b2_4F27); **F**, *Ischyosporites disjunctus* in distal view (FV4B4L491); **G**, *Matonisporites equiexinus* in proximal view (FV4A1R194); **H**, *Patellasporites distaverrucosus* in proximal view (PS10a); **I**, *Microfoveolatosporites baconicus* in lateral view (FV1A2G43); **J**, *Gabonisporis* sp., high focus (FV1A2K503); **K**, *Neoraistrickia robusta* in proximal view (FV1B2O334); **L**, **M**, *Nodosisporites* sp. 2 in proximal (**L**) and distal (**M**) views (PS134P38); **N**, **O**, *Patellasporites* sp. in proximal (**N**) and distal (**O**) views (PS10b1_4L362); **P**, **Q**, *Patellasporites tavadarensis* in proximal (**P**) and distal (**Q**) views (FV1A2H37). Scale bars: A–G, I–Q, 20 µm; H, 10 µm.

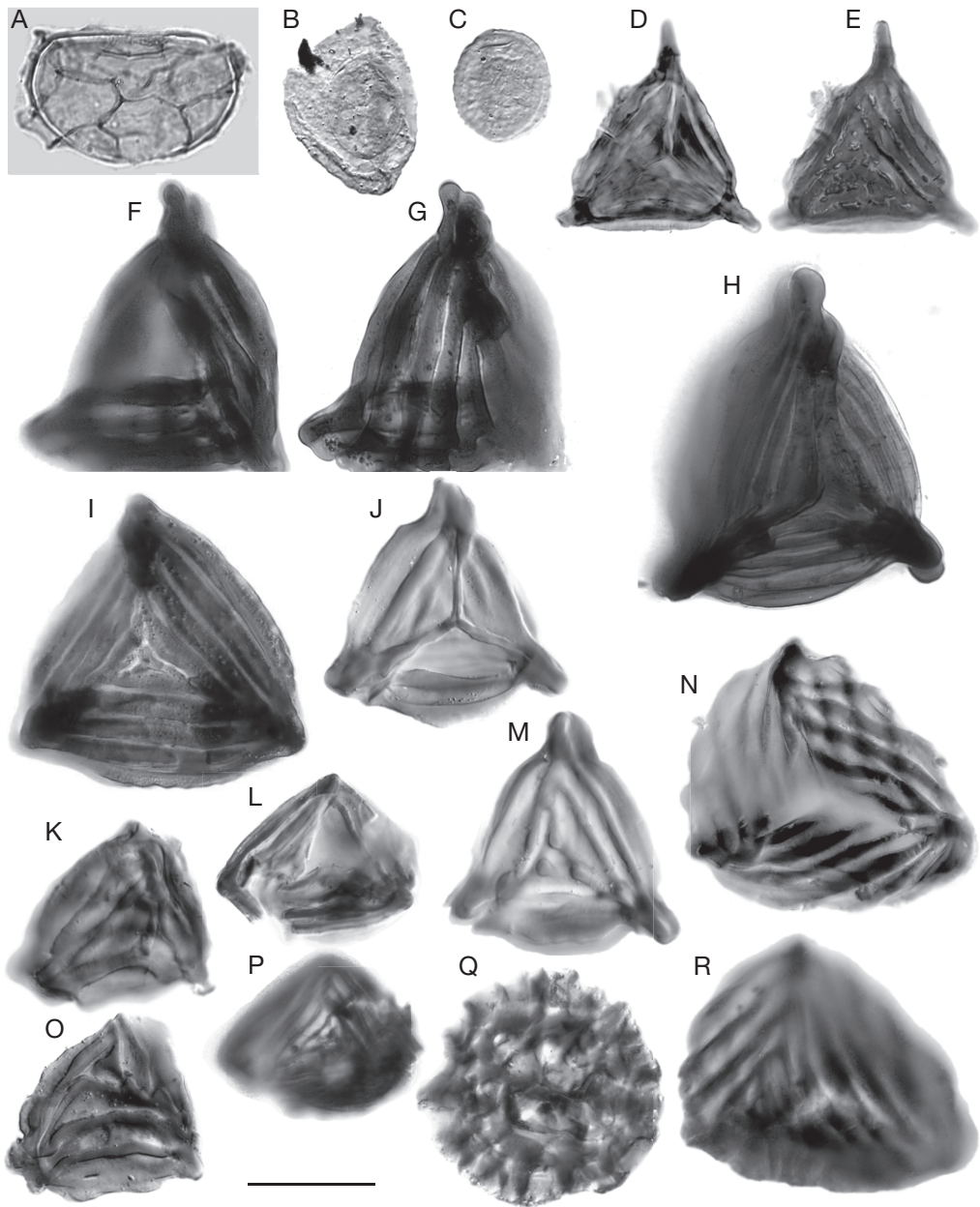


FIG. 12. — **A**, *Perinomonolites* sp. in lateral view (FV1A2O281); **B**, *Peromonolites fragilis* in proximal view (PS121N492); **C**, *Peromonolites* sp. in distal view (PS5aA2H223); **D**, **E**, *Plicatella appendicifera* in proximal (**D**) and distal (**E**) views (FV4B4X432); **F**, **G**, *Plicatella cristata* in proximal (**F**) and distal (**G**) views (FV1B1U470); **H**, *Plicatella bilateralis* in proximal view (FV2B1K421); **I**, *Plicatella gigantica* in proximal view (PS8bB4H394); **J**, **M**, *Plicatella* sp. cf. *P. potomacensis* in proximal (**J**) and distal (**M**) views (PS10a6D30); **K**, **O**, *Plicatella problematica* in proximal (**K**) and distal (**O**) views (PS8bA3H47); **L**, **P**, *Plicatella potomacensis* in proximal (**L**) and distal (**P**) views (PS7c3X33); **N**, **R**, *Plicatella triceps* in proximal (**N**) and distal (**R**) views (PS8bB3D562); **Q**, *Reticulatisporites arcuatus* in distal view (PS10a3W261). Scale bar: 20 μ m.

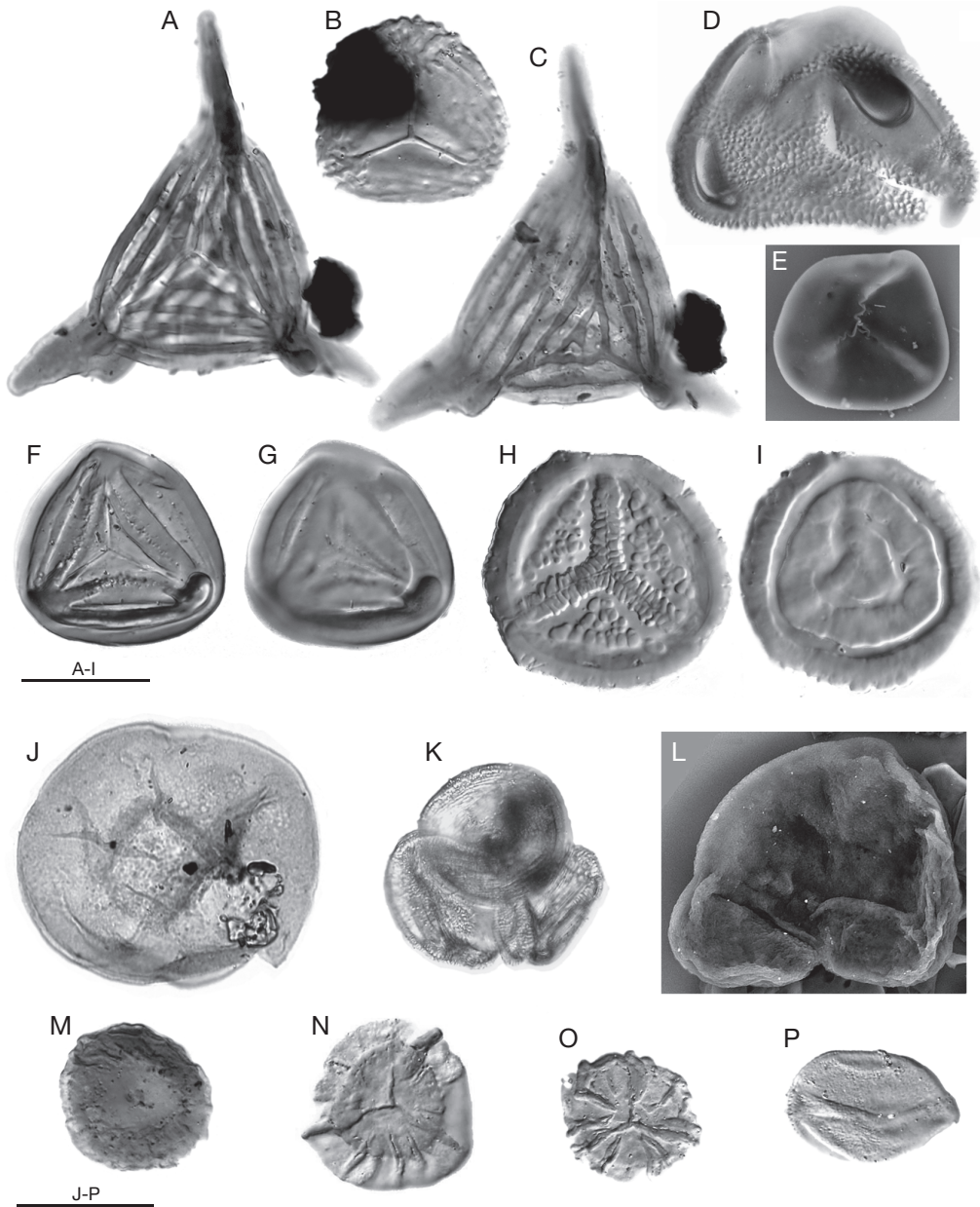


FIG. 13. — **A, C**, *Plicatella unica* in proximal (**A**) and distal (**C**) views (FV4B2P57); **B**, *Ruffordiaspora australiensis* in proximal view (PS10A2O43); **D**, *Vadaszsporites sacalii* in proximal view (PS133K543); **E**, *Undulatisporites undulapulus* in proximal view (PS10a); **F, G**, *Vinculisporites flexus* in proximal (**F**) and distal (**G**) views (FV4 3_3R30); **H, I**, *Taurocusporites segmentatus* in proximal (**H**) and distal (**I**) views (PS8a2N28); **J**, *Araucariacites australis*, mid focus (FV1B1P404); **K**, *Classopollis major*, tetrad (PS131Q361); **L**, *Cedripites canadensis* in lateral view (PS10a); **M**, *Applanopsis segmentatus* in distal view (FV4 3_3N264); **N**, *Applanopsis dampieri* in proximal view (PS10a2H54); **O**, *Applanopsis* sp. in proximal view (PS10a3N553); **P**, *Classopollis classoides* in lateral view (PS10b1_6Q47). Scale bar: 20 μ m.

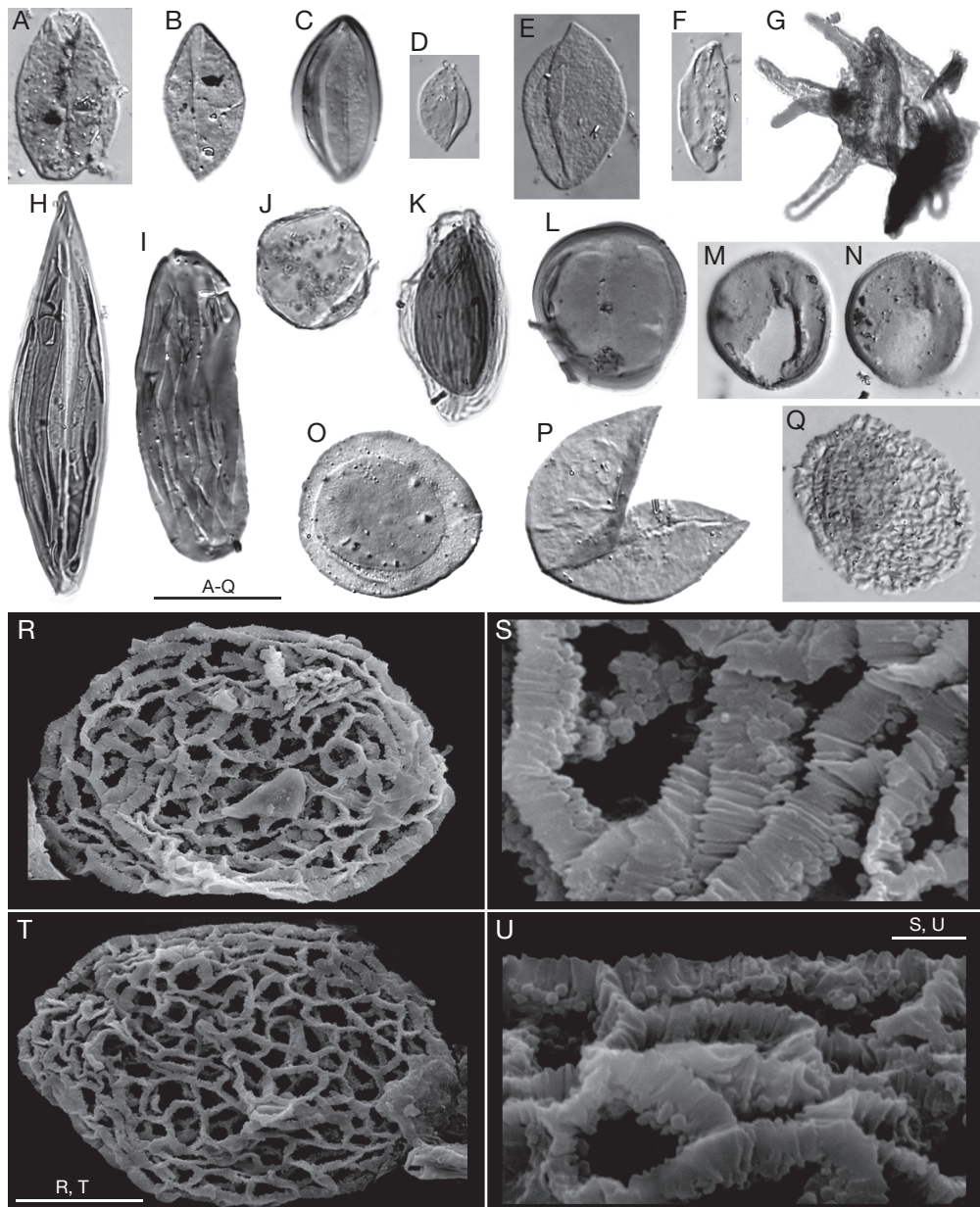


FIG. 14. — **A**, *Cycadopites* sp. 1 in proximal view (PLB02_4R42); **B**, *Cycadopites* sp. 2 in proximal view (PS10c1O22); **C**, *Cycadopites* sp. 3 in proximal view (PS8bA3U322); **D**, *Cycadopites* sp. 4 in proximal view (PLB02_4B44); **E**, *Cycadopites* sp. 5 in proximal view (HCB0_6_F282); **F**, *Cycadopites* sp. 7 in proximal view (PLB02_4O43); **G**, *Elaterosporites klaszii* in lateral view (FV3A1K484); **H**, *Singhia acicularis* in equatorial view (FV1A2H393); **I**, *Singhia minima* in equatorial view (PS126N54); **J**, *Spheripollenites psilatus*, mid focus (FV1A2S272); **K**, *Equisetosporites ambiguus*, high focus (FV1A2O444); **L**, *Eucommiidites minor* in equatorial view (FV3_3_3D291); **M**, **N**, *Clavatipollenites hughesii* in distal (M) and proximal (N) views (FV4G294); **O**, *Perinopollenites halonatus*, mid focus (PS10a4T45); **P**, *Taxodiaceapollenites hiatus* in lateral view (PS122W37); **Q**, *Afropollis jardinus*, mid focus (FV4_3F29); **R-U**, *Afropollis jardinus*, SEM, mid focus; **R**, HCB004; **S**, detail of R, T (HCB005); **U**, detail of T. Scale bars: A-Q, 20 μ m; R, T, 10 μ m; S, U, 1 μ m.

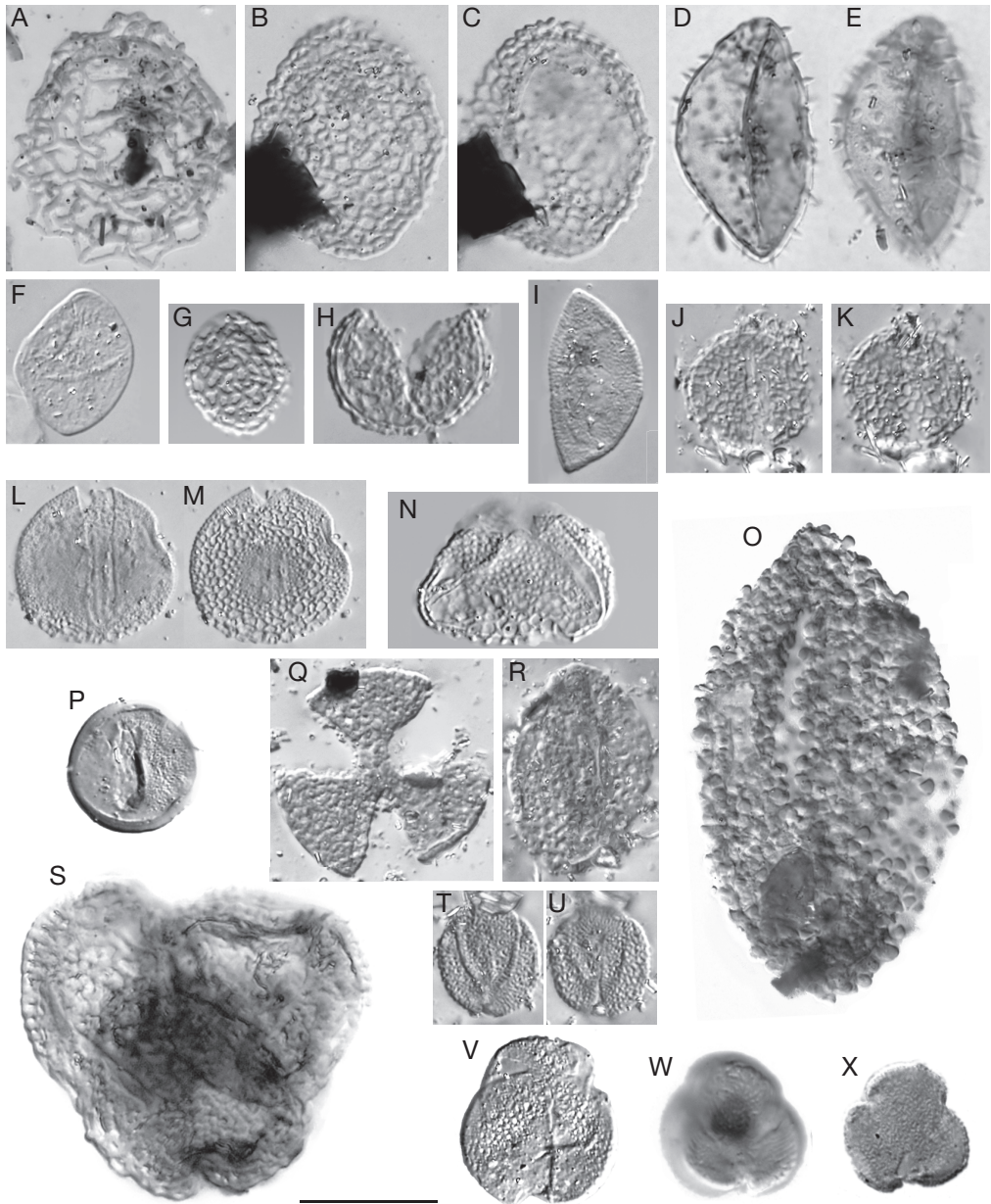


FIG. 15. — **A**, *Dichastopollenites dunveganensis*, high focus (FV1_2_3_0354); **B**, **C**, *Dichastopollenites* sp. cf. *D. reticulatus*, high (**B**) and mid (**C**) focus (FV4H31); **D**, **E**, *Echimonocolpites* sp., high (**E**) and mid (**D**) focus (FV4A3O253); **F**, *Monosulcites minimus* in proximal view (HCB2_3_6_L324); **G**, *Pennipollis reticulatus* in proximal view (PS122P293); **H**, *Pennipollis* sp. in lateral view (HCB2_3U30); **I**, *Retimonocolpites fragilis* in lateral view (HCB0_2_6_K312); **J**, **K**, *Retimonocolpites textus* in distal (**J**) and proximal (**K**) views (PLB02_4R383); **L**–**N**, *Similipollis* sp. in distal (**L**) and proximal (**M**) views (PLB02_4K3); **N**, high focus (PS11b4R292); **O**, *Stellatopollis barghoornii* in distal view (FV4W271); **P**, *Transitoripollis* sp. cf. *T. similis* in distal view (PS11a1S551); **Q**, **R**, *Rousea brenneri*; **Q**, polar view (PLB02_4O332); **R**, equatorial view (PLB02_4T39); **S**, *Senectotetradites varireticulatus*, tetrad (FV3_3_3_T282); **T**, **U**, *Rousea georgiensis* in polar view (PLB02_4K544); **T**, high focus; **U**, low focus; **V**, *Rousea* sp. B in Burger 1993 in polar view (PS126V372); **W**, *Striatopollis paraneus* in polar view (FV4_3_3V334); **X**, *Tricolpites blechrus* in polar view (FV1_2D43). Scale bar: 20 μ m.

most Albian sea-level rise is contemporary with the dispersion of parent plants producing the spores and pollen grains across the Tethys from Northern Gondwana to Southern Laurasia and *vice versa*. Although rising sea level tended to inhibit rather than permit dispersal of terrestrial plants, it would be associated with a climatic change that may have favoured their dispersal in freshwater habitats into lowland fluvial-deltaic environments.

In the area of study, the Boundary Marls Unit is characterized by a peak of abundance of Gondwanan elements such as *Elaterosporites klaszii*, *Afropollis jardinus*, *Gnetaceaepollenites barghoornii*, *Ephedripites* spp. and *Stellatopollis barghoornii* from the Tethyan realm. The penetration of Northern Gondwanan elements into Southern Laurasia is in agreement with the view of Batten & Li (1987), Herngreen & Dueñas Jiménez (1990) and, Pactlová & Lashin (1998, 1999) that the geographic extent of the floral province characterised by elater-bearing species was much greater than originally estimated. It is also supported by the presence in the present work of the typically Laurasian form *Dichastopollenites reticulatus*, also found in Northern Gondwana at the same time interval. This indicates a transitional area between Northern Gondwana and Southern Laurasian floral belts that has been already reported by other authors in France, Portugal and the Southern Alps (Hochuli 1981). Based on the presence of *Afropollis* and other Gondwanan taxa, Hochuli (1981) suggested a climatic change as the cause for the northward extension of the Northern Gondwana floral belt during the late Albian-Cenomanian.

For better understanding of the palaeogeographical setting during the late Albian-early Cenomanian in terms of admixture of microfloras from adjacent areas, some selected taxa (*Afropollis jardinus*, *Asbeckiasporites*, *Elaterosporites klaszii*, *Penetetrapites mollis*, *Stellatopollis barghoornii*, *Vadaszispores sacalii* and *Cyclonephelium chabaca*) have been plotted (Figs 4-6) on reconstruction of continental areas for this time interval.

The first undoubted appearance of the genus *Afropollis* has been reported from the late Barremian both in Northern Gondwana (Egypt) and Southern Laurasia Provinces (England) represented by cryptaperturate forms (Penny 1989). It disappeared possibly

in the middle Cenomanian in Gondwana (Doyle *et al.* 1982) and in the late Cenomanian in Laurasia (Doyle *et al.* 1982; Penny 1989, 1991; Schrank & Nesterova 1993). Highest frequencies of the genus *Afropollis* are observed toward the supposed paleo-equator between 15°N and S (northeast Brazil, Peru, Senegal, Ivory Coast, Mali, Egypt), decreasing to the south (Gabon, Congo, Angola, 15-20°S) and to the north (Northern Africa: Morocco, Algeria; southern Alps, 15-20°N) (Doyle *et al.* 1982).

On the one hand, in Gondwana, the genus *Afropollis* appeared probably in Gabon at the same time (late Barremian) as in Egypt and England based on the Elf-Aquitaine correlation of the relevant zone (C-VII), represented by zonosulcate forms (*A. operculatus*, *A. zonatus*, *A. aff. zonatus*), being zone C-VII older than previously thought (Doyle 1992). Gabon record is also in line with Brazil, being Barremian rather than Aptian the interval containing the first *Afropollis* (Regali & Viana 1989). After a first maximum of *Afropollis* during the late Barremian, this genus became rarer in the late Aptian-early Albian, where zonosulcates were replaced by strongly heteropolar inaperturates (*A. aff. jardinus*). However, it reached a second maximum during the early-middle Albian in Northern Gondwana, Africa-South America (Fig. 7), with the almost isopolar, inaperturate species *A. jardinus*. It declined again during the latest Albian-early Cenomanian and disappeared during the (middle?) Cenomanian (Doyle *et al.* 1982).

On the other hand, it is noteworthy that all the reports of the genus *Afropollis* in the southern Laurasia (Fig. 4) are from the Tethyan-North Atlantic-Gulf Coastal fringe of Laurasia: England, France, Italy, Portugal and Spain in Europe, and also from Canada (Nova Scotia) and USA (Maryland and Oklahoma) (Hasenboehler 1981; Doyle *et al.* 1982; Penny 1989; Fiet & Pons 1998; De la Fuente *et al.* 2007; Villanueva-Amadoz 2009; Denise Pons, unpublished observations). Its presence coincides with two main rare extensions of northern Gondwanan elements across the Tethys into southern Laurasia (Doyle *et al.* 1982). The first one corresponds to the occurrence of the species *A. zonatus* in the early Aptian from the Breggia River section of southern Switzerland and the Cison section of northern

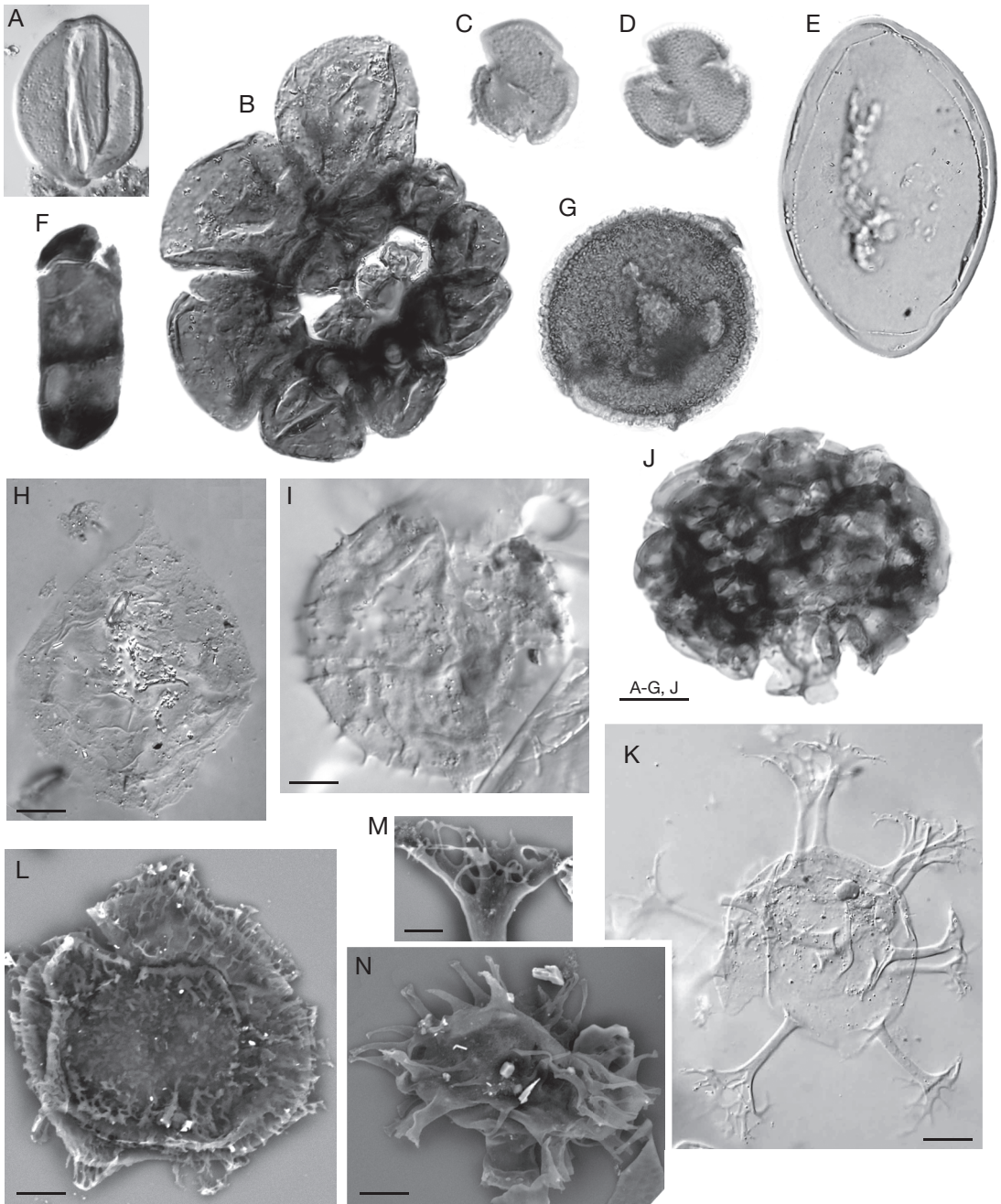


FIG. 16. — **A**, *Tricolpites crassimurus* in equatorial view (HCB0_2J45); **B**, Foraminiferal lining (PS131V513); **C**, aff. *Tricolpites crassimurus* in polar view (FV4A3H32); **D**, aff. *Tricolpites crassimurus* in polar view (FV2A4N294); **E**, *Schizophacus spriggi* in equatorial view (HUII1W43); **F**, *Dicaellaesporites* sp. (FV1A2S224); **G**, *Schizosporis microreticulatus*, mid focus (FV1A2H384); **H**, *Sublitisphaera* sp. (HCB0_2_6J32); **I**, *Criboeridinium* sp. (PS8bB2W35); **J**, *Plochmopeltinites* sp. (FV2A1M221); **K**, **M**, *Oligosphaeridium pulcherrimum*; **K**, PS8bB2M544; **M**, SEM (PS10a); **L**, *Cyclonephelium chabaca*, SEM (PS10a); **N**, *Florentinia* sp., SEM (PS10a). Scale bars: A, C, D, 10 μ m; B, E-N, 7 μ m.

Italy (Hochuli 1981), and also by *A. operculatus* and *A. zonatus* from the DSDP sites 417D, 418A, and 418B, located near the latitude of Rio de Oro of the North Atlantic (Hochuli & Kelts 1980). The presence of these species has been correlated with Zone C-VII in Gabon by Doyle *et al.* (1977). The peak of abundance of *Afropollis jardinus* in the late Albian-early Cenomanian in the present work (Fig. 7) is coincident with the second main peak reported by Doyle *et al.* (1982). This taxon, associated with *Elaterosporites klaszii*, *Elateroplicites africaensis*, and *Elaterocolpites castelainii*, has been reported from Breggia River and Cismon sections in the Southern Alps (Hochuli 1981) and also from the North Atlantic (Hochuli & Kelts 1980). *Afropollis jardinus* has also been reported, with a maximum of 2-5% of the total palynological content, from the late Albian in Portugal (Hasenboehler 1981). This second peak seems to correspond with the third Albian peak (Fig. 7) reported from the “marnes à Fucoïdes” Formation in Marches-Ombrie (Italy), also associated with the first appearance of *Elaterocolpites castelainii* (Fiet & Pons 1998; Fiet 1999). The latter formation has been dated as latest Albian (Vraconian) within stratigraphic zone I4 including the foraminiferal biozone *Praeglobotruncana buxtorfi* and ammonite biozone *Stoliczkaia dispar*. Another peak of Northern Gondwanan elements (elaterates, *Afropollis*, *Cretacaeiporites*, etc.) in Laurasia, possibly different from that described in the present work (Fig. 7), has been reported from the fluvial and estuarine successions of the Peruc-Korycany Formation of the Bohemian mid-Cenomanian (*Afropollis jukesbrownei* Zone) (Pactlová & Lashin 1998, 1999), which coincides with the initial transgression during the Cenomanian.

The presence of this taxon in the two most complete reference sections with *Afropollis* in Gondwana (Fig. 7) appears to be slightly earlier than or diachronous relative to the late Albian deposits in the study area and other southern Laurasian areas. It corresponds to Palynozones VIII to X (late Albian-early Cenomanian) from Senegal and to Palynozones C-X to C-XIIa (early-middle Albian) corresponding to Madièla Formation from the eastern Basin of North Gabon (Doyle *et al.* 1982). High values of *Afropollis jardinus* from other Gondwanan

sections could also be correlated with the Gabon zonation: deposits from Angola and southeastern Brazil (Zone PC42, Riachuelo Formation) are correlated with Subzone C-XIIa, northeastern Brazil with Zones C-IX to C-XI (Zones IA and IB, Itapecuru and Tutoiá Formations), Ivory Coast/Ghana with Subzones C-XIIa to C-XIIb and Algeria with Zones C-IX or C-X to C-XIIb (Doyle *et al.* 1982). However, the age of the deposits (especially from wells) in northern Gondwana need revision as there are some imprecisions in faunal dating. Moreover, some successions are based on composite sections (i.e. Senegal reference section).

Elaterosporites klaszii is more abundant in coastal environments between palaeolatitudes of 15°N and 15°S; however, exceptionally it is also present 5° northwards and southwards during the Albian-Cenomanian (Fig. 5).

The typically Tethyan taxa *Stellatopollis barghoornii* and *Penetetrapites mollis* are more frequent between palaeolatitudes of 40°N and 20°S (Fig. 6).

Another Tethyan taxon, *Cyclonephelium chabaca* (Fig. 4), is also present in the association. It is a specialized tropical-subtropical species, which has palaeolatitudinal ranges between 25°/30°N and 40°S (Masure & Vrielynck 2009). The high abundance of the dinocyst assemblage at level PS 13, mainly dominated by the single species *Cyclonephelium chabaca*, could reflect an algal bloom event in response to the mid-Cretaceous marine transgression under lagoonal or other limited marine circulation paleoenvironments. This event has been previously reported by Nelson (2008) for the Albian-Cenomanian nearshore deposits (Vermelha and Pinda formations) from the offshore of Cabinda in Angola.

Furthermore, the presence in this work of typical microfossil elements known from the Carpathian Mountains, Moessic platform and Donetz Basin, represented by the genera *Asbeckiasporites*, *Matonisorites*, *Vadaszisorites* and *Vinculisporites* (Fig. 5), suggests a boreal origin. The appearance of *Asbeckiasporites* at the Damodar Basin in India (Vijaya 2011), not figured in the paper, constitutes the southernmost reported occurrence of this genus to date. It could correspond to a transported element or endemic species due to the restriction of other boreal

taxa to palaeolatitudes between 20–45°N. However, India was much farther south at this time as seen in Figure 5. Such taxa have also been observed in the late Albian in Marches–Ombrie Basin in Italy by Fiet (1999) and Fiet & Pons (1998) who interpreted its presence as a result of transport by the north-Tethyan marine currents oriented NE–SW (Francis & Frakes 1993). However, the possibility is more acceptable that the mid-Cretaceous transgression together with a climatic change, would have favoured an expansion of the Tethyan areas that were subjected to equivalent environmental conditions.

PALAEOCLIMATICAL AND PALEOECOLOGICAL IMPLICATIONS

The climatic conditions at the palaeolatitude of 25°N of the Iberian Plate changed from a warm humid climate during the Aptian (Gröcke 2002) to a more arid climate during the late Albian. The high proportion of *Classopollis* (from PS 6 to PS 10), together with the presence of the species *Gnetaceapollenites barghoornii*, *Elaterosporites klaszii* and some types of *Ephedripites* in the deposits of the Boundary Marls Unit and Mosqueruela Formation, may indicate more arid conditions than in the underlying Escucha Formation, which shows higher percentages of fern spores with high abundance and diversity of Schizaeaceae. However, although aridity increases, we observe a high percentage of *Afropollis*, possibly related to humid tropical climates (Doyle *et al.* 1982), and lycopod spores, which indicate locally wet conditions in the studied sections.

The highest values of *Afropollis jardinus* (Table 1), reaching in some levels the 43% of the total palynological assemblage at FV-4 and 99% at HU-B0 (the latter of the total 1520 palynomorphs), are coincident with very low values of dinoflagellate cysts (0.1–2.6%) and the genus *Classopollis* ($\leq 1.5\%$). The correlation of high percentages of the genus *Afropollis* with coastal lacustrine environments with low marine influence has also been reported from Gabon (maximum 6 % of the total palynomorph assemblage in the lower Aptian Cocobeach Forma-

tion in Doyle *et al.* 1990) and Brazil [maximum 40% in the lower Albian from Maranhão Basin (Müller 1966) and maximum 50 % in the Crato Formation from Araripe Basin (Pons *et al.* 1996), late Aptian in age (Heimhofer & Hochuli 2010). Hochuli (1981) noted the possibility that the recovered Gondwanan taxa including *Afropollis jardinus* had undergone long-distance transport before their deposition and thus, reflect the latitudinal position of their area of origin. Later, Doyle *et al.* (1982) mentioned the possibility that the presence of *Afropollis* in Laurasian palynofloras might be the result of long-distance wind transport of pollen across the Tethys. However, this work shows that the abundance of the species *Afropollis jardinus* is variable, suggesting a facies control. The markedly high abundances of this species at HU-B0, its good preservation, the numerous tetrads (also preserved in clumps) and their presence restricted to lacustrine facies supports a short-distance transport prior their deposition.

Marine influence is also indicated by low percentages of the total palynomorph assemblage of foraminiferal linings (about 0.3%) and dinoflagellate cysts (0.1–21.8% except for sample PS-7 with a 48%). The presence of the prasinophycean alga *Pterospermella aristotelesii* in samples PS-6, PS-11, FV-3, HU-II and HU-B1 is concordant with the marine influence, which occurs in brackish or estuarine settings (Brocke & Riegel 1996; Prauss 2001).

CONCLUSIONS

A latest Albian-earliest Cenomanian age has been established for the Boundary Marls Unit in the Aliaga and Oliete Sub-basins in northeastern Spain.

These palaeogeographical data improve our knowledge of the mid-Cretaceous phytogeographical provinces and their distribution through time. At this time the studied area was located within a transitional floristic belt between southern Laurasian to the northern Gondwana provinces under a humid climate. Moreover, boreal elements are also represented by *Asbeckiasporites*, *Matonisporites*, *Vadasziasporites* and *Vinculisporites*.

The worldwide late Albian marine transgressions, together with the opening of the Tethys and the Atlantic Ocean, favoured the northward extension of some typically Gondwanan elements such as *Afropollis jardinus*, *Crybelosporites pannuceus*, *Elaterosporites klaszii*, *Gabonisoris* spp., *Stellatopollis barghoornii* and some types of *Ephedripites*.

Data from these sections show that *Afropollis jardinus* appeared in high abundance in the late Albian in the Maestrat Basin coinciding with the appearance of *Elaterosporites klaszii* and the second main maximum abundance of the genus *Afropollis*. It seems that *Afropollis jardinus* occurred in high percentages in coastal lacustrine or lagoon environments. However, it is noteworthy that *Afropollis jardinus* is absent in the Escucha Formation, with its presence restricted to the overlying Utrillas Formation, Boundary Marls Unit and the base of the Mosqueruela Formation.

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APPENDIX

List of palynomorphs from the studied sections. Distribution of the taxa and their abundance expressed in percentages of the total palynomorph number. The inferred stratigraphic range is represented in light grey. Abbreviations: **PS**, Puerto de San Just; **FV**, Fuente del Vaso; **PL**, Plou; **HU**, Huesa del Común; ®, reworked palynomorphs.

samples	PS					FV				PL	HU										
	6	7	8	9	10	11	12	13	1	2	3	4	0	I	II	III	B9	B3	B2	B1	B0
BRYOPHYTA																					
<i>Aequitriradites spinulosus</i> (Cookson & Dettmann) Cookson & Dettmann, 1961				0.3						0.3											
<i>Aequitriradites</i> sp. 1			0.3																		
<i>Aequitriradites</i> sp. 2			0.3																		
<i>Antulsporites varigranulatus</i> (Levet-Carette) Reiser & Williams, 1969										0.3											
<i>Stereisporites antiquasporites</i> (Wilson & Webster) Dettmann, 1963										0.3											
<i>Triporoletes cenomanianus</i> (Agasie) Srivastava, 1977			0.3		0.3																
<i>Triporoletes laevigatus</i> (Pocock) Playford, 1971													0.4								
<i>Triporoletes reticulatus</i> (Pocock) Playford, 1971			0.3		0.3							0.3®									
PTERIDOPHYTA																					
<i>Anapiculatisporites</i> sp.				0.3		3.2															
<i>Apiculatisporites</i> sp.																					
<i>Asbeckiasporites</i> sp.			0.3		0.6		6.4														
<i>Biretisporites potoniaei</i> Delcourt & Sprumont, 1955	0.4									0.3		0.3	0.7								
<i>Camarozonosporites insignis</i> Norris, 1967			0.8		1.6		3.2	0.4	0.7			0.4		0.4				0.7			
<i>Camarozonosporites</i> sp. 1							3.2														
<i>Camarozonosporites</i> sp. 2												0.7									
<i>Cibotiumspora juncta</i> (Kara-Murza) Singh, 1983	0.4				0.3					0.3		0.3									
<i>Cicatricosisporites</i> sp. cf. <i>A. exilioides</i> (Maljavkina) Bolkhovitina, 1961		0.3					3.2					0.4									
<i>Cicatricosisporites coconinoensis</i> Agasie, 1969								0.4													
<i>Cicatricosisporites hallei</i> Delcourt & Sprumont, 1955	®			®				®		0.3	0.7										
<i>Cicatricosisporites hughesi</i> Dettmann, 1963			0.3							0.3	0.3										
<i>Cicatricosisporites imbricatus</i> (Markova) Singh, 1971							3.2														
<i>Cicatricosisporites</i> sp. cf. <i>C. imbricatus</i> (Markova) Singh, 1971								0.4													
<i>Cicatricosisporites minutaestriatus</i> (Bolkhovitina, 1961) Pocock, 1964			0.3																		
<i>Cicatricosisporites myrtellii</i> Burger, 1966							3.2														

APPENDIX. — Continuation.

samples	PS										FV				PL	HU						
	6	7	8	9	10	11	12	13	1	2	3	4	0	I	II	III	B9	B3	B2	B1	B0	
<i>Cicatricosisporites perforatus</i> (Bolkhovitina) Singh, 1964		0.3																				
<i>Cicatricosisporites pseudotripartitus</i> (Bolkhovitina) Dettmann, 1963			0.3		1.3					0.3												
<i>Cicatricosisporites subrotundus</i> Brenner, 1963			0.5		0.3						0.3											
<i>Cicatricosisporites venustus</i> Deák, 1963			0.3		0.3																	
<i>Cicatricosisporites</i> sp. 1			0.3																			
<i>Cicatricosisporites</i> sp. 3					0.3																	
<i>Cicatricosisporites</i> sp. 4			1		0.3																	
<i>Concavisporites punctatus</i> Delcourt & Sprumont, 1955		0.3			0.3					0.3												
<i>Concavissimisporites verrucosus</i> (Delcourt & Sprumont) Delcourt et al., 1963					0.3					0.7	1.3	0.7										
<i>Converrucosisporites platyverrucosus</i> Brenner, 1963					0.3																	
<i>Coronatispora valdensis</i> (Couper) Dettmann, 1963								3.2														
<i>Coronatispora</i> sp.			0.3		0.3																	
<i>Costatoperforosporites foveolatus</i> Deák, 1962					0.3																	
<i>Crybelosporites pannuceus</i> (Brenner) Srivastava, 1975			0.3		0.6					0.3	0.3		0.4		2.2@	6.4@						
<i>Crybelosporites</i> sp.											0.3											
<i>Cyathidites australis</i> Couper, 1953	2.5	3	1.8	3.7	0.6			@	4.1	3.3	3.1	1.1	10	1.3			1.1					0.2
<i>Cyathidites minor</i> Couper, 1953	12	1.3	12	7.7	7.2	13	3.2	3.8	6.4	13	13	9.3	1.5			0.7			0.3			0.1
<i>Deltoidospora psilostoma</i> Rouse, 1959				0.3					0.3	0.3	1.4											
<i>Deltoidospora</i> sp.	0.4		0.3						0.3		0.3											
<i>Dictyophyllidites harrisii</i> Couper, 1958			0.3	0.3							0.3	1.9										
<i>Distaltriangulisporites</i> sp.									0.3													
<i>Fisciniasporites brevilaesuratus</i> (Couper) Dettmann & Clifford, 1992					0.3																	
<i>Foveosporites subtriangularis</i> Brenner, 1963		0.3																				
<i>Gabonispuris pseudoreticulatus</i> Boltenhagen, 1975		2.3	3.4	1	3.8		3.2	0.4	0.7	1.3	4.8											
<i>Gabonispuris</i> sp.					0.3				1													
<i>Gleicheniidites senonicus</i> Ross, 1949	0.8		0.8	2	0.3		3.2		1.4	0.3	2.8	4.5										
<i>Heliosporites</i> sp.							3.2															
<i>Impardecispora</i> sp. cf. <i>crassa</i> (Brenner) Burden & Hill, 1989											0.3@											

APPENDIX. — Continuation.

samples	PS													FV				PL	HU					
	6	7	8	9	10	11	12	13	1	2	3	4	0	I	II	III	B9	B3	B2	B1	B0			
<i>Impardecispora marylandensis</i> (Brenner) Srivastava, 1975													0.3											
<i>Impardecispora trioreticulosa</i> (Cookson & Dettmann) Venkatachala et al., 1969													0.7	0.7	0.3	0.7								
<i>Ischyosporites disjunctus</i> Singh, 1971																0.4								
<i>Klukisporites</i> sp. cf. <i>Klukisporites foveolatus</i> Pocock, 1964														0.3®	0.4									
<i>Klukisporites</i> sp. cf. <i>Klukisporites variegatus</i> Couper, 1958				0.3																				
<i>Laevigatosporites haardtii</i> (Potonié & Venitz) Thomson & Pflug, 1953	0.8		0.3	0.3												1.1								
<i>Leptolepidites verrucatus</i> Couper, 1953					0.3	13										0.3®								
<i>Lophotriletes babsae</i> (Brenner) Singh, 1971												0.3				0.3®								
<i>Matonisporites equixinus</i> Couper, 1958	0.4	0.3	0.3	0.7	0.6				0.3®	0.3	7.6	0.3	0.7											
<i>Microfoveolatosporis baconicus</i> Juhász, 1977										0.3		0.3												
<i>Microreticulatisporites crassiexinus</i> Brenner, 1963																0.4								
<i>Neoraistrickia robusta</i> Brenner, 1963										0.3		0.7												
<i>Neoraistrickia truncata</i> (Cookson) Potonié, 1956					0.3																			
<i>Nodosisporites</i> sp. 1												0.3												
<i>Nodosisporites</i> sp. 2			0.8						0.4		0.3													
<i>Patellasporites distaverrucosus</i> (Brenner) Kemp, 1970		®	0.3		2.2					0.3	0.3													
<i>Patellasporites tavadarensis</i> Groot & Groot, 1962	®	0.3	2.1	4.7	3.4	13	3.2	0.4	0.7	0.3	0.3®													
<i>Patellasporites</i> sp.					0.9																			
<i>Perinomonoletes</i> sp.										0.3														
<i>Peromonolites fragilis</i> Burger, 1966								3.2																
<i>Peromonolites</i> sp.		1.7	15		0.3			0.8	13	4.3					1.5	0.4								
<i>Plicatella appendicifera</i> (Thiergart) Davies, 1985																0.4								
<i>Plicatella bilateralis</i> (Singh) Dörhöfer, 1977											0.3													
<i>Plicatella cristata</i> (Markova) Davies, 1985										0.6		0.6												
<i>Plicatella gigantea</i> (Groot & Groot, 1962) Davies, 1985			0.3																					
<i>Plicatella potomacensis</i> (Brenner) Davies, 1985		0.3																						

APPENDIX. — Continuation.

samples	PS													FV				PL	HU					
	6	7	8	9	10	11	12	13	1	2	3	4	0	I	II	III	B9	B3	B2	B1	B0			
<i>Plicatella</i> sp. cf. <i>P. potomacensis</i> (Brenner) Davies, 1985					0.3																			
<i>Plicatella problematica</i> (Burger) Davies, 1985		0.3	0.3						0.3		0.3													
<i>Plicatella triceps</i> (Weyland & Krieger) Sung, Li & Li, 1976			®																					
<i>Plicatella tricostata</i> (Bolkhovitina) Davies, 1985					0.3																			
<i>Plicatella unica</i> (Markova) Dörhöfer, 1977													0.3®											
<i>Polycingulatisporites reduncus</i> (Bolkhovitina) Playford & Dettmann, 1965			0.3	0.3																				
<i>Reticulatisporites arcuatus</i> Brenner, 1963					0.3																			
<i>Reticulatisporites elongatus</i> Singh, 1971	2.5																							
<i>Reticulisporites</i> sp. 1										0.3														
<i>Ruffordiaspora australiensis</i> (Cookson) Dettmann & Clifford, 1992					0.6							1.4												
<i>Taurocusporites segmentatus</i> Stover, 1962			0.5	0.3			3.2																	
<i>Todisporites major</i> Couper, 1958													0.7											
<i>Todisporites minor</i> Couper, 1958									0.3															
<i>Undulatisporites sinuosis</i> Groot & Groot, 1962																								
<i>Undulatisporites undulapolus</i> Brenner, 1963			0.3		0.3						0.3													
<i>Vadaszisorites sacalii</i> Deák & Combaz, 1967									1.9															
<i>Vinculisporites flexus</i> Deák, 1964												0.3	0.4											
GYMNOSPERMS																								
<i>Alisporites grandis</i> (Cookson) Dettmann, 1963		2.5	0.5	0.3						0.3		0.7	0.4	5.9			2.6							
<i>Applanopsis dampieri</i> (Balme) Döring, 1961	0.4		0.3	0.3	0.6			0.4	0.6	0.6			0.4											
<i>Applanopsis segmentatus</i> (Balme) Venkatachala & Kar, 1969									0.3				0.4											
<i>Applanopsis trilobatus</i> (Balme) Venkatachala & Kar, 1969															0.3									
<i>Applanopsis</i> sp.					0.3																			
<i>Araucariacites australis</i> Cookson ex Couper, 1953	17.7	1	7.1	4	2.2					4.4	6.6	4.1	4.1	8.8	7.8	8.5	2.6	1.1		0.3		0.1		
<i>Araucariacites hungaricus</i> Deák, 1964												0.7	1.1											
<i>Balmeiopsis limbata</i> (Balme) Archangelsky, 1977					1.6					1.7	0.7	6	2.9											

APPENDIX. — Continuation.

samples	PS												FV				PL	HU					
	6	7	8	9	10	11	12	13	1	2	3	4	0	I	II	III	B9	B3	B2	B1	B0		
<i>Cedripites canadensis</i> Pocock, 1962					0.3				0.3	0.7													
<i>Classopollis classoides</i> Pflug emend. Pocock & Jansonius, 1961	31	17	19	39	22		3.2	17	1.4	5.3	4.8	1.5											
<i>Classopollis major</i> Groot & Groot, 1962								1.5															
<i>Cycadopites carpentieri</i> (Delcourt & Sprumont) Singh, 1964									0.3														
<i>Cycadopites</i> sp. 1													1.5										
<i>Cycadopites</i> sp. 2	0.4				0.6				0.3	0.3													
<i>Cycadopites</i> sp. 3			0.3																				
<i>Cycadopites</i> sp. 4													1.5										
<i>Cycadopites</i> sp. 5														0.4	0.7				0.3	0.7	0.1		
<i>Cycadopites</i> sp. 7													1.5										
<i>Elaterosporites klaszii</i> (Jardiné & Magloire) Jardiné, 1967											0.7												
<i>Ephedripites multicostatus</i> Brenner, 1963									0.3	0.3													
<i>Equisetosporites ambiguus</i> (Hedlund) Singh, 1983									0.3	0.3			1.5										
<i>Eucommiidites minor</i> Groot & Penny, 1960									0.3		0.3	0.4											
<i>Eucommiidites troedssonii</i> (Erdtman) Potonié, 1958	®									0.3	0.3												
<i>Eucommiidites</i> sp. – Kemp 1970													0.3										
<i>Exesipollenites tumulus</i> Balme, 1957	4.5		0.3	7	0.9				1	4.3	0.7	0.7											
<i>Parvisaccites radiatus</i> Couper, 1958													0.4										
<i>Perinopollenites halonatus</i> Phillips & Felix, 1971	0.4				0.3		3.2	0.4	0.7	1		1.5											
<i>Podocarpidites biformis</i> Rouse, 1957		1.3	2.4	0.3	5.3			0.4	0.3		0.3												
<i>Podocarpidites ornatus</i> Pocock, 1962																				0.3			
<i>Podocarpidites potomacensis</i> Brenner, 1963											1.4												
<i>Singhia acicularis</i> Lima, 1980					0.9				0.3														
<i>Singhia minima</i> Lima, 1980							3.2																
<i>Spheripollenites psilatus</i> Couper, 1958	4.1	1.7		2.3	5.6			0.4	3.1	0.7	0.7	0.4	1.5	0.9	1.1	6.6	0.7	23.3	0.3	0.2			
<i>Taxodiaceapollenites hiatus</i> (Potonié) Kremp, 1949	7.7	3	1.8	6.3	1.3	13	12.9	3	7.8	24.8	23.8	4.1	4.4	0.9	2.1	0.7							
ANGIOSPERMS																							
<i>Afropollis jardinus</i> Doyle <i>et al.</i> , 1982	3.7	2.7	2.3	0.3	0.6	13	3.2	1.1	29.2	2	20.7	43.3	4.4	73.3	63.8	61.8	90.3	26.6	76.9	89.1	98.9		
<i>Clavatipollenites hughesii</i> Couper, 1958	2.5	4.7	6.8	4.4	0.6				3.4	2.6	1	0.4	1.5				0.7	1.1	26.7	1.5	1.7	0.1	

APPENDIX. — Continuation.

samples	PS												FV				PL	HU					
	6	7	8	9	10	11	12	13	1	2	3	4	0	I	II	III	B9	B3	B2	B1	B0		
<i>Clavatipollenites minutus</i> Brenner, 1963	5.3	3		2.7	0.6					0.3			1.5	0.4	1.1	3.3	2.2	6.7		0.7			
<i>Clavatipollenites</i> sp.		2	0.3	1.7	0.6				0.7	0.3		0.4	4.4	0.9		0.7	1.5		1.2	2.2	0.1		
<i>Dichastopollenites dunveganensis</i> Singh, 1983									0.3					0.4									
<i>Dichastopollenites</i> sp. cf. <i>D. reticulatus</i> May, 1975												0.4											
<i>Echimonocolpites</i> sp.												0.4											
<i>Hammenia fredericksburgensis</i> (Hedlund & Norris) Ward, 1986		0.3	0.5																	0.2			
<i>Liliacidites doylei</i> Ward, 1986														0.4									
<i>Liliacidites inaequalis</i> Singh, 1971																0.7							
<i>Monosulcites chaloneri</i> Brenner, 1963				0.3																			
<i>Monosulcites minimus</i> Cookson, 1947																				0.3			
<i>Penetetrapites mollis</i> Hedlund & Norris, 1968										1		1.5		0.4									
<i>Pennipollis escuchensis</i> Villanueva-Amadoz et al., 2010											0.7												
<i>Pennipollis peroreticulatus</i> (Brenner) Friis et al., 2000			0.3	0.3																0.3			
<i>Pennipollis reticulatus</i> (Brenner) Friis et al., 2000								6.4		1													
<i>Pennipollis</i> sp.																				0.3	0.1		
<i>Retimonocolpites dividuus</i> (Pierce) Brenner, 1963				0.3																			
<i>Retimonocolpites fragilis</i> Pierce, 1961																		3.3	0.6		0.1		
<i>Retimonocolpites textus</i> (Norris) Singh, 1983														2.9									
<i>Retitricolpites virgeus</i> (Groot et al.) Brenner, 1963					0.3																		
<i>Rousea brenneri</i> (Couper) Singh, 1983														7.3									
<i>Rousea georgensis</i> (Brenner) Dettmann, 1973														2.9									
<i>Rousea marthae</i> Ward, 1986																							
<i>Rousea</i> sp. B in Burger 1993									3.2														
<i>Rousea</i> sp.															0.4								
<i>Senectotetradites varireticulatus</i> (Dettmann) Singh, 1983											0.7												
<i>Similipollis</i> sp.								13						0.3									
<i>Stellatopollis barghornii</i> Doyle, 1975		0.3	0.3		0.6				0.4	3.4	1.7		3.4	14.7		1.1	0.7	0.7		0.3	0.5	0.1	
<i>Striatopollis paraneus</i> (Norris) Singh, 1971													0.4										

APPENDIX. — Continuation.

samples	PS									FV				PL	HU						
	6	7	8	9	10	11	12	13	1	2	3	4	0	I	II	III	B9	B3	B2	B1	B0
<i>Transitoripollis</i> sp. cf. <i>T. similis</i> Góczán & Juhász, 1984				7.7	2.2	13		0.8	0.3	0.7			4.4			0.7			1.2	1	
<i>Tricolpites blechrus</i> Ward, 1983									0.3			0.3									
<i>Tricolpites crassimurus</i> (Groot & Penny) Singh, 1971			0.3								0.3		7.4		2.1	4.6	0.4		0.6	0.5	0.2
Aff. <i>Tricolpites crassimurus</i> (Groot & Penny) Singh, 1971							6.4		0.7	1		0.4				1.3					0.5
ALGAE																					
<i>Pterospermella aristotelesii</i> (Ioannides et al.) Srivastava, 1984	0.4						12.5					0.3			1.1						0.2
<i>Schizophacus grandis</i> (Hedlund) Pierce, 1976		0.7												0.4		0.7	0.4				0.1
<i>Schizophacus parvus</i> (Cookson & Dettmann) Pierce, 1976									0.3	1		0.7		3.9	3.2		0.4		0.3		
<i>Schizophacus spriggi</i> (Cookson & Dettmann) Pierce, 1976														2.2	3.2	0.7					
<i>Schizosporis microreticulatus</i> Brenner, 1963									0.3												
<i>Schizosporis reticulatus</i> Cookson & Dettmann, 1959			0.3						0.3												
FUNGI																					
<i>Dicellaesporites</i> sp.									0.3												
<i>Plochrompeltinites</i> sp.										0.3											
<i>Pluricellaesporites</i> sp.			0.3																		
<i>Polyadosporites</i> sp.			0.3						0.3												
OTHER PALYNOMORPHS																					
Foraminiferal linings		0.3					3.2	4.6				0.3 [Ⓢ]									
Cuticle 1	0.8				0.3																
Cuticle 2					0.3																
<i>Incertae sedis</i> 1			0.3																		
<i>Incertae sedis</i> 2								0.4													
<i>Incertae sedis</i> 3								0.4													
DINOFLAGELLATE CYSTS																					
<i>Cribopteridinium</i> sp.			0.3																		0.1
<i>Cyclonephelium chabaca</i> Below, 1981		3	12	0.3	21.3			54.2	1	4					1.1				0.6		0.1
<i>Florentinia</i> spp.			0.3	0.3	0.3		3.2	0.4			0.3										
<i>Oligosphaeridium pulcherrimum</i> (Deflandre & Cookson) Davey & Williams, 1966			0.3		0.3			6.1	0.3		0.7	0.4									
<i>Subtilisphaera</i> sp.			0.3																		0.1
Indeterminate dinoflagellate cysts		45							0.7	2	2.1	2.2	5.9	1.7	5.3	5.3		13.3	14.8	2.4	

APPENDIX. — Continuation.

	PS								FV				PL	HU									
	6	7	8	9	10	11	12	13	1	2	3	4	0	I	II	III	B9	B3	B2	B1	B0		
Total Palynomorphs (excluding dinoflagellate cysts)	243	156	333	296	251	8	30	104	288	286	281	261	63	228	88	144	267	26	276	403	1515		
Total Palynomorphs (including dinoflagellate cysts)	243	301	383	298	321	8	31	264	294	304	290	268	69	232	94	152	267	30	326	413	1520		
Bryophyta/Total (%)	0.4		1.3	0.3	0.6				1	1.3	0.3	0.4											
Pteridophyta/Total (%)	19.7	11	42.3	21	29.9	38	52	8.7	34.7	35.2	32.4	23.9	13	2.2		1.3	1.1		0.3		0.3		
Gymnosperms/Total (%)	67	27	31.6	60	41.4	13	23	23	22.4	45.7	40	21.6	29	10.3	11.7	17.8	1.9	23.4	1.2	1	0.2		
Angiosperms/Total (%)	11.5	13	10.7	18	5.6	38	19	2.3	38.4	10.2	23.8	50.8	52.2	76.3	68.1	74.3	96.2	63.3	82.8	96.4	99.1		
Algae/Total (%)	0.4	1				13			1	1	0.3	0.7		6.5	7.4	1.3	0.7		0.3	0.2	0.1		
Fungi/Total (%)			0.5						0.7	0.3													
Other Palynomorphs/Total (%)	0.8	0.3	0.3		0.6		3.2	5.3			®												
Dinoflagellate cysts/Total (%)		48	13	0.7	21.8		3.2	61	2	5.9	3.1	2.6	5.8	1.7	6.4	5.3		13.3	15.3	2.4	0.1		