

Organic-walled microphytoplankton assemblage of the Middle Devonian (Givetian) Arkona, Hungry Hollow and Widder formations, Ontario, Canada: biostratigraphic and palaeogeographic significance

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ABSTRACT

A diverse and abundant organic-walled microphytoplankton assemblage, consisting of 49 species of acritarchs, prasinophyte phycmata and chitinozoans, was recovered from a 13.3 m-section of the Middle Devonian (Givetian) Arkona, Hungry Hollow and Widder formations at Hungry Hollow, Ontario, Canada. Close similarity exists between this assemblage and others described previously from the Givetian of North America. Marine palynofloras of comparable age from elsewhere in North America share between 59–96% of the species identified in the present assemblage, thus testifying to its stratigraphic-correlative applicability in a regional context. Species widely occurring in North America and typically Givetian (although not restricted therein) include: *Arkonites bilixus*, *Cymatiosphaera canadense*, *Diexallophasis simplex*, *Duvernaysphaera angelae*, *D. tenuicingulata*, *Estiastra rhytidoa*, *Exochoderma arca*, *Gorgonisphaeridium inflatum*, *Hapsidopalla chela*, *Leiofusa pyrena*, *Muraticavea munifica*, *Oppilatala sparsa*, *Palacanthus ledanoisii*, *Polyedryxium ambitum*, *Staplinium cuboides*, *Tyligmasoma alargada*, *Uncinisphaera acantha*, *Veryhachium pastoris*, *Villosacapsula compta* and *V. rosendae*. Palaeogeographically, Middle Devonian organic-walled microphytoplankton taxa display a conspicuous degree of cosmopolitanism, with many species shared with Laurasia (Laurentia, Avalonia, Baltica), Gondwana (principally Argentina, Ghana, Libya, Algerian Sahara, Western Australia) and Kazakhstan (northwestern China).

Keywords: Acritarchs, Givetian, Canada, biostratigraphy, palaeogeography.

Asociaciones de micropláncton de pared orgánica del Devónico Medio (Givetiense) de Arkona, formaciones Hungry, Hollow y Widder, Ontario, Canadá: significado bioestratigráfico y paleogeográfico

RESUMEN

Una asociación diversa de micropláncton de pared orgánica con gran abundancia de ejemplares, que está integrada por 49 especies de acritarcos, ficomas de prasinofitos y quitinozoos, fue obtenida en los materiales de la sección de 13,3 m de potencia del Devónico Medio (Givetiense) de Arkona, formaciones Hungry, Hollow y Widder, Ontario, Canadá. Esta asociación es muy parecida a otras que previamente se describieron en el Givetiense de Norte América. Algunas palinofloras marinas de otras partes de Norte América presentan asociaciones compuestas por un 59-96% de las especies que se estudian en este trabajo. De este modo, se pone de manifiesto su aplicación estratigráfica y de correlación en un contexto regional. Entre el conjunto de especies norteamericanas y típicamente givetienses (aunque no se encuentran restringidas a esta edad) identificadas están: *Arkonites bilixus*, *Cymatiosphaera canadense*, *Diexallophasis simplex*, *Duvernaysphaera angelae*, *D. tenuicingulata*, *Estiastra rhytidoa*, *Exochoderma arca*, *Gorgonisphaeridium inflatum*, *Hapsidopalla chela*, *Leiofusa pyrena*, *Muraticavea munifica*, *Oppilatala sparsa*, *Palacanthus ledanoisii*, *Polyedryxium ambitum*, *Staplinium cuboides*, *Tyligmasoma alargada*, *Uncinisphaera acantha*, *Veryhachium pastoris*, *Villosacapsula compta* y *V. rosendae*. Paleogeográficamente, los taxones microplanctónicos de

pared orgánica del Devónico Medio que hemos identificados, son cosmopolitas en un alto grado, con muchas especies distribuidas por Laurasia (Laurentia, Avalonia, Báltica), Gondwana (principalmente Argentina, Ghana, Libia, el Sahara argelino, el Oeste de Australia) y Kazakhstan (noroeste de China).

Palabras clave: Acritarcos, Givetiense, Canadá, bioestratigrafía, paleogeografía.

VERSIÓN ABREVIADA EN CASTELLANO

Introducción

El registro publicado sobre las asociaciones de micropláncton de pared orgánica del Devónico Medio (acritarcos y ficomas de prasinofitos) es menos conocido de lo que puede ser esperado. Muchos de los trabajos, especialmente los más antiguos sobre el tema, no tienen una estratigrafía precisa y/o son inadecuados desde un punto de vista taxonómico y de la ilustración de los taxones. Además, las asociaciones inferidas simplemente se atribuyeron al Devónico Medio sin considerar los pisos Eiffeliense y Givetiense. Afortunadamente, las publicaciones más reciente tienden a presentar una mejor documentación estratigráfica y una sistemática e ilustración de los taxones mucho más precisa. En relación con esto, se han mejorado las interpretaciones bioestratigráficas y paleogeográficas.

El estudio de una palinoflora del Devónico Medio (Givetiense) del suroeste de Ontario (Canadá) presenta una interesante estimación taxonómica de una asociación microplanctónica bien conservada y diversa de acritarcos y prasinofitos. La identificación de los taxones que la integran facilita su comparación con otras palinofloras de edad similar tanto norteamericanas como de otras partes del mundo. De esta manera, se incrementa el conocimiento de la distribución de las palinofloras planctónicas de pared orgánica del Devónico Medio.

Metodología

Se recogieron catorce muestras en los materiales de 13,3 m de potencia de edad Givetiense de las formaciones Arkona, Hungry Hollow y Widder que están situadas a lo largo del banco norte del río Au Sable en Hungry Hollow (Ontario, Canadá) (Figs. 1-2). Todas las muestras tuvieron contenido palinológico, aunque sus asociaciones presentaron diferente grado de preservación, abundancia y diversidad de taxones.

En esta localización, la Formación Arkona está compuesta por 6,8 m de pizarras con un nivel delgado de limestones arcillosos cerca de su techo. La Formación Hungry Hollow que se encuentra de forma disconforme por encima de la anterior, muestra 0,5 m de limestones cristalinos seguidos por 1 m de niveles calizos muy fosilíferos. Por encima de la anterior, de forma conforme o disconforme, está la Formación Widder (la que se encuentra en la parte más superior en esta localidad) que es una unidad fosilífera de unos 5 metros de niveles carbonáticos con intercalaciones de limestones y de limestones arcillosos.

Las tres formaciones mencionadas comprenden la mitad de las que constituyen el Grupo Hamilton del sur de Ontario (Fig. 3). Estas seis formaciones en orden estratigráfico ascendente son las de Bell, Rockport Quarry, arkona, Hungry Hollow, widder e lpperwash, y están principalmente constituidas por mudstones y pizarras con delgadas y persistentes unidades carbonáticas laterales. Los materiales de las seis están atribuidos al Givetiense a partir de relaciones estratigráficas y evidencias de faunas de invetebrados (Stumm et al., 1956; Driscoll et al., 1965; Boneham 1967a,b; Mitchell, 1967; Winder and Sanford, 1972; Legault, 1973; Uyeno et al., 1982; Landing and Brett, 1987; Johnson et al., 1992).

Las catorce muestras que representan todas las litologías recogidas en Hungry Hollow, fueron procesadas usando las técnicas palinológicas tipo. Las láminas fueron preparadas a partir de los residuos resultantes después de filtrarlos a través de tamices de 52 y 20 μm . Se realizó una contabilización de los diferentes taxones que se encontraron en cada muestra realizándose una tabulación de las abundancias de palinomorfos.

Resultados

Las asociaciones microplanctónicas obtenidas en la localidad de Hungry Hollow están integradas por 49 taxones: 32 de acritarcos (27 especies y cinco mencionadas informalmente, que se han asignado a 25 géneros), 16 de prasinofitos (14 especies y dos que se han dejado en nomenclatura abierta, pertenecientes a nueve géneros) y uno de quitinozoos. Adicionalmente se han encontrado otros quitinozoos, escolecodontos, miosporas y partículas amorfas de kerógeno en proporciones variables, pero no se han identificado.

Los ficomas de prasinofitos están encuadrados en la Clase Prasinophyceae Christensen, 1962 y las espe-

cies identificadas se han ordenado considerando los géneros a los que pertenecen. Los acritarcos se han tratado como géneros y especies-forma siguiendo las normas del Código Internacional de Nomenclatura para algas, hongos y plantas (ICN: McNeill et al., 2012), y también se han ordenado alfabéticamente bajo el informal Grupo Acritarcha Evitt, 1963. Los quitinozoos se han consignado en el Orden Operculatifera Eisenack, 1931.

En la lista de sinonimias de cada especie, se indica la designación binomial (basiónimo) de cada una de ellas así como cualquier transferencia genérica que se haya realizado. Además, se señalan las especies tipo de cada género. Cuando nos pareció apropiado, se incluye la referencia completa de una sinonimia. En donde ha sido posible, se han documentado observaciones y comparaciones sobre cada especie, así como su presencia en cada una de las muestras estudiadas. La distribución estratigráfica y geográfica de cada especie se señala de en la sección denominada registros previos.

Los acritarcos dominan numéricamente la palinoflora tanto a nivel genérico como específico (83% y 67%, respectivamente). Los taxones más comunes de acritarcos y prasinofitos se encuentran regularmente a lo largo de la sección muestreada. Excluyendo a las leiosferas y a los tasmanítidos, las cinco especies más abundantes son en orden decreciente: Multiplicisphaeridium ramusculosum, Navifusa bacilla, Duvernaysphaera tenuicingulata y D. angelae. Los cinco taxones hallados en menor número, en orden también decreciente y cuantitativo, son: Arkonites bilixus, Solisphaeridium sp. A, Tylligasoma alargada, Cymatiosphaera cornifera y Diexallophasis simplex. La presencia a lo largo de la sección del resto de los taxones identificados oscila de raro a muy abundante.

Numerosos estudios fundamentados en los principios modernos de la Sedimentología, Biología y de la relación físico-química de las aguas marinas, junto con los análisis sedimentológicos de facies, los de asociaciones de invertebrados así como la distribución de fitopláncton y de esporas/polen, han sido utilizados para analizar paleoambientes. Particularmente, la pequeña talla y durabilidad de los palinomorfos son de una gran ayuda para realizar tales interpretaciones. Además, las fluctuaciones en la relación inversa entre el micropláncton marino y las esporas-polen derivados de las zonas continentales están bien establecidas y se usan de forma general para determinar la extensión de las paleolíneas de costa, y el reconocimiento de ciclos transgresivos/regresivos.

Varios modelos basados en la diversidad del microfítolpláncton, la composición de las asociaciones y las clases de morfotipos se han propuesto para interpretar y reconocer paleolíneas de costa, medios cercanos y alejados a la orilla, profundidades y ciclos transgresivos/regresivos. Los estudios basados sobre estos modelos y los principios previamente articulados están en general de acuerdo cuando se aplica a interpretaciones paleoambientales.

El uso de estos principios generales de síntesis paleoambiental, litologías y fauna invertebrada asociada, claramente indica que las formaciones Arkona, Hungry Hollow y Widder fueron depositadas en un medio marino normal de baja energía, alejado de la costa. Además, la palinoflora obtenida confirma esta interpretación paleoambiental.

Cambios en la diversidad y abundancia de las asociaciones de Arkona/Hungry Hollow/Widder están en consonancia con los ciclos transgresivos/regresivos litológicamente inferidos. Además, la composición de las asociaciones es también indicativa de un medio marino rocoso alejado de la costa.

Teniéndolos en cuenta de forma conjunta, los factores citados anteriormente denotan que los sedimentos de las formaciones Arkona, Hungry Hollow y Widder se acumularon en medios marinos bien oxigenados, alejados de la costa. Además, esto se encuentra ejemplificado por las asociaciones palinológicas que se encontraban asociadas a sedimentos de grano fino, con regresiones periódicas que promovían el desarrollo de limestones coralinos de grano grueso dentro de un medio arrecifal.

Comparaciones de las palinofloras Arkona/Hungry Hollow/Widder con asociaciones abundantes, diversas y bien conservadas del Devónico Medio de otras seis localidades de Norte América (Figs. 4-5), muestran apreciables similitudes (aproximadamente un 59-60% de taxones en común). Esto no debe sorprendernos y, a causa de la proximidad geográfica, encontramos un alto porcentaje de taxones en común (89%) en el Grupo Hamilton del suroeste de Ontario. Lo mismo puede ser observado en el Givetiense de Dolomite Boyle (Kentucky) en donde hay un 96% de elementos en común.

El número sustancial de especies de acritarcos/prasinofitos que podemos encontrar en las siete asociaciones norteamericanas mencionadas es claramente sintomático de una entidad palinostratigráfica devónica que posibilita una correlación estratigráfica con el paleocontinente de Laurentia.

Aunque se han publicado numerosos estudios de asociaciones microplanctónicas de pared orgánica fuera de Norte América, muchas de estas son inaceptables para hacer comparaciones a causa de una o varias limitaciones, esencialmente, un insuficiente control estratigráfico, una pobre preservación de los palinomorfos, y una inadecuada documentación sistemática o de ilustración. No menos de doce asociaciones de Sudamérica, África, Europa, Australia y China poseen el criterio necesario para realizar una comparación significativa con la asociación de Ontario. El grado de parecido de estas asociaciones oscila entre el 12% de los taxones (Cuenca de Canning, Oeste de Australia) y más de un 77% (Cuenca de Junggar, Xinjiang, China).

Durante el Devónico Medio (Fig. 6), Laurentia se encontraba en latitudes bajas, entre unos 30°N y 30°S.

Las asociaciones bien conservadas y estratigráficamente delimitadas de acritarcos/prasinofitos del Devónico Medio que se discuten en este trabajo son, en un alto grado, cosmopolitas. Aunque un buen número de taxones se encuentran predominantemente en Laurentia, la mayoría de las especies muestra una dispersión por todo el mundo durante el Devónico Medio. Por último, algunas especies como Maranhites brasiliensis, M. mosesii, Pterospermella pernambucensis, Umbellasphaeridium deflandrei y U. saharicum, fueron endémicas de regiones de latitudes altas de Gondwana y estuvieron ausentes en latitudes bajas y medias hasta el Devónico tardío.

Conclusiones

La asociación diversa y bien conservada de acritarcos/prasinofitos obtenida en los 13,3 m de exposición que presentan los materiales del Devónico Medio (Givetense) de las formaciones Arkona, Hungry Hollow y Widder (Hungry Hollow, suroeste de Ontario, Canadá), está compuesta por 49 especies (32 acritarcos, 16 prasinofitos y 1 quitinozoo).

La edad givetense de la asociación estudiada está confirmada por los rangos estratigráficos de ciertas especies de acritarcos y prasinofitos que se habían identificado previamente en otras bien delimitadas biostratigráficamente en Norte América y otras regiones.

La composición de la palinoflora indica una deposición de los sedimentos que la contiene en un medio marino y rocoso, bien oxigenado y alejado de la costa con periódicas regresiones que se producían por el desarrollo de medios de tipo arrecifal.

La asociación de microfitorpláncton de pared orgánica de Arkona/Hungry Hollow/Widder es altamente cosmopolita, y solo contiene un conjunto pequeño de especies que se encontraban confinadas en Norte América.

La distribución paleogeográfica global de las especies del Devónico Medio confirma la existencia de un componente endémico de latitudes altas de Gondwana. Muchas de sus especies no se dispersaron a latitudes bajas o medias hasta el Devónico tardío.

Introduction

Acritarchs and prasinophyte phycomata (collectively termed organic-walled microphytoplankton) of the Middle Devonian (Givetian) Arkona, Hungry Hollow and Widder formations of the Hamilton Group have previously been reported from the subsurface by Legault (1973). Although not extensively studied, Middle Devonian phytoplankton assemblages have also been reported from elsewhere in North America by Baschnagel (1942), Deunff (1954, 1955, 1961, 1966a, 1971), Audretsch (1967), Peppers and Damberger (1969), Nautiyal (1975), Playford (1977), Wicander and Wood (1981, 1997), Wicander (1983, 1984), Wicander and Wright (1983), Wood and Clendening (1985) and Huysken *et al.* (1992).

Several of these papers are only of historical interest, and negligible for biostratigraphic correlation. The first record of North American Middle Devonian acritarchs is that of Baschnagel (1942), who described and illustrated several taxa from cherts of the Onondaga Formation in the Syracuse area of New York State. His specimens are from thin sections only and are poorly preserved.

Acritarchs recovered from sediment within the corallum of the tabulate coral *Favosites turbinata*, provided the basis of a series of papers by Deunff (1954, 1955, 1961, 1966a, 1971). Although Deunff named many new species, there is uncertainty as to

the stratum and geographic location of the coral specimen, thus limiting the biostratigraphical usefulness of his papers.

Audretsch (1967) briefly described and illustrated six acritarch species from the Givetian Pine Point Formation, Great Slave Lake area, Northwest Territories. Peppers and Damberger (1969) recorded *Leiospheridia* sp., *Tasmanites huronensis* and *Stellinium octoaster* (= *S. micropolygonale*) from the lower Givetian Davenport Limestone Member of the Wapsipinicon Formation, Illinois. Lastly, Nautiyal (1975) reported, and illustrated, a number of previously named organic-walled microphytoplankton species from the subsurface Givetian Elk Point Group of Saskatchewan and Alberta.

The other papers listed above, all document reasonably well preserved and diverse suites of Middle Devonian acritarchs and prasinophyte phycomata with reliable stratigraphic control. These assemblages are analyzed and discussed in subsequent sections as they relate to Middle Devonian biostratigraphy and palaeogeography.

Stratigraphy and correlation

Fourteen samples for this study were collected from a 13.3 m-exposure of the Givetian-age Arkona, Hungry Hollow and Widder formations along the north bank

of the Au Sable River at Hungry Hollow, Ontario, located ca 3 km northeast of Arkona (Fig. 1). These samples (Fig. 2) were subsequently processed for palynomorphs.

At this site, the Arkona Formation (sometimes referred to as the Arkona Shale) consists of 6.8 m of bluish-gray to gray shale with a thin argillaceous limestone bed near its top. Disconformably overlying the Arkona, is the 1.5 m-thick Hungry Hollow Formation, comprising 0.5 m of blue-gray, coarsely crystalline limestone, succeeded by 1.0 m of richly fossiliferous, gray, calcareous shale. Either conformably or possibly disconformably, the Hungry Hollow Formation is overlain by the Widder Formation, a 5 m-thick unit of fossiliferous, gray, calcareous shale with interbeds of limestone and argillaceous limestone.

The Hamilton Group in southern Ontario (Fig. 3) consists mostly of mudstones and shales, with thin, laterally persistent carbonate units. It is divided into six formations that, in ascending stratigraphic order, are: the Bell, Rockport Quarry, Arkona, Hungry Hollow, Widder and Upperwash formations (Stumm *et al.*, 1956; Boneham, 1967a; Legault, 1973; Johnson *et al.*, 1992; Armstrong and Carter, 2006). Based on

invertebrate faunal evidence (e.g. corals, brachiopods, trilobites, crinoids) and stratigraphic relationships, all six formations are considered Givetian in age (Stumm *et al.*, 1956; Driscoll *et al.*, 1965; Boneham, 1967a, b; Mitchell, 1967; Winder and Sanford, 1972; Legault, 1973; Uyeno *et al.*, 1982; Landing and Brett, 1987; Johnson *et al.*, 1992).

The Hamilton Group of Ontario correlates with the middle part of the more arenaceous Hamilton Group of New York State, and with the calcareous Traverse Group of the Michigan Basin (Uyeno *et al.*, 1982; Johnson *et al.*, 1992). In Ohio, the Plum Brook and Silica formations, along with the Olenangy Shale, are correlative with the Arkona Formation (Driscoll *et al.*, 1965; Bartholomew and Brett, 2007; Brett *et al.*, 2011), and the Ten Mile Creek Formation is considered stratigraphically equivalent to the Hungry Hollow Formation (Sandford, 1967).

Materials and methods

The fourteen samples collected and prepared for palynologic analysis represent all of the lithotopes of the three aforementioned formations (Fig. 2).

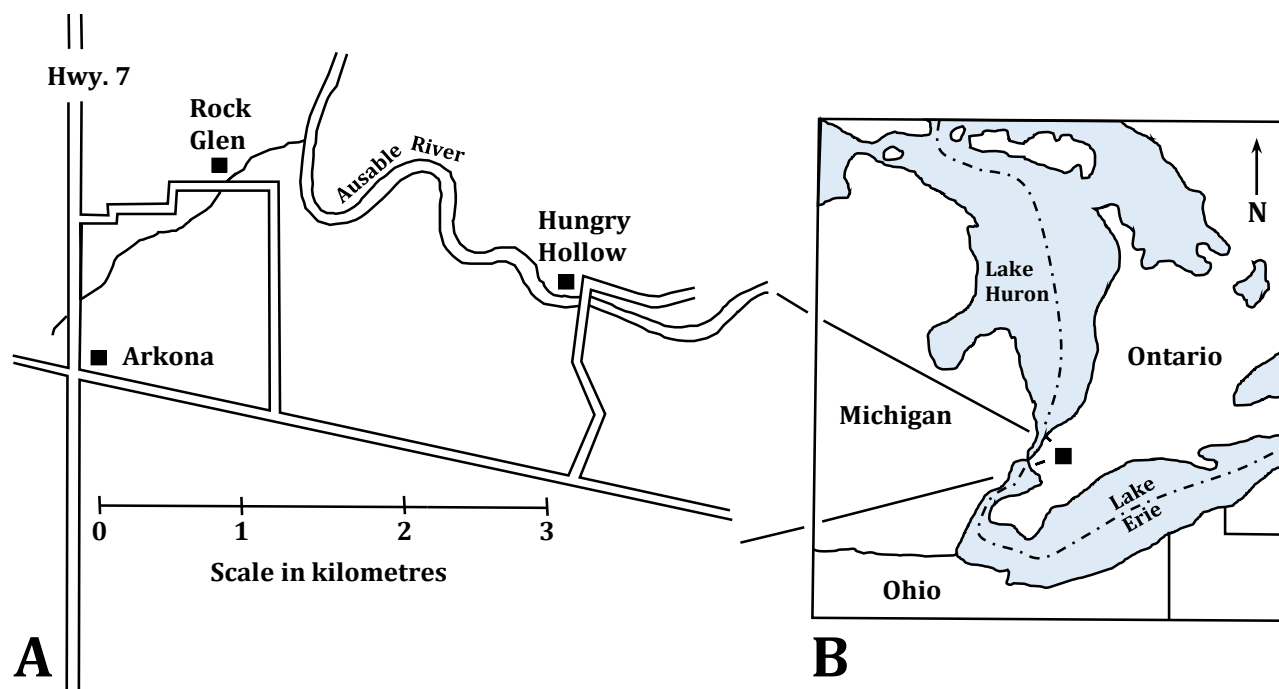


Figure 1. A. Hungry Hollow locality where 14 samples from the Middle Devonian (Givetian) Arkona, Hungry Hollow and Widder formations were collected from an exposure along the north bank of the Au Sable River. B. Generalized map of southwestern Ontario, Canada, with the location of the Hungry Hollow collecting site indicated by a solid square.

Figura 1. A. Localidad de Hungry Hollow donde se tomaron catorce muestras del Devónico Medio (Givetiense) de las formaciones Arkona, Hungry Hollow y Widder, en una zona expuesta a lo largo del banco norte del Río Au Sable. B. Mapa general del sur de Ontario (Canadá), con la localización del lugar de recogida de muestras en Hungry Hollow indicada por un cuadrado.

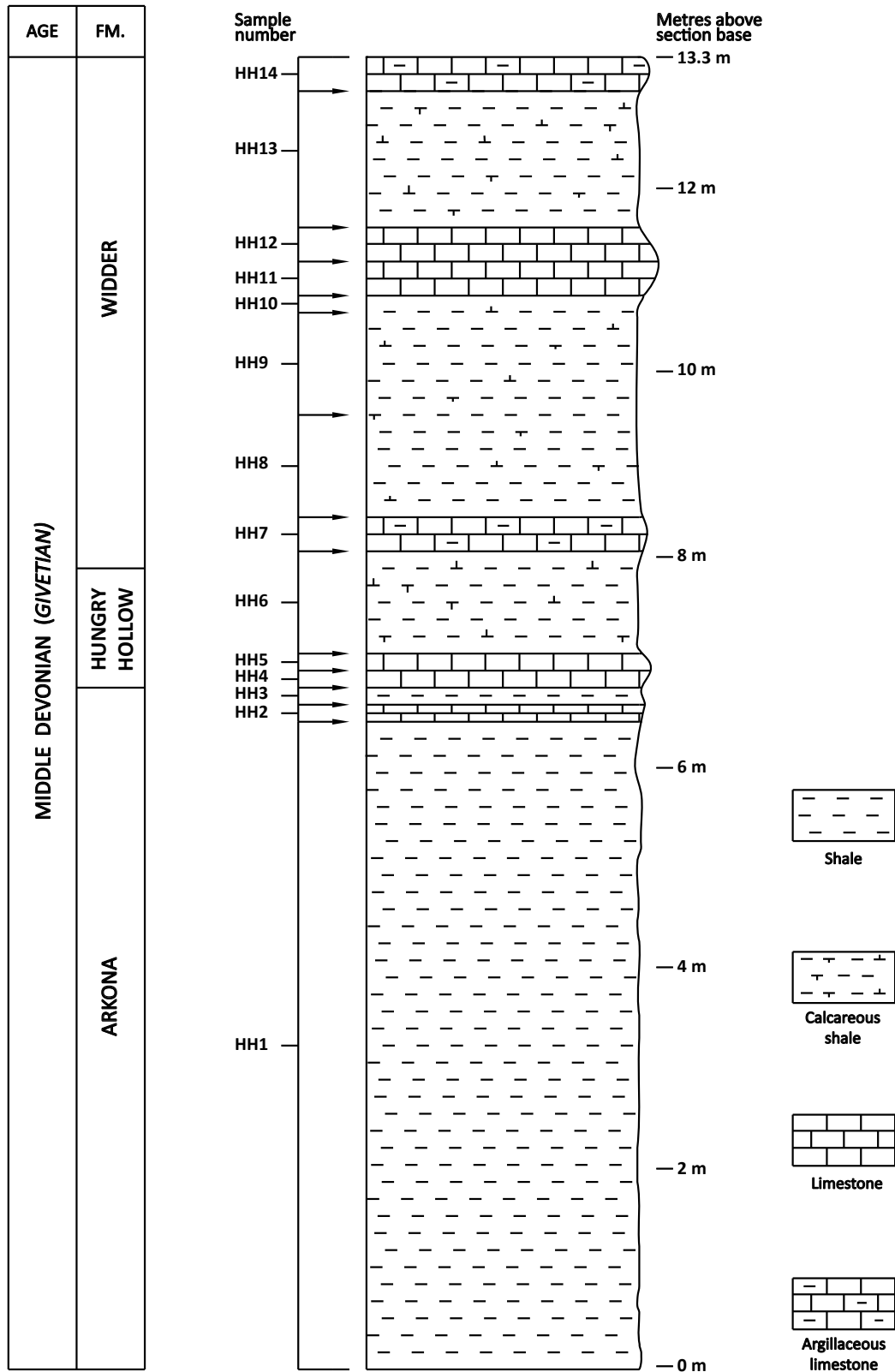


Figure 2. Stratigraphic section at the Hungry Hollow collecting site showing palynologic sampling levels in the Arkona, Hungry Hollow and Widder formations.

Figura 2. Sección estratigráfica de la zona de recogida de muestras en Hungry Hollow en la que se indican los niveles palinológicos en las formaciones Arkona, Hungry Hollow y Widder.

SERIES	STAGE	GROUP	FORMATION
MIDDLE DEVONIAN	GIVETIAN	Hamilton	Ipperwash
			Widder
			Hungry Hollow
			Arkona
			Rockport Quarry
			Bell

Figure 3. Stratigraphy of the Middle Devonian Hamilton Group in southwestern Ontario, Canada (modified from Armstrong and Carter, p. 17, table 3). Shading indicates the three formations sampled for the present study.

Figura 3. Estratigrafía del Devónico Medio del Grupo Hamilton en el suroeste de Ontario, Canadá (modificado de Armstrong and Carter, p. 17, tabla 3). El sombreado indica las tres formaciones muestreadas para el presente estudio.

Sampling consisted of either individual spot samples (HH2–HH5), or composite samples within an interval of uniform lithology (HH1, HH6–HH14).

Approximately 50 g of each sample were processed using standard palynologic techniques consisting of successive treatments with cold HCl, HF and HNO₃ for the respective removal of carbonates, silicates and sulfides, with washings in distilled water for neutralization between each acid treatment. The resultant residue was treated with 3% NH₃OH to remove excess humic material.

Those residues showing significant disparities in palynomorph size were sieved through a 52 µm screen and three slides of the > 52 µm fraction were prepared. The remaining residue was sieved via a 20 µm screen and three slides of the 20–52 µm fraction and one slide of the < 20 µm fraction were prepared (samples HH1–3, HH7–10, HH12, HH13). The residues con-

taining palynomorphs of relatively uniform size were sieved only through a 20 µm screen and three slides of the > 20 µm fraction and one slide of the < 20 µm fraction were prepared (samples HH4–6, HH11, HH14). Petropoxy 154 was the permanent mounting medium for all slides.

For relative abundance data (Table 1), all palynomorphs from the three > 20 µm fraction slides were counted. In those samples where > 52 µm slides were prepared, the palynomorphs from the three > 52 µm fraction slides, as well as the three 20–52 µm slides, were counted. Counts were not made from the < 20 µm slide, but the slide was examined to confirm that there were no palynomorphs in that fraction that were not present in the larger fractions.

Strew slides (HH1–HH14) of the > 52 µm, 20–52 µm and > 20 µm fractions were examined with an Olympus BH2 binocular microscope, under bright-field illumination. With the exception of *Tasmanites* sp. (Plate 2, Fig. 5), which was photographed using a 40x objective, all the other palynomorphs are illustrated via a 60x oil-immersion objective, with an Olympus DP26 digital camera. The images were captured with Olympus cellSens® software.

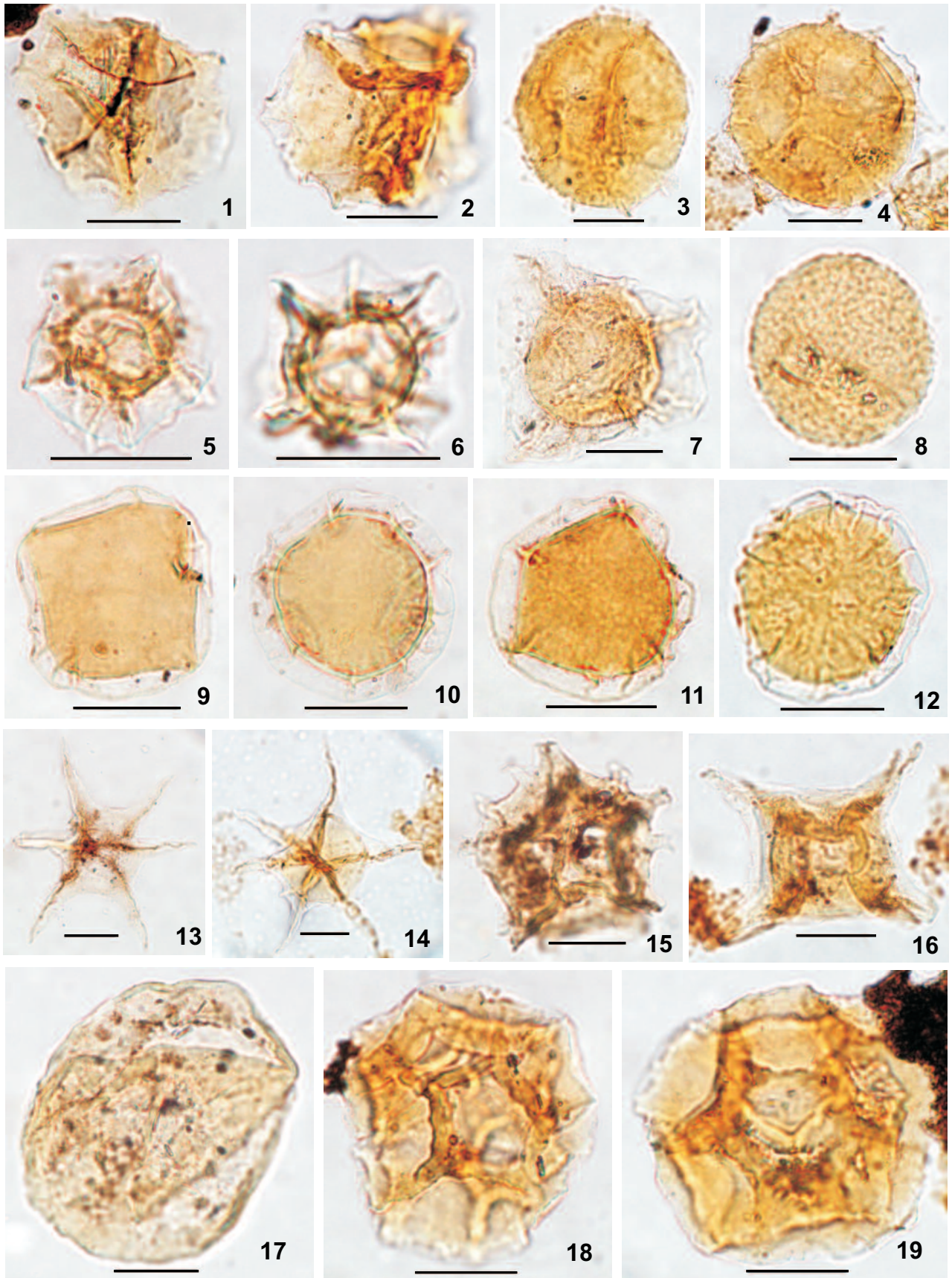
Repository

The 31 strew slides from which 71 palynomorph specimens are illustrated (Plates 1–4), are housed permanently in the Geological Survey of Canada, National Invertebrate and Plant Type Fossil Collection, 601 Booth Street, Ottawa, Ontario, Canada. Curatorial details (slide numbers, England Finder™ (EF) coordinates of individual specimens on the slides and the Geological Survey of Canada type catalogue numbers) are specified in Appendix 1.

Systematic palaeontology

Forty-nine species of organic-walled microphytoplankton – 32 acritarch species, 16 prasinophyte species and one chitinozoan species – were recovered from the Hungry Hollow locality (Fig. 1). The assemblage consists of 27 named acritarch species, 14 named prasinophyte species and one named chitinozoan species. Five acritarch and two prasinophyte species are left in open nomenclature. In addition, other chitinozoans, scolecodonts (e.g. Plate 4, Fig. 4) and amorphous kerogen particles in varying proportions were also encountered, but not identified taxonomically.

Taxa considered herein to be prasinophyte phyco-



mata are placed in the Class Prasinophyceae Christensen, 1962, and arranged alphabetically by genera. The acritarchs are treated as form genera and species following the rules of the International Code of Nomenclature for algae, fungi, and plants (ICN: McNeill *et al.*, 2012), and are also arranged alphabetically under the informal Group Acritarcha Evitt, 1963. The named chitinozoan species is placed in the chitinozoan Order Operculatifera Eisenack, 1931.

In the synonymy listings, the original binomial designation (basionym) and any subsequent generic transfers are listed, and where deemed apt, a reference to a complete synonymy is given. Remarks and comparisons (where appropriate), sample occurrence and stratigraphic and geographic distribution are also documented. Measurements of each species are not recorded because of close conformity with published size ranges thereof. For those species cited in open nomenclature, and those in which it was thought necessary for clarification, descriptions and measurements are appended.

Type-species designations are abbreviated as follows: OD, original designation; SD, subsequent designation; M, monotypy.

Prasinophyte phycmata

Division CHLOROPHYTA Pascher, 1914
Class PRASINOPHYCEAE Christensen, 1962
Genus *Arkonites* Legault, 1973

Type species: *Arkonites bilixus* Legault, 1973 [OD; M].

Arkonites bilixus Legault, 1973
Plate 1, Figs. 1, 2

1967a *Polyedryxium* sp. Brito, p. 13, pl. 2, fig. 8.
1973 *Arkonites bilixus* Legault, pp. 52-53, pl. 11, figs. 22, 23.
1974 Acritarch sp. Anan-Yorke, p. 200, pl. 20, fig. 10.
1979 *Polyedryxium* sp. cf. *P. talus* Pöthe de Baldis, pp. 167-168, pl. 1, figs. 6, 10, pl. 2, fig. 2.
1999 *Arkonites bilixus* (sic) Legault; Turnau and Racki, pp. 249, 268, pl. 4, fig. 19.

Occurrence. Samples HH2, HH4, HH5, HH9.

Previous records. *Arkonites bilixus* Legault, 1973 has

been reported from the Givetian, Ontario (Legault 1973); Givetian, Ohio (Wicander and Wood 1981); Middle Devonian, Ohio and Kentucky (Wicander and Wright 1983; Huysken *et al.* 1992); Givetian-early Frasnian, Argentina (Barreda 1986; Ottone 1996; Rubinstein 1999, 2000; Amenábar *et al.* 2006); Late Devonian, Paraguay (Pöthe de Baldis 1979); ?Mississippian, Lake Titikaka, Bolivia (Vavrdová *et al.* 1993); Givetian, central Poland (Turnau and Racki 1999); and possibly Emsian-Frasnian, Ghana (Anan-Yorke 1974).

Genus *Cymatiosphaera* O. Wetzel, 1933 ex Deflandre, 1954

Type species: *Cymatiosphaera radiata* O. Wetzel, 1933 [SD; Deflandre 1954, p. 257].

Cymatiosphaera canadense Deunff, 1954 ex Deunff, 1961
Plate 1, Figs. 3, 4

1954 *Cymatiosphaera canadensis* Deunff, p. 1065, fig. 10 (*nom. nud.*).

1955 *Cymatiosphaera canadensis* Deunff, p. 142, fig. 10 (*nom. nud.*).

1961 *Cymatiosphaera canadensis* Deunff, p. 218.

Remarks. We doubt that Górká's (1969) Tremadoc occurrence of *Cymatiosphaera canadense* from Poland is correct because of poor preservation and the fact that *C. canadense* has been reported authentically only from the Devonian (see *Previous records* below).

Occurrence. Samples HH3, HH4, HH7-HH10, HH12, HH13.

Previous records. *Cymatiosphaera canadense* Deunff, 1954 ex Deunff, 1961 has been reported as follows: from the presumed Early or Middle Devonian of Ontario (Deunff 1954, 1955, 1956, 1961, 1966a); late Pragian-Givetian, Ontario (Legault 1973; Playford 1977); Middle Devonian, Ohio (Wicander and Wright 1983); Givetian-early Frasnian, Argentina (Rubinstein 1999, 2000; Amenábar *et al.* 2006); late Tremadoc and

Plate 1 (lámina 1). Prasinophyte photomicrographs. 1, 2, *Arkonites bilixus* Legault, 1973. 3, 4, *Cymatiosphaera canadense* Deunff, 1954 ex Deunff, 1961. 5, 6, *Cymatiosphaera cornifera* Deunff, 1955. 7, *Cymatiosphaera winderi* Deunff, 1967. 8, *Dictyotidium variatum* Playford, 1977. 9, *Duvernaysphaera angelae* Deunff, 1964. 10-12, *Duvernaysphaera tenuicingulata* Staplin, 1961. 13, 14, *Polyedryxium ambitum* Wicander and Wood, 1981. 15, *Polyedryxium decorum* Deunff, 1955. 16, *Polyedryxium embudum* Cramer, 1964. 17, *Leiosphaeridia* sp. 18, 19, *Muraticavea munifica* Wicander and Wood, 1981. Scale bars = 20 µm.

late Famennian, Poland (Górka 1969, 1974); and Givetian, western Libya (Moreau-Benoit 1984).

Cymatiosphaera cornifera Deunff, 1955
Plate 1, Figs. 5, 6

1955 *Cymatiosphaera cornifera* Deunff, p. 147, fig. 23.

Remarks. Notwithstanding Deunff's (1955) provision of only a single line-drawing, this species is easily recognized by its delicate high muri and the relatively large meshes of its reticulum (Playford 1977, p. 17, pl. 4, figs. 4-14).

Occurrence. Samples HH1, HH4, HH12.

Previous records. *Cymatiosphaera cornifera* Deunff, 1955 has been recorded from the Middle Devonian–Frasnian, Ontario (Deunff 1955, 1966a, 1967); late Pragian–middle Givetian, Ontario (Playford 1977); Givetian, Ohio (Wicander and Wood 1981); Middle Devonian, Ohio (Wicander and Wright 1983); Pragian, northern Bolivia (Vavrdová *et al.* 1996); late Givetian–early Frasnian, Boulonnais, France (Deunff 1981); Eifelian, China (Zhu Huaicheng *et al.* 2008); and Tournaisian/Tn1b, Xizang/Tibet (Gao Lianda 1986). Stockmans and Williè (1969) figured a putative example of *C. cornifera* from the early Famennian of Belgium, but a positive attribution is considered questionable (Playford 1977).

Cymatiosphaera winderi Deunff, 1967
Plate 1, Fig. 7

1967 *Cymatiosphaera winderi* Deunff, pp. 259-260, figs. 13, 17.

1967 *Cymatiosphaera* sp. cf. *C. winderi* Deunff; Deunff, p. 259, fig. 15.

Occurrence. Samples HH1, HH2, HH4, HH6-HH9, HH12, HH13.

Previous records. *Cymatiosphaera winderi* Deunff, 1967 occurs in the Frasnian, Ontario (Deunff 1967); Emsian–middle Eifelian and early–middle Givetian, Ontario (Playford 1977); Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); late Givetian, Iowa (Wicander and Wood 1997); and Givetian, western Libya (Moreau-Benoit 1984).

Genus *Dictyotidium* Eisenack, 1955 emend. Staplin, 1961

Type species: *Dictyotidium dictyotum* (Eisenack, 1938) Eisenack, 1955 [OD].

Dictyotidium variatum Playford, 1977
Plate 1, Fig. 8

1973 *Dictyotidium dictyotum* Legault, p. 52 (*pars*), pl. 11, fig. 10 (only).

1977 *Dictyotidium variatum* Playford, pp. 18-19, pl. 5, figs. 2-4, pl. 6, figs. 1-6.

1983 *Dictyotidium* sp. cf. *D. variatum* Playford; Wicander and Wright, p. 5, fig. 3 (5).

Occurrence. Samples HH2, HH4.

Previous records. Prior reports of *Dictyotidium variatum* Playford, 1977 are as follows: Givetian, Ontario (Legault 1973); late Pragian–middle Givetian, Ontario (Playford 1977); Lochkovian, Oklahoma (Wicander 1986); Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); late Givetian, Iowa (Wicander and Wood 1997); Middle Devonian, Ohio (Wicander and Wright 1983); and Tournaisian/Tn1b, Xizang/Tibet (Gao Lianda 1986).

Genus *Duvernaysphaera* Staplin, 1961, emend. Deunff, 1964

Type species: *Duvernaysphaera tenuicingulata* Staplin, 1961 [OD].

Duvernaysphaera angelae Deunff, 1964
Plate 1, Fig. 9

1964 *Duvernaysphaera angelae* Deunff, pp. 211-212, fig. 1.

1964 *Duvernaysphaera tessella* Deunff, p. 212, fig. 5.

1966 *Veliferites tenuimarginatus* Brito, p. 79 (*nom. nud.*).

1967b *Veliferites tenuimarginatus* Brito, p. 477, pl. 1, figs. 4-8.

1981 *Duvernaysphaera tessella* Deunff; Playford and Dring, pp. 26-28, pl. 6, figs. 4-9.

1986 *Duvernaysphaera tessella* Deunff; Barreda, p. 231, pl. 1, figs. 1, 2.

For further synonymy up to 1981, see Wicander and Wood (1981, p. 23).

Description. Vesicle typically quadrangular (\pm square) in outline, each side 26–32 μm long; margins straight to slightly convex or slightly concave; eilyma \sim 1 μm thick, psilate to faintly scabrate; thin, diaphanous, psilate membrane (equatorial flange), 2.4–4.8 μm wide,

surrounding vesicle; membrane supported by 1–4, narrow, solid, rod-like planar extensions (1.6–4 µm long) at or near vesicle corners; flange, where complete, presenting an overall subcircular outline, 34–40 µm in diameter. No excystment structure observed.

Remarks and comparison. The holotype description of *Duvernaysphaera* Deunff, 1964 does not mention the vesicle wall surface, and although its line-drawing suggests superficial punctation or scabration, we interpret his illustrations as artistic license because all of the other described species show the same type of surface character for both the vesicle and the equatorial membrane. This artistic rendition likewise applies to *Duvernaysphaera tessella* Deunff, 1964, despite Deunff's description specifying a granulate vesicle.

Our specimens have a psilate to faintly scabrate eilyma and the same vesicle diameter as, but slightly smaller overall diameter than, *D. tessella* of Playford (in Playford and Dring 1981). The latter author considered *Veliferites tenuimarginatus* Brito, 1967 to be a junior synonym of *D. tessella*; this is endorsed herein.

Occurrence. Samples HH1-HH10, HH12, HH13.

Previous records. The extensive palaeogeographic and (mainly Middle–Late) Devonian distribution of *Duvernaysphaera angelae* Deunff, 1964 is evident from prior publications, as follows: Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); Middle Devonian, Ohio (Wicander and Wright 1983); Middle and Late Devonian, Kentucky (Huysken *et al.* 1992); Early Devonian (= Zone R), Maranhão Basin, Brazil (Brito 1966, 1967a, b, c); Middle Devonian, northwest Paraguay (Pöthe de Baldis 1974); Givetian–early Frasnian, Argentina (Barreda 1986; Ottone 1996; Amenábar *et al.* 2006); late Famennian, southeast Bolivia (Wicander *et al.* 2011); Late Devonian–Mississippian, Bolivia (Vavrdová *et al.* 1993, 1996); early Frasnian, Boulonnais, France (Deunff 1981); late Famennian, Portugal (Pereira *et al.* 2008); undifferentiated Devonian, Tunisia (Deunff 1964, 1966b); Eifelian–Famennian, Algerian Sahara (Jardiné and Yapaudjian 1968; Lanzoni and Magloire 1969; Jardiné 1972; Jardiné *et al.* 1974); Emsian–Frasnian, Ghana (Anan-Yorke 1974); and Frasnian, Western Australia (Playford and Dring 1981).

Duvernaysphaera tenuicingulata Staplin, 1961
Plate 1, Figs. 10–12

1961 *Duvernaysphaera tenuicingulata* Staplin, pp. 415–416, pl. 49, figs. 10, 11.

Description. Vesicle circular to rounded polygonal in outline, 29–37 µm in diameter; eilyma 1.8–2.1 µm thick, psilate to slightly scabrate; vesicle surrounded equatorially by thin, diaphanous, psilate membrane (equatorial flange), 3.2–4.8 µm wide, exhibiting an overall circular outline, 35–45 µm in diameter; equatorial flange braced by 9–13 narrow, irregularly spaced, solid, spine-like planar extensions, extending 4.8–8 µm radially. No method of excystment observed.

Remarks. Although showing some morphological variation, the present specimens conform to the description and measurements cited in numerous publications (see below).

Occurrence. Samples HH1-HH14.

Previous records. *Duvernaysphaera tenuicingulata* Staplin, 1961 occurs in the late Emsian, late Eifelian and early–middle Givetian, Ontario (Playford 1977); Late Devonian, Alberta (Staplin 1961); Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); late Givetian, Iowa (Wicander and Wood 1997); Middle Devonian, Ohio (Wicander and Wright 1983); late Givetian–early Frasnian, Argentina (Barreda 1986; Ottone 1996); early Frasnian, Boulonnais, France (Deunff 1981); undifferentiated Devonian, Tunisia (Deunff 1964, 1966b); late Famennian, Portugal (Pereira *et al.* 2008); Givetian–Famennian, Algerian Sahara (Jardiné *et al.* 1974); and Frasnian, Western Australia (Playford and Dring 1981).

Genus *Leiosphaeridia* Eisenack, 1958

Type species: *Leiosphaeridia baltica* Eisenack, 1958
[OD].

Leiosphaeridia sp.
Plate 1, Fig. 17

Remarks. Numerous specimens of *Leiosphaeridia* Eisenack, 1958 occur in all 14 samples. However, because of their simple, psilate, spherical morphology, we are leaving them in open nomenclature and simply noting their presence as part of the palynoflora.

Occurrence. Samples HH1-HH14.

Previous records. *Leiosphaeridia* spp. are widely dispersed, with a stratigraphic range of Proterozoic to Recent.

Genus *Muraticavea* Wicander, 1974

Type species: *Muraticavea enteichia* Wicander, 1974
[OD; M].

Muraticavea munifica Wicander and Wood, 1981
Plate 1, Figs. 18, 19

1981 *Muraticavea munificus* Wicander and Wood, pp. 24-25, pl. 2, figs. 6-9.

Occurrence. Samples HH1-HH9, HH11-HH13.

Previous records. This species has been reported from the Givetian, Ohio (Wicander and Wood 1981); late Givetian, Iowa (Wicander and Wood 1997); Middle Devonian, Ohio (Wicander and Wright 1983); Givetian-early Frasnian, Argentina (Barreda 1986; Ottone 1996; Rubinstein 1999, 2000, Amenábar *et al.* 2006); and late Famennian, southeast Bolivia (Wicander *et al.* 2011).

Genus *Polyedryxium* Deunff, 1954 ex Deunff, 1961

Type species: *Polyedryxium deflandrei* Deunff, 1954
[SD; Deunff 1961, p. 216].

Polyedryxium ambitum Wicander and Wood, 1981
Plate 1, Figs. 13, 14

1981 *Polyedryxium ambitum* Wicander and Wood, p. 26, pl. 3, figs. 1, 2.

1983 *Polyedryxium* sp. cf. *P. ambitum* Wicander and Wood; Wicander and Wright, p. 10, fig. 3 (9).

Occurrence. Samples HH2, HH6-HH9, HH13.

Previous records. *Polyedryxium ambitum* Wicander and Wood, 1981 has been recorded from the Givetian, Ohio (Wicander and Wood 1981); Middle Devonian, Ohio (Wicander and Wright 1983, cf. designation only); and late Givetian-early Frasnian, Argentina (Barreda 1986; Ottone 1996).

Polyedryxium decorum Deunff, 1955
Plate 1, Fig. 15

1955 *Polyedryxium decorum* Deunff, pp. 146-147, pl. 2, fig. 1.

1967 *Polyedryxium* sp. cf. *P. decorum* Deunff; Deunff, p. 259, fig. 6.

For further synonymy, see Wicander and Wood (1981, p. 27).

Occurrence. Sample HH1.

Previous records. *Polyedryxium decorum* Deunff, 1955 occurs in the Middle Devonian, Ontario (Deunff 1955, 1966a, 1971); Late Devonian, Saskatchewan and Ontario (Deunff 1967; Nautiyal 1977); late Emsian, early-middle Eifelian and early-middle Givetian, Ontario (Playford 1977); Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); late Givetian, Iowa (Wicander and Wood 1997); late Frasnian, Iowa (Wicander and Playford 1985); Givetian-early Frasnian, Argentina (Rubinstein 1999, 2000; Amenábar *et al.* 2006); Ludlovian-Emsian (in part), northwest Spain (Cramer 1963, 1964); Givetian, western Libya (Moreau-Benoit 1984; Massa and Moreau-Benoit 1985); and late Emsian-Famennian, Algerian Sahara (Jardiné 1972; Jardiné *et al.* 1974).

Polyedryxium embudum Cramer, 1964
Plate 1, Fig. 16; Plate 2, Fig. 1

1964 *Polyedryxium embudum* Cramer, pp. 318-319, fig. 32 (5).

1966a *Polyedryxium nudatum* Deunff, pp. 91-92, pl. 13, fig. 150.

1981 *Polyedryxium* sp. cf. *P. embudum* Cramer; Wicander and Wood, p. 27, pl. 3, fig. 5.

1983 *Polyedryxium embudum?* Cramer; Wicander and Wright, p. 10, fig. 3 (12).

1984 *Polyedryxium* sp. cf. *P. embudum* Cramer; Molyneux, Manger and Owens, p. 47, pl. 2, figs. 9, 10.

1985 *Polyedryxium* sp. cf. *P. embudum* Cramer; Wicander and Playford, p. 114, pl. 5, figs. 4, 7.

1990 *Polyedryxium* sp. cf. *P. embudum* Cramer; Colbath, p. 198, pl. 3, figs. 7, 21, 22, text-fig. 7.

Remarks. Playford (1977, p. 34) noted that when Deunff (1971) included both *Polyedryxium nudatum* and Cramer's (1964) *P. embudum* in his treatise on *Polyedryxium* and related species, he did not attempt any differential distinction between them. In fact, neither species was given anything other than a cursory description, nor was either adequately illustrated. Hence, we consider *P. nudatum* and *P. embudum* as conspecific.

Occurrence. Samples HH2, HH7-HH11, HH13.

Previous records. With an inclusive stratigraphic range of Pragian-Famennian, *Polyedryxium embudum* Cramer, 1964 has been variously reported as follows: Early and Middle Devonian, Ontario (Deunff 1966a, 1971); Emsian and early Eifelian, Ontario

(Playford 1977); Late Devonian, Alberta (Nautiyal 1977); Givetian, Ohio (Wicander and Wood 1981); Middle Devonian, Ohio (Wicander and Wright 1983); late Frasnian, Iowa (Wicander and Playford 1985); late Famennian, Ohio (Molyneux *et al.* 1984) and Illinois (Wicander and Playford 2013); Givetian–early Frasnian, Argentina (Barreda 1986; Ottone 1996; Amenábar 2009); middle Pragian–Emsian (in part), northwest Spain (Cramer 1964); undifferentiated Devonian, Tunisia (Deunff 1971); Frasnian–Famennian, northern Iran (Ghavidel-syooki 1994); Eifelian, China (Zhu Huaicheng *et al.* 2008); late Frasnian–Famennian, Xinjiang, China (Lu Li-chang and Wicander 1988); Givetian–Frasnian, Western Australia (Colbath 1990); and Frasnian, Western Australia (Playford and Dring 1981).

Polyedryxium fragosulum Playford, 1977
Plate 2, Figs. 2, 3

1977 *Polyedryxium fragosulum* Playford, pp. 34-35, pl. 16, figs. 8-14.

1986 *Eisenackidium duplex auct. non* Cramer; Barreda, p. 231, pl. 2, fig. 10.

Occurrence. Samples HH1, HH2, HH4, HH7-HH9, HH13.

Previous records. *Polyedryxium fragosulum* Playford, 1977 is known from the late Pragian–middle Emsian, Ontario (Playford 1977); Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); Middle Devonian, Ohio (Wicander and Wright 1983); late Givetian–early Frasnian, Argentina (Ottone 1996); and undifferentiated Devonian, Tunisia (Deunff 1966b).

Polyedryxium pharaone Deunff, 1961
Plate 2, Figs. 6, 7

1954 *Polyedryxium pharaonis* Deunff, p. 1065, fig. 13 (*nom. nud.*).

1955 *Polyedryxium pharaonis* Deunff, p. 143, fig. 13 (*nom. nud.*).

1961 *Polyedryxium pharaonis* Deunff, p. 217.

1966a *Polyedryxium pharaonis* (Deunff, 1961); Deunff, pp. 58-62, pl. 7, figs. 79, 80, 82-85, pl. 8, figs. 92-94, pl. 12, fig. 126, pl. II, fig. 12, pl. VI, figs. 42, 43.

1972 *Crameria pharaonis* (Deunff, 1961) Jardiné, Combaz, Magloire, Peniguel and Vachey, pp. 301-302, pl. 2, figs. 6-10. (?non *Crameria pharaonis* (Deunff) subsp. *duplex* (Cramer) Jardiné, Combaz, Magloire, Peniguel and Vachey, 1972, p. 301).

For further synonymy, see Wicander and Wood (1981, pp. 28-29), Wicander (1983, p. 71) and Lu Li-chang and Wicander (1988, p. 127).

Occurrence. Samples HH1-HH14.

Previous records. *Polyedryxium pharaone* Deunff, 1961 is widely distributed in North America, South America, North Africa, the Middle East, Europe, Australia and China, with a stratigraphic range of Pragian–Famennian (Wicander and Playford 2013). For citations of preceding occurrences and their stratigraphic ranges therein, see Playford and McGregor (1993) and Hashemi and Playford (1998).

Genus *Staplinium* Jansonius, 1962

Type species: *Staplinium hexaeder* Jansonius, 1962 [OD; M].

Staplinium cuboides (Deunff, 1955) Deunff, 1971
Plate 2, Fig. 4

1955 "*Polyedryxium*" *cuboides* Deunff, p. 147, fig. 19.
1967 *Polyedryxium* sp. aff. *P. cuboides* Deunff; Deunff, p. 258, fig. 18.

1971 *Staplinium cuboides* (Deunff, 1955); Deunff, p. 42, pl. 1, figs. 11, 12, 17, pl. 8, fig. 16.

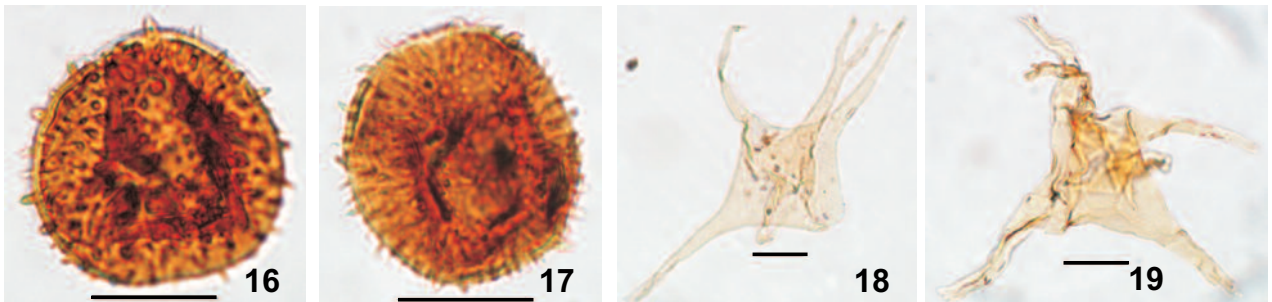
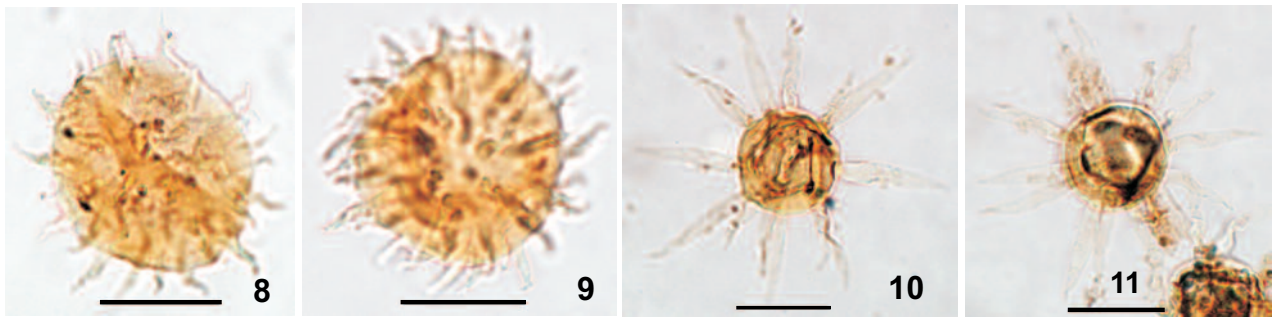
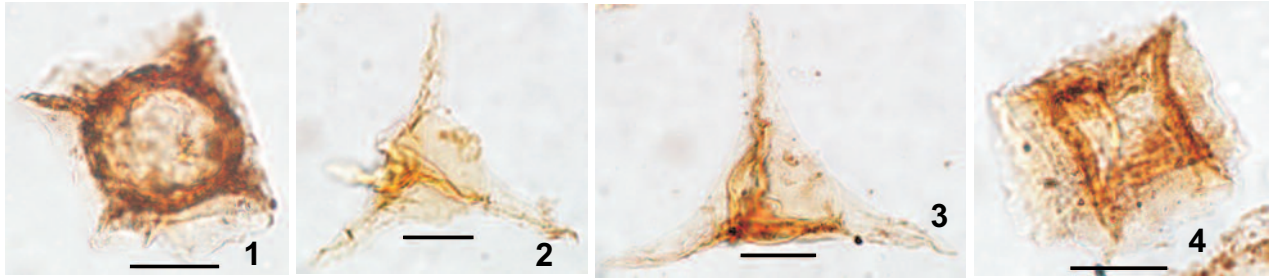
1980 *Cymatiosphaera cubus* Deunff, p. 493, table 1.

Remarks and comparison. Deunff (1961, p. 216; 1971, p. 42) implied that *Polyedryxium cuboides* Deunff, 1955 might be synonymous with *Staplinium hexaeder* Jansonius, 1962 (= type species of *Staplinium*). However, *S. hexaeder* is Early Triassic in age, whereas all occurrences of *Staplinium cuboides* (Deunff, 1955) Deunff, 1971 are Devonian.

This species is similar to *Polyedryxium embudum* Cramer, 1964 but lacks the irregularly crenate boundaries or crests present in Cramer's species. This distinction is not always clearly evident, and the two species cannot be differentiated unequivocally, especially if the specimens are not well preserved. Hence, indifferently preserved specimens are sometimes attributed to *S. cuboides*, rather than to *P. embudum*.

Occurrence. Samples HH1, HH2, HH4-HH9, HH12, HH13.

Previous records. *Staplinium cuboides* (Deunff, 1955) Deunff, 1971 has been reported from the Middle Devonian, Ontario (Deunff 1955, 1956, 1971); Givetian, Ontario (Legault 1973); Lochkovian, Frasnian, France



(Deunff 1980, 1981); and Pragian–Emsian (in part), northwest Spain (Cramer 1963).

Genus *Tasmanites* Newton, 1875

Type species: *Tasmanites punctata* Newton, 1875 [OD].

Tasmanites sp.
Plate 2, Fig. 5

Remarks. Specimens of *Tasmanites* Newton, 1875 are present throughout the sampled section. However, because of their simple, thick-walled, punctate, spherical morphology, we are leaving the cohort in open nomenclature and simply noting their occurrence as part of the palynologic assemblage.

Occurrence. Samples HH1–HH14.

Previous records. *Tasmanites* spp. are globally distributed, ranging from Proterozoic to Recent.

Acritarcha

Group ACRITARCHA Evitt, 1963
Genus *Ammonidium* Lister, 1970

Type species: *Ammonidium microcladum* (Downie, 1963) Lister, 1970 [OD].

Ammonidium sp. A
Plate 2, Figs. 8, 9

Description. Vesicle originally spherical, circular to subcircular in outline, distinct from processes; 34–38 µm in diameter; eilyma 0.6–1.6 µm thick, surface psilate; numerous (24–31) hollow, homomorphic (predominantly) to heteromorphic psilate processes, 6–10 µm long, ± evenly distributed over eilyma; typically straight to curved proximal contacts (1.6–3.2 µm in diameter); processes slightly taper to typically spine-like bifurcant or less commonly acuminate distal tip; bifurcant spine-like projections seemingly solid, subequal, 0.5–1 µm long; process interiors appear

uncommunicative with vesicle interior. No method of excystment observed.

Comparison and remarks. This species differs from *Ammonidium inornatum* Colbath, 1990 (Givetian–Frasnian, Western Australia) in having a larger vesicle and more numerous and longer processes, which are either distally acuminate or bifurcant. It differs from *A. garrasinoi* Ottone, 1996 (late Givetian–early Frasnian, Argentina) in possessing a psilate eilyma and numerous, shorter processes that are either acuminate or bifurcant distally. Lastly, the present form differs from *A. hamatum* Wicander, 1974 (Late Devonian, Ohio) in its larger vesicle, somewhat longer and distally bifurcant or acuminate processes.

Although distinct from other named species of *Ammonidium*, a lack of sufficient, well-preserved specimens necessitates leaving this form in open nomenclature.

Occurrence. Samples HH1–HH10, HH12, HH13.

Genus *Baltisphaeridium* Eisenack, 1958 ex Eisenack, 1959 emend. Eisenack, 1969

Type species: *Baltisphaeridium longispinosum* (Eisenack, 1931) Eisenack, 1958 [OD].

Baltisphaeridium distentum Playford, 1977
Plate 2, Figs. 10, 11

1977 *Baltisphaeridium distentum* Playford, pp. 12–13, pl. 1, figs. 13, 14, pl. 2, figs. 1–5, text-fig. 4.

1993 *Baltisphaerosum* sp. A Playford and McGregor, pp. 12–13, pl. 3, figs. 3, 4.

1996 *Baltisphaerosum distentum* (Playford, 1977) Ottone, pp. 121–122, pl. 4, fig. 8.

For further synonymy, see Ottone (1996, p. 121).

Remarks. *Baltisphaeridium distentum* Playford, 1977 is a distinctive species with basally constricted processes having well-developed basal plugs preventing free communication with the vesicle interior. Furthermore, the processes are thin-walled in contrast to the thicker-walled eilyma.

Plate 2 (lámina 2). Prasinophyte (1–7) and acritarch (8–19) photomicrographs. 1, *Polyedryxium embudum* Cramer, 1964. 2, 3, *Polyedryxium fragosulum* Playford, 1977. 4, *Staplinium cuboides* (Deunff, 1955). 5, *Tasmanites* sp. 6, 7, *Polyedryxium pharaone* Deunff, 1961. 8, 9, *Ammonidium* sp. A. 10, 11, *Baltisphaeridium distentum* Playford, 1977. 12, *Daillydium pentaster* (Staplin, 1961) emend. Playford in Playford and Dring, 1981. 13, *Diexallophasis simplex* Wicander and Wood, 1981. 14, *Eisenackidium appendiculum* Wicander and Wood, 1981. 15, *Estiastra rhytidia* Wicander and Wood, 1981. 16, 17, *Gorgonisphaeridium inflatum* Wicander and Wood, 1981. 18, 19, *Exochoderma arca* Wicander and Wood, 1981. Scale bars = 20 µm.

Occurrence. Samples HH1-HH13.

Previous records. *Baltisphaeridium distentum* Playford, 1977 is known from the Pragian–Famennian of North America (Playford 1977; Wicander and Wood 1981; Wicander and Wright 1983; Wood and Clendening 1985; Wood 1986; Playford and McGregor 1993; Wicander and Playford 2013); late Givetian–early Frasnian, Argentina (Barreda 1986; Ottone 1996); and late Famennian, southeast Bolivia (Wicander *et al.* 2011).

Genus *Daillydium* Stockmans and Willièrè, 1969

Type species: *Daillydium pentaster* (Staplin, 1961) Playford in Playford and Dring, 1981 [OD as *Daillydium quadridactylites* (Stockmans and Willièrè, 1962a) Stockmans and Willièrè, 1969 = junior synonym of *D. pentaster*].

Daillydium pentaster (Staplin, 1961) emend.
Playford, 1981
Plate 2, Fig. 12

1961 *Cymatiosphaera pentaster* Staplin, p. 416, pl. 49, fig. 18.

1961 *Cymatiosphaera tetraster* Staplin, p. 416, pl. 49, fig. 15.

1962a *Hystrichosphaeridium quadridactylites* Stockmans and Willièrè, pp. 67-68, pl. 1, fig. 18, text-fig. 29.

non 1962b *Cymatiosphaera pentaster* Staplin; Stockmans and Willièrè, p. 97, pl. 1, fig. 15, text-fig. 16.

1969 *Daillydium quadridactylites* (Stockmans and Willièrè, 1962a) Stockmans and Willièrè, pp. 33-35, pl. 1, figs. 1-14.

1976 *Cymatiosphaera* sp. 3 Nautiyal, p. 299, fig. 1 (4).

1976 *Cymatiosphaera* sp. 6 Nautiyal, p. 299, fig. 1 (5).

1976 *Cymatiosphaera* sp. 4 Nautiyal, p. 299, fig. 1 (6).

1977 *Cymatiosphaera pentaster* Staplin; Nautiyal, pp. 56-57, pl. 1, figs. 2, 3.

1977 *Cymatiosphaera* sp. 3 Nautiyal, pp. 56-57, pl. 1, figs. 4, 5.

1977 *Cymatiosphaera* sp. 4 Nautiyal, pp. 56-57, pl. 1, figs. 6, 7.

1981 *Daillydium pentaster* (Staplin, 1961) Playford, in Playford and Dring, pp. 17-18, pl. 3, figs. 1-14, text fig. 4.

For further synonymy, see Colbath (1990, p. 114.)

Remarks. Playford in Playford and Dring (1981) discussed the morphological variability of *Daillydium pentaster* (Staplin, 1961) Playford, 1981 and provided an overview of the taxonomy of this species as it rela-

tes to *Cymatiosphaera pentaster* Staplin, 1961, *C. tetraster* Staplin, 1961 and *Daillydium quadridactylites* (Stockmans and Willièrè, 1962a) Stockmans and Willièrè, 1969.

Occurrence. Samples HH1, HH2, HH4, HH6-HH8, HH10-HH13.

Previous records. Although *Daillydium pentaster* (Staplin, 1961) Playford, 1981 is characteristic of the Late Devonian, it has also been recorded from the Middle Devonian. Its occurrence and stratigraphic range are as follows: Late Devonian, western Canada (Staplin 1961; Nautiyal 1976, 1977); late Famennian–?early Tournaisian, southern Saskatchewan (Playford and McGregor 1993); Givetian–?Frasnian, Tennessee (Reaugh 1978, listed without illustration); late Givetian and late Frasnian, Iowa (Wicander and Playford 1985; Wicander and Wood 1997); Givetian–Frasnian boundary, Argentina (Barreda 1986); Late Devonian, Paraguay (Pöthe de Baldis 1979); late Famennian, southeast Bolivia (Wicander *et al.* 2011); Givetian, central Poland (Turnau and Racki 1999); late Givetian–middle Frasnian, France (Deunff 1981; Le Hérissé and Deunff 1988); Frasnian–Famennian, Franco-Belgian Ardennes (Stockmans and Willièrè 1962a, 1969, 1974; Bain and Doubinger 1965; Martin 1981, 1985); late Frasnian–early Famennian, Brabant Massif, Belgium (Kimpe *et al.* 1978); Famennian, Portugal (Cunha and Oliveira 1989; Pereira *et al.* 1994; Pereira *et al.* 2008); late Famennian, Poland (Górka 1974); Frasnian, east-central Iran (Hashemi and Playford 1998); undifferentiated Devonian, Tunisia (Deunff 1966b); Givetian–Famennian, Algerian Sahara (Jardiné 1972; Jardiné *et al.* 1974); late Frasnian–Famennian, Xinjiang, China (Lu Li-chang and Wicander 1988); Givetian–Frasnian, Western Australia (Colbath 1990); and Frasnian, Western Australia (Playford 1981; Playford and Dring 1981).

Genus *Diexallophasis* Loeblich, 1970

Type species: *Diexallophasis denticulata* (Stockmans and Willièrè, 1963) Loeblich, 1970 [OD].

Remarks. Le Hérissé (1989, p. 125) considered both *Diexallophasis* Loeblich, 1970 and *Exochoderma* Wicander, 1974 as junior synonyms of *Evittia* Brito, 1967 emend. Lister, 1970. However, we do not accept that these genera constitute the morpho-continuum synthesized by Le Hérissé (1989), viz., from an inflated vesicle bearing short processes without consistent

vesicle-process differentiation (cf. *Evittia*), to a distinct vesicle clearly segregated from long processes having well-defined acuminate to multi-furcate distal tips (as in *Diexallophasis* and *Exochoderma*).

We are cognizant that it is sometimes difficult to assign generically, some species that appear intermediate between these morphotype categories. Nevertheless, we consider it practicable to consign those species bearing processes that are clearly separated from the vesicle, to either *Diexallophasis* or *Exochoderma*.

Diexallophasis simplex Wicander and Wood, 1981
Plate 2, Fig. 13

1977 *Diexallophasis remota* (Deunff, 1955) Playford, pp. 19-20 (*pars*), pl. 7, figs. 2, 6, 8 (only).

1981 *Diexallophasis simplex* Wicander and Wood, pp. 33-34, pl. 5, fig. 7, pl. 6, figs. 1-3.

2008 *Diexallophasis remota* (Deunff, 1955) Playford; Zhu Huaicheng, Wicander and Marshall, p. 148, pl. 4, fig. 3.

Comparison and remarks. *Diexallophasis simplex* Wicander and Wood, 1981 superficially resembles several of the specimens illustrated by Playford (1977). However, as noted by Wicander and Wood (1981), there is a wide variety in eilyma sculpture, process width, and types of distal furcations, such that they did not consider all of Playford's illustrated specimens to represent a single species.

Furthermore, *D. simplex* closely resembles *Hystrichosphaeridium spiciferum* Deunff, 1955, but no description of the latter's eilyma surface was given, nor were the described grana putatively present on the processes evident in Deunff's figured specimen.

Our specimens clearly fit the circumscription of *D. simplex*, and are therefore assigned to that species rather than to *D. remota* (Deunff, 1955) Playford, 1977.

Occurrence. Samples HH1, HH6, HH13.

Previous records. *Diexallophasis simplex* Wicander and Wood, 1981 has been reported from the Givetian, Ohio (Wicander and Wood, 1981). The stratigraphic range of *D. remota* given in Playford (1977) for Ontario is Pragian–Givetian. *D. remota* has also been reported from the Eifelian, China (Zhu Huaicheng *et al.* 2008).

Genus *Eisenackidium* Cramer and Diez, 1968, ex Eisenack, Cramer and Diez, 1973

Type species: *Eisenackidium triplodermum* (Cramer, 1967) Eisenack, Cramer and Diez, 1973 [OD].

Eisenackidium appendiculum Wicander and Wood, 1981
Plate 2, Fig. 14

1981 *Eisenackidium appendiculum* Wicander and Wood, pp. 35-36, pl. 6, fig. 4, pl. 7, figs. 1, 2.

Occurrence. Samples HH1-4, HH6, HH9, HH12, HH13.

Previous records. This species has been reported from the Givetian, Ohio (Wicander and Wood 1981) and late Famennian–?Tournaisian, Saskatchewan (Playford and McGregor 1993).

Genus *Estiastra* Eisenack, 1959

Type species: *Estiastra magna* Eisenack, 1959 [OD].
Estiastra rhytidoa Wicander and Wood, 1981
Plate 2, Fig. 15

1973 *Veryhachium* sp. 1 Legault, p. 54, pl. 12, figs. 1, 2, 15, 18.

1981 *Estiastra rhytidoa* Wicander and Wood, pp. 37-38, pl. 7, figs. 5, 6, pl. 8, figs. 1, 2.

1999 *Estiastra* sp. cf. *E. rhytidoa* Wicander and Wood; Rubinstein, p. 16, fig. 3. D.

Occurrence. Samples HH1, HH9, HH13.

Previous records. *Estiastra rhytidoa* Wicander and Wood, 1981 occurs in the Givetian, Ontario (Legault 1973); Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); Middle Devonian, Ohio (Wicander and Wright 1983); Eifelian–early Frasnian, Argentina (Barreda 1986; Rubinstein 1999, 2000; Amenábar *et al.* 2006).

Genus *Exochoderma* Wicander, 1974

Type species: *Exochoderma irregularis* Wicander, 1974 [OD].

Remarks. Our rationale for distinguishing between *Evittia* (Brito, 1967) emend. Lister, 1970 and *Diexallophasis* Loeblich, 1970 and *Exochoderma* Wicander, 1974 is discussed above, under *Diexallophasis*. Although *Diexallophasis* and *Exochoderma* are morphologically similar, and in our opinion, distinct from *Evittia* (notwithstanding Le

Hérissé's (1989) arguments of a morphologic continuum), we consider *Exochoderma* to be differentiable from *Diexallophasis* in having a triangular to quadrate vesicle, that commonly bears broader processes than the latter genus.

Exochoderma arca Wicander and Wood, 1981
Plate 2, Figs. 18, 19

1965 *Baltisphaeridium* aff. *B. visbyense* Brito, p. 3, pl. 1, fig. 4.

1972 *Evittia remota* (Deunff, 1955) *remota* Jardiné, Combaz, Magloire, Peniguel and Vachey, pp. 297-298, pl. 1, figs. 11, 12.

1973 *Veryhachium* sp. cf. *V. lairdii* Legault, pp. 53-54 (*pars*), pl. 12, figs. 3, 7, 11 (only).

1974 *Veryhachium rabiosum* Anan-Yorke, pp. 122-123, pl. 23, fig. 4.

1976 *Diexallophasis remotum* (Deunff, 1955) Brito, p. 753, fig. 6d.

1977 *Diexallophasis remota* (Deunff) Playford, pp. 19-20 (*pars*), pl. 6, fig. 14 (only).

1981 *Exochoderma arca* Wicander and Wood, pp. 38-39, pl. 8, figs. 3, 4, pl. 9, figs. 1-3.

2008 *Exochoderma* sp. cf. *E. arca* Wicander and Wood; Zhu Huaicheng, Wicander and Marshall, p. 148, pl. 4, fig. 1.

Occurrence. Samples HH1-HH14.

Previous records. *Exochoderma arca* Wicander and Wood, 1981 has a stratigraphic range and occurrence as follows: Givetian, Ontario (Legault 1973); late Pragian–middle Givetian, Ontario (Playford 1977); Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); late Givetian, Iowa (Wicander and Wood 1997); Middle Devonian, Ohio (Wicander and Wright 1983) and Kentucky (Huysken *et al.* 1992); Middle Devonian, Brazil (Brito, 1965; 1976); Givetian–early Frasnian, Argentina (Ottone 1996; Amenábar *et al.* 2006); late Famennian, southeast Bolivia (Wicander *et al.* 2011); Givetian, central Poland (Turnau and Racki 1999); Givetian–Frasnian, Ghana (Anan-Yorke 1974); Emsian–Frasnian, Algerian Sahara (Jardiné *et al.* 1972); and Eifelian, China (Zhu Huaicheng *et al.* 2008; cf. designation).

Genus *Gorgonisphaeridium* Staplin, Jansonius and Pocock, 1965

Type species: *Gorgonisphaeridium winslowiae* Staplin, Jansonius and Pocock, 1965 [OD].

Gorgonisphaeridium inflatum Wicander and Wood, 1981
Plate 2, Figs. 16, 17

cf. 1954 *Micrhystridium sericum* Deunff, p. 1065, fig. 16 (*nom. nud.*).

cf. 1955 *Micrhystridium sericum* Deunff, p. 143, fig. 16 (*nom. nud.*).

cf. 1956 *Micrhystridium sericum* Deunff, p. 80, fig. 19 (*nom. nud.*).

cf. 1961 *Micrhystridium sericum* Deunff, p. 218.

1977 *Gorgonisphaeridium* sp. cf. *Micrhystridium sericum* Deunff, 1961; Playford, p. 24, pl. 9, figs. 17-21.

1981 *Gorgonisphaeridium inflatum* Wicander and Wood, p. 41, pl. 10, figs. 3-5.

Remarks. *Gorgonisphaeridium inflatum* Wicander and Wood, 1981 was erected because the description of *Micrhystridium sericum* Deunff, 1961 was very brief, generalized and seemingly based on only one specimen (Playford 1977).

Occurrence. Samples HH1, HH2, HH7, HH8, HH13.

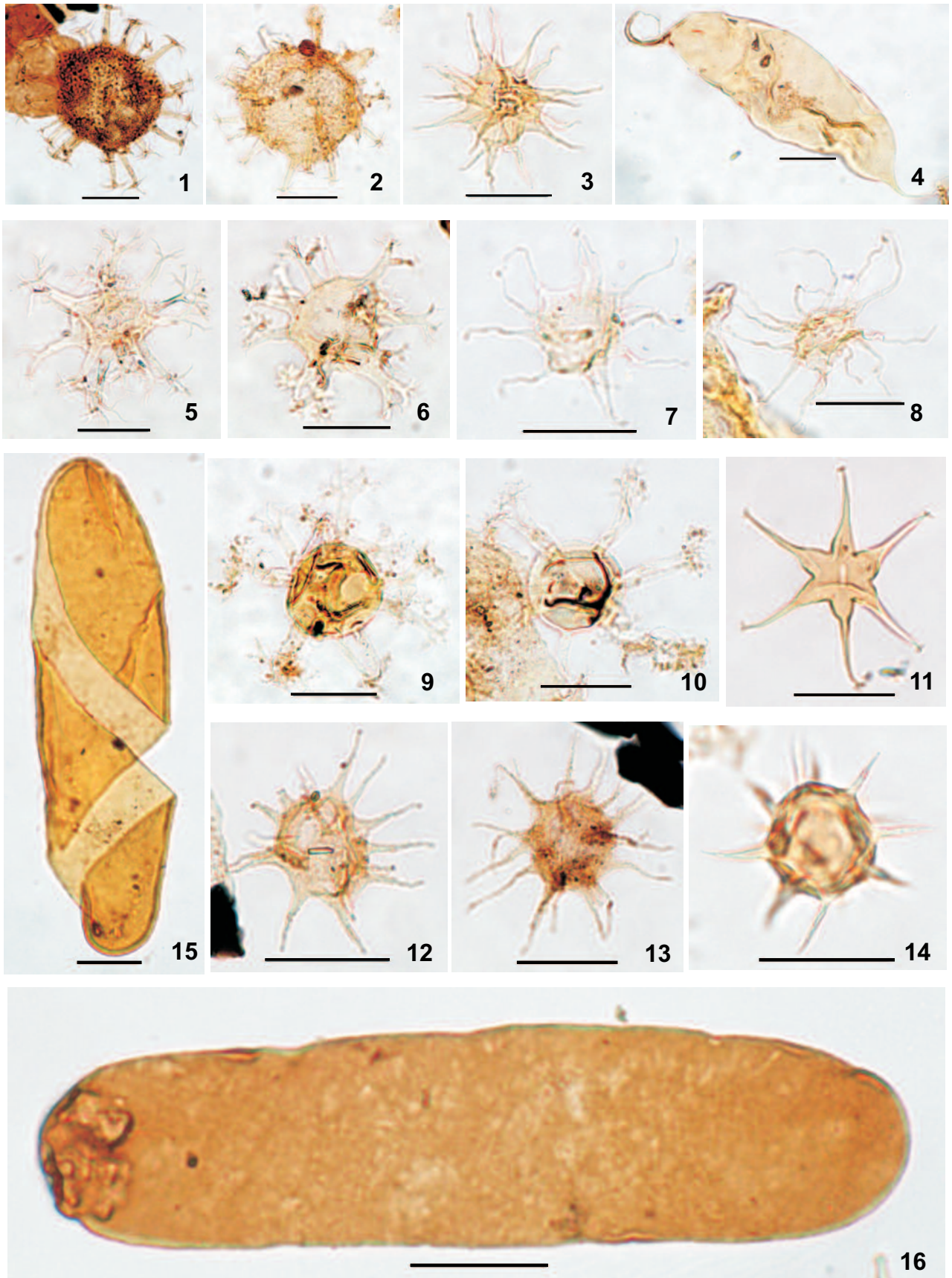
Previous records. The cf. designations of Deunff (1954, 1955, 1956, 1961) are from imprecisely dated Early, but probably Middle Devonian samples from Ontario, whereas *Gorgonisphaeridium* sp. cf. *Micrhystridium sericum* (Deunff) Playford, 1977 is from the late Eifelian, Ontario (Playford 1977), and *G. inflatum* Wicander and Wood, 1981 occurs in the Givetian/Middle Devonian, Ohio (Wicander and Wood 1981; Wicander and Wright 1983).

Genus *Hapsidopalla* Playford, 1977 emend. Wicander and Wood, 1981

Type species: *Hapsidopalla sannemannii* (Deunff, 1957) Playford, 1977 [OD].

Hapsidopalla chela Wicander and Wood, 1981
Plate 3, Figs. 1, 2

Plate 3 (lámina 3). Acritarch photomicrographs. 1, 2, *Hapsidopalla chela* Wicander and Wood, 1981. 3, *Micrhystridium stellatum* Deflandre, 1942 ex Deflandre, 1945. 4, *Leiofusa pyrena* Wicander and Wood, 1981. 5, *Multiplicisphaeridium ramusculosum* (Deflandre, 1945) Lister, 1970. 6, *Multiplicisphaeridium* sp. A. 7, 8, *Micrhystridium* sp. A. 9, 10, *Oppilatala sparsa* Wicander and Wood, 1981. 11, *Palacanthus ledanoisii* (Deunff, 1957) emend. Playford, 1977. 12, 13, *Uncinisphaera acantha* Wicander and Wood, 1981. 14, *Solisphaeridium* sp. A. 15, 16, *Navifusa bacilla* (Deunff, 1955) Playford, 1977. Scale bars = 20 µm.



1981 *Hapsidopalla chela* Wicander and Wood, p. 46, pl. 10, fig. 8, pl. 11, figs. 1, 2.

Comparison. *Hapsidopalla chela* Wicander and Wood, 1981 differs from *H. exornata* (Deunff, 1967) Playford, 1977 and *H. sannemannii* (Deunff, 1957) Playford, 1977 in having typically more and longer distal spinose projections, and a finer vesicle rosette-like sculpture.

Occurrence. Samples HH1, HH2, HH4, HH6-HH10, HH12, HH13.

Previous records. This distinctive species has previously been reported from the Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985), and Middle Devonian, Ohio (Wicander and Wright 1983).

Genus *Leiofusa* Eisenack, 1938 emend. Eisenack, 1965, emend. Combaz, Lange and Pansert, 1967

Type species: *Leiofusa fusiformis* Eisenack (1934) ex Eisenack, 1938 [OD].

Leiofusa pyrena Wicander and Wood, 1981
Plate 3, Fig. 4

1981 *Leiofusa pyrena* Wicander and Wood, p. 45, pl. 12, figs. 2-5.

Occurrence. Samples HH1, HH2, HH4, HH6, HH9, HH12, HH13.

Remarks. Ottone (1996) considered that the specimen illustrated by Barreda (1986) as *Leiofusa pyrena* Wicander and Wood, 1981, should be referred simply to *Leiofusa* sp. (Ottone 1996, p. 126, 128; plate 7, figs. 7, 8). However, we disagree and note that Ottone (1996) included *Leiofusa pyrena* in his synonymy for *Leiofusa* sp.

Previous records. *Leiofusa pyrena* Wicander and Wood, 1981 has been recorded previously from the Givetian, Ohio (Wicander and Wood 1981), and Givetian-Frasnian boundary, Argentina (Barreda 1986).

Genus *Micrhystridium* Deflandre, 1937

Type species: *Micrhystridium inconspicuum* Deflandre, 1937 [OD].

Micrhystridium stellatum Deflandre, 1942 ex Deflandre, 1945
Plate 3, Fig. 3

1942 *Micrhystridium stellatum* Deflandre, p. 476, figs. 7, 8 (*nom. nud.*).

1945 *Micrhystridium stellatum* Deflandre, p. 65, pl. 3, figs. 16-19.

Occurrence. Samples HH1-HH5, HH7-HH14.

Previous records. *Micrhystridium stellatum* Deflandre, 1942 ex Deflandre, 1945, cosmopolitan in distribution, has a stratigraphic range of Ordovician-Mesozoic.

Micrhystridium sp. A Wicander and Wood, 1981
Plate 3, Figs. 7, 8

1981 *Micrhystridium* sp. A Wicander and Wood, p. 49, pl. 13, fig. 4.

Remarks. Our specimens accord with Wicander and Wood's (1981) description of their *Micrhystridium* sp. A, and we follow them in leaving it in open nomenclature.

Occurrence. Samples HH1, HH2, HH4, HH7-HH10, HH12.

Previous records. Previously reported only from the Middle Devonian, Ohio (Wicander and Wood 1981; Wicander and Wright 1983).

Genus *Multiplicisphaeridium* Staplin, 1961 emend. Staplin, Jansonius and Pocock, 1965

Type species: *Multiplicisphaeridium ramispinosum* Staplin, 1961 [OD].

Multiplicisphaeridium ramusculosum (Deflandre, 1945) Lister, 1970
Plate 3, Fig. 5

1942 *Hystrichosphaeridium ramusculosum* Deflandre, p. 475, figs. 2-6 (*nom. nud.*).

1945 *Hystrichosphaeridium ramusculosum* Deflandre, p. 63, pl. 1, figs. 8-16, text-figs. 38, 39.

1961 *Multiplicisphaeridium ramispinosum* Staplin, p. 411, pl. 48, fig. 24, text-fig. 9g-h.

1970 *Multiplicisphaeridium ramusculosum* (Deflandre, 1945) Lister, pp. 92-93, pl. 11, figs. 8, 11-14, text-fig. 25a.

1974 *Multiplicisphaeridium anastomosis* Wicander, p. 29, pl. 14, figs. 7-9.

Occurrence. Samples HH1-HH14.

Previous records. *Multiplicisphaeridium ramusculosum* (Deflandre, 1945) Lister, 1970 is a cosmopolitan species with a stratigraphic range of Late Ordovician through Late Devonian.

Multiplicisphaeridium sp. A
Plate 3, Fig. 6

Description. Vesicle originally spherical, circular to subcircular in outline, 19–21 µm in diameter; eilyma ca 0.5 µm thick, surface psilate; 11–12 distinct, hollow, subcylindrical, psilate processes, opening into vesicle interior; proximal contacts slightly curved, thence near-cylindrical to point of furcation (ca 50–60% of distance from base); each bifurcant splitting to third, occasionally fourth order; distal tips sharply pointed, processes 2.4–4 µm wide basally, 11–16 µm long. No exocystment structure observed.

Comparison and remarks. *Multiplicisphaeridium* sp. A superficially resembles *M. ramusculosum*, but differs in having more numerous and commonly longer processes that initially bifurcate ca 50–60% from their base, and typically have shorter distal tips. The limited number of well-preserved specimens necessitates informal species designation.

Occurrence. Samples HH2-HH5, HH7-10, HH12, HH13.

Genus *Navifusa* Combaz, Lange and Pansart, 1967

Type species: *Navifusa navis* (Eisenack, 1938)
Eisenack, 1976 [OD].

Navifusa bacilla (Deunff, 1955) Playford, 1977
Plate 3, Figs. 15, 16

1955 *Leiofusa bacillum* Deunff, p. 148, pl. 4, fig. 2.

1977 *Navifusa bacillum* (Deunff, 1955) Playford, pp. 29-30, pl. 12, figs. 1-9.

For a complete synonymy and taxonomic discussion, see Fatka and Brocke (2008, pp. 117-118).

Occurrence. Samples HH1-HH14.

Previous records. *Navifusa bacilla* (Deunff, 1955) Playford, 1977 is a cosmopolitan Devonian

(Emsian–Famennian) species (Wicander and Wood 1981; Le Hérissé *et al.* 2000).

Genus *Oppilatala* Loeblich and Wicander, 1976

Type species: *Oppilatala vulgaris* Loeblich and Wicander, 1976 [OD].

Oppilatala sparsa Wicander and Wood, 1981
Plate 3, Figs. 9, 10

1981 *Oppilatala sparsa* Wicander and Wood, p. 54, pl. 14, figs. 2-4.

2008 *Oppilatala* sp. cf. *O. sparsa* Wicander and Wood; Zhu Huaicheng, Wicander and Marshall, p. 148, pl. 4, fig. 4.

Occurrence. Samples HH1-4, HH7-12.

Previous records. *Oppilatala sparsa* Wicander and Wood, 1981 has previously been reported from the Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); late Givetian, Iowa (Wicander and Wood 1997); and Eifelian, China (Zhu Huaicheng *et al.* 2008, cf. designation).

Genus *Ozotobrachion* Loeblich and Drugg, 1968

Type species: *Ozotobrachion palidodigitatus* (Cramer, 1967) Playford, 1977 [OD; as *O. dactylos* Loeblich and Drugg, 1968 (p. 130) = junior synonym of *O. palidodigitatus* vide Playford (1977, p. 31)].

Ozotobrachion furcillatus (Deunff, 1955) Playford,
1977
Plate 4, Fig. 1

1955 *Veryhachium furcillatum* Deunff, p. 146, fig. 18.

1966a *Veryhachium vipereum* Deunff, pp. 80-81, pl. 6, figs. 69, 70, pl. 10, fig. 78.

1968 *Ozotobrachion dicros* Loeblich and Drugg, p. 132, pl. 6, figs. 1-7.

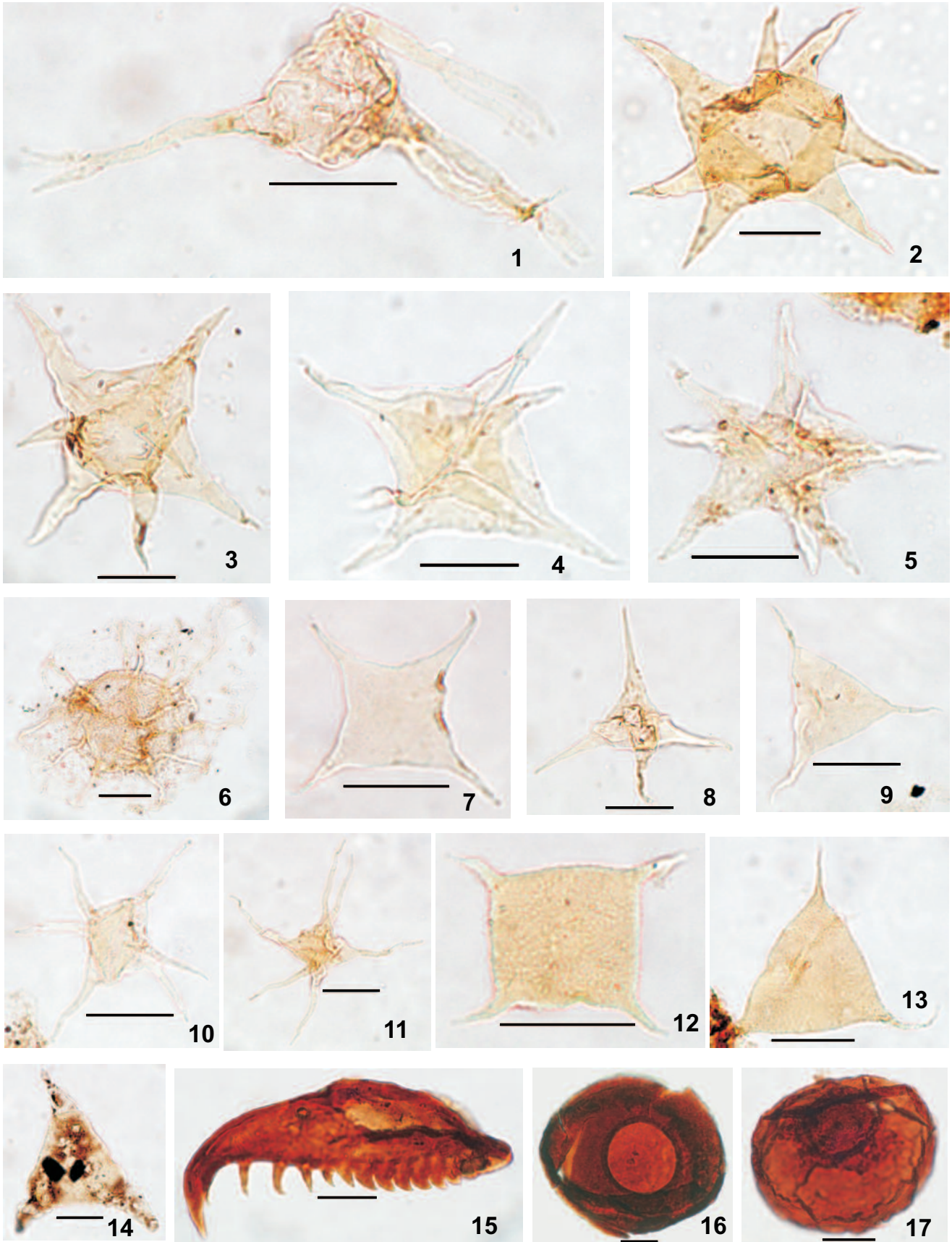
?1971 *Baltisphaeridium dicros* Cramer, p. 170, pl. 13, fig. 189, fig. 52k.

1973 *Multiplicisphaeridium dicros* (Loeblich and Drugg, 1968); Eisenack, Cramer and Díez, pp. 605-606.

1973 *Multiplicisphaeridium furcillatum* (Deunff, 1955) Eisenack, Cramer and Díez, p. 649.

1975 *Ozotobrachion?* sp. Pöthe de Baldis, p. 512, pl. 3, fig. 4.

1977 *Ozotobrachion furcillatus* (Deunff, 1955) Playford, p. 31, pl. 13, figs. 1-9, pl. 14, figs. 13-16.



Occurrence. Samples HH1, HH4, HH5, HH7-HH9, HH12.

Comparison. See discussion in Playford (1977, p. 31) for distinction of present specimens from *O. palidodigitatus*.

Previous records. *Ozotobrachion furcillatus* (Deunff, 1955) Playford, 1977 has been recorded from the Middle Devonian, Ontario (Deunff 1955, 1966a); late Pragian-early Eifelian, Ontario (Playford 1977); Ludlovian, Florida (Cramer 1971; Cramer and Díez 1972); late Lochkovian, Oklahoma (Loeblich and Drugg 1968; Loeblich and Wicander 1976); Givetian, Ohio (Wicander and Wood 1981); late Givetian, Iowa (Wicander and Wood 1997); Middle Devonian, Ohio (Wicander and Wright 1983); Wenlockian, Argentina (Pöthe de Baldis 1975); Ludlovian, northwest Spain (Cramer 1971; Cramer and Díez 1972); and Lochkovian, Algerian Sahara (Jardiné *et al.* 1974).

Genus *Palacanthus* Wicander, 1974

Type species: *Palacanthus acutus* Wicander, 1974 [OD].

Palacanthus ledanoisii (Deunff, 1957) emend.
Playford, 1977
Plate 3, Fig. 11

1957 *Veryhachium le danoisi* Deunff, p. 9, fig. 9.

1962b *Veryhachium stelligerum auct. non* Deunff, 1957; Stockmans and Willièrè, p. 85, pl. 1, fig. 8, text-fig. 10.

1966a *Veryhachium* sp. cf. *V. stelligerum* Stockmans and Willièrè, 1962b; Deunff, p. 78 (*pars*), pl. 3, figs. 35, 38, 39 (only).

1966b *Veryhachium* sp. cf. *V. le danoisi* Deunff; Deunff, p. 23, fig. 7.

1974 *Estiastra pentagonalis* Pöthe de Baldis, p. 71, pl. 2, fig. 5.

1977 *Palacanthus ledanoisii* (Deunff, 1957) Playford, p. 32, pl. 14, figs. 1-10.

1988 *Palacanthus* sp. cf. *P. ledanoisii* (Deunff, 1957)

Playford; Lu Li-chang and Wicander, p. 126, pl. 2, fig. 8.

Occurrence. HH1-HH5, HH7-HH13.

Previous records. *Palacanthus ledanoisii* (Deunff, 1957) Playford, 1977 has been recorded from the Middle Devonian, Ontario (Deunff 1957, 1966a); Emsian-middle Givetian, Ontario (Playford 1977); Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); late Givetian, Iowa (Wicander and Wood 1997); Middle Devonian, Ohio and Kentucky (Wicander and Wright 1983; Huysken *et al.* 1992); Middle Devonian, Paraguay (Pöthe de Baldis 1974); Givetian-Frasnian boundary, Argentina (Barreda 1986; Ottone 1996); Frasnian-early Famennian, Belgium (Stockmans and Willièrè 1962b; Martin 1985); Famennian, Portugal (Cunha and Oliveira 1989; Pereira *et al.* 2008); Devonian, Brittany, France (Deunff 1966a); undifferentiated Devonian, Tunisia (Deunff 1966b); late Frasnian-Famennian, Xinjiang, China (Lu Li-chang and Wicander 1988); Tournaisian/Tn1b, Xizang/Tibet (Gao Lianda 1986); and Frasnian, Western Australia (Playford and Dring 1981).

Genus *Polygonium* Vavrdová, 1966

Type species: *Polygonium gracilis* Vavrdová, 1966 [OD; M].

Polygonium sp. A
Plate 4, Figs. 2, 3

Description. Vesicle originally inflated, subcircular to subpolyhedral in outline, 30–32 µm in diameter; eilyma < 0.5 µm thick, psilate; 6–8 homomorphic psilate processes, 24–30 µm long, ± distinct from vesicle, freely communicating with vesicle interior; processes tapering from subcircular base, 6.4–12.8 µm in diameter, to simple, acuminate tip; proximal contacts curved. No method of excystment observed.

Remarks and comparison. We assign this form to

Plate 4 (lámina 4). Photomicrographs of acritarchs (1–14), scolecodont (15), and chitinozoan (16, 17). 1, *Ozotobrachion furcillatus* (Deunff, 1955) Playford, 1977. 2, 3, *Polygonium* sp. A. 4, *Stellinium comptum* Wicander and Loeblich, 1977. 5, *Stellinium micropolygonale* (Stockmans and Willièrè, 1960) Playford, 1977. 6, *Tunisphaeridium tentaculaferum* (Martin, 1967) Cramer, 1971. 7, *Veryhachium lairdii* (Deflandre, 1946) ex Deunff, 1959. 8, *Veryhachium europaeum* Stockmans and Willièrè, 1960. 9, *Veryhachium trispinosum* (Eisenack, 1938) Stockmans and Willièrè, 1962 "complex." 10, *Veryhachium pastoris* Deunff, 1966. 11, *Veryhachium polyaster* Staplin, 1961. 12, *Villosacapsula compta* Wicander and Wood, 1997. 13, *Villosacapsula rosendae* (Cramer, 1964) Loeblich and Tappan, 1976. 14, *Tyligmasoma alargada* (Cramer, 1964) Playford, 1977. 15, Scolecodont. 16, 17, *Hoegisphaera glabra* Staplin, 1961. Scale bars = 20 µm.

Polygonium Vavrdová, 1966 rather than to *Micrhystridium* Deflandre, 1937, partly because our specimens are larger than those that characterize *Micrhystridium* (generally < 20 µm) and, moreover, they display a somewhat distinct vesicle. Sarjeant and Stancliffe (1994, p. 42; 1996, p. 357) emended *Polygonium* and relegated a number of species to synonymy. However, Vavrdová's (1966, p. 413) diagnosis is followed here because the vesicle is polygonal in outline, with few (~15) relatively long, broad-based processes disposed regularly around the vesicle.

Polygonium sp. A differs from other species of the genus (e.g. *P. gracilis* Vavrdová, 1966; *P. barredae* Ottone, 1996) in having a mostly larger vesicle, generally fewer processes and wider proximal contacts with the vesicle. However, given the insufficiency of specimens, they are herein designated only informally.

Occurrence. Samples HH3, HH6-HH9, HH12.

Genus *Solisphaeridium* Staplin, Jansonius and Pocock, 1965 emend. Sarjeant, 1968

Type species: *Solisphaeridium stimuliferum* (Deflandre, 1968) Staplin, Jansonius and Pocock, 1965 [OD].

Remarks. On balance, we incline toward retaining *Solisphaeridium* Staplin, Jansonius and Pocock, 1965 emend. Sarjeant, 1968 as a genus distinct from *Micrhystridium*, notwithstanding the arguments expressed by Sarjeant and Stancliffe (1994, p. 12; 2000, p. 164) cf. Moczydlowska (1998, p. 44).

Solisphaeridium sp. A
Plate 3, Fig. 14

Description. Vesicle originally inflated, roundly polygonal to circular in outline, 14–16 µm in diameter; eilyma < 1 µm thick, psilate; processes numerous (15), clearly distinct from vesicle, psilate, ± rigid, opening proximally into vesicle interior; processes discrete, homomorphic, spine-like in form, regularly tapering from angular proximal contacts (1.6–2.4 µm in basal diameter), to simple acuminate tips; process length 8–11 µm. No excystment structure observed.

Remarks. Although resembling several described species, e.g. *Solisphaeridium spinoglobosum* (Staplin, 1961) Wicander, 1974, numerical insufficiency of the

present specimens, and their somewhat nondescript morphology, preclude formal designation at the specific level.

Occurrence. Samples HH4, HH7, HH8, HH12.

Genus *Stellinium* Jardiné, Combaz, Magloire, Peniguel and Vachey, 1972

Type species: *Stellinium micropolygonale* (Stockmans and Willièrè, 1960) Playford, 1977 [OD, as *Stellinium octoaster* (Staplin, 1961) Jardiné, Combaz, Magloire, Peniguel and Vachey, 1972 by Jardiné *et al.* (1972, p. 298)].

Stellinium comptum Wicander and Loeblich, 1977
Plate 4, Fig. 4

1977 *Stellinium comptum* Wicander and Loeblich, pp. 151-152, pl. 9, figs. 1-6.

Occurrence. Samples HH1-HH3, HH7-HH10, HH12, HH13.

Previous records. *Stellinium comptum* Wicander and Loeblich, 1977 is a widely occurring species, with reports from the late Famennian–?Tournaisian, Saskatchewan (Playford and McGregor 1993); Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); late Givetian, Iowa (Wicander and Wood 1997); late Frasnian, Iowa (Wicander and Playford 1985); late Famennian, Ohio (Molyneux *et al.* 1984); Late Devonian, Indiana (Wicander and Loeblich 1977); late Famennian, Illinois (Wicander and Playford 2013); late Givetian–early Frasnian, Argentina (Barreda 1986; Ottone 1996); late Frasnian–early Famennian, Belgium (Martin 1981, 1985); late Givetian–early Frasnian, Boulonnais, France (Deunff 1981; Le Hérissé and Deunff 1988); Famennian, Portugal (Cunha and Oliveira 1989; Pereira *et al.* 2008); late Famennian–Mississippian, South Wales (McNestry 1988); Frasnian, northern Iran (Ghavidel-syooki 1995); Frasnian, east-central Iran (Hashemi and Playford 1998); and late Frasnian–Famennian, Xinjiang, China (Lu Li-chang and Wicander 1988).

Stellinium micropolygonale (Stockmans and Willièrè, 1960) Playford, 1977
Plate 4, Fig. 5

1960 *Micrhystridium micropolygonale* Stockmans and Willièrè, p. 4, pl. 1, fig. 12.

1961 *Veryhachium octoaster* Staplin, pp. 413-414, pl. 49, figs. 3, 4.

1962a *Veryhachium micropolygonale* (Stockmans and Willièrè, 1960) Stockmans and Willièrè, pp. 52-53, pl. 2, fig. 19, text-figs. 9a, b.

1962b *Veryhachium* sp. aff. *Veryhachium octoaster* Staplin; Stockmans and Willièrè, p. 85, pl. 1, fig. 7.

1962b *Veryhachium vandenbergheni* Stockmans and Willièrè, pp. 86-87, pl. 2, figs. 11, 13, text-figs. 5a, b.

1972 *Stellinium octoaster* (Staplin, 1961) Jardiné, Combaz, Magloire, Peniguel and Vachey, pp. 298-299, pl. 2, figs. 1, 2.

1972 *Stellinium octoaster* (Staplin, 1961) var. *elongatum* Jardiné, Combaz, Magloire, Peniguel and Vachey, p. 299, pl. 2, figs. 3-5.

1975 *Polyedryxium micropolygonale* (Stockmans and Willièrè, 1960) Jux, p. 128, pl. 6, figs. 3a-c.

1977 *Stellinium micropolygonale* (Stockmans and Willièrè, 1960) Playford, pp. 36-37, pl. 18, figs. 7-9.

1983 *Stellinium octoaster* (Staplin, 1961) Jardiné, Combaz, Magloire, Peniguel and Vachey; Wicander and Wright, p. 11, fig. 5 (15).

For additional synonymy, see Wicander and Wood (1981, pp. 57-58).

Occurrence. Samples HH1-HH5, HH7-HH14.

Previous records. *Stellinium micropolygonale* (Stockmans and Willièrè, 1960) Playford, 1977 is a commonly occurring, globally distributed species with a stratigraphic range of Pragian–Famennian, and possibly lowermost Mississippian (Wicander and Wood 1981; Playford and McGregor 1993; González *et al.* 2005; Wicander and Playford 2013).

Genus *Tunisphaeridium* Deunff and Evitt, 1968

Type species: *Tunisphaeridium concentricum* Deunff and Evitt, 1968 [OD].

Tunisphaeridium tentaculaferum (Martin, 1967)
Cramer, 1971
Plate 4, Fig. 6

1961 'A Silurian hystrichosphere' Evitt, p. 396, pl. 4, fig. 11.

1967 *Baltisphaeridium tentaculaferum* Martin, p. 312, pl. 1, fig. 23, text-fig. 3.

1968 *Tunisphaeridium venosum* Deunff (1966?) Cramer, p. 66, pl. 1, fig. 5.

1968 *Tunisphaeridium concentricum* Deunff and Evitt, p. 3, pl. 1, figs. 1-12.

1971 *Tunisphaeridium tentaculaferum* (Martin, 1967) Cramer, pp. 192-193, pl. 6, figs. 105, 106, 108, 109.

For expanded synonymy, see Wicander and Wood (1981, pp. 59-60).

Occurrence. Samples HH1-HH14.

Previous records. *Tunisphaeridium tentaculaferum* (Martin, 1967) Cramer, 1971 has a predominately northern hemisphere, Silurian–Late Devonian distribution. Previous reports are as follows: Silurian, Ontario (Thusu 1973a); late Pragian–middle Givetian, Ontario (Playford 1977); Givetian, Ontario (Legault 1973); Middle Silurian, New York (Evitt 1961; Deunff and Evitt 1968; Cramer 1968; Thusu 1973b; Thusu and Zenger 1974); Givetian, Ohio and Kentucky (Wicander and Wood 1981; Wood and Clendening 1985); late Givetian, Iowa (Wicander and Wood 1997); Middle Devonian, Ohio (Wicander and Wright 1983); Wenlockian–Ludlovian?, Argentina (Pöthe de Baldis 1975); early Llandoveryan–late Ludlovian, Gotland, Sweden (Le Hérisse 1989); Silurian, Belgium (Martin 1967); ?Silurian, France (Moreau-Benoit 1974); late Ludlovian, northwest Spain (Cramer 1967, 1971); late Llandoveryan–Ludlovian, Turkey (Erkmen and Bozdogan 1979); Givetian, western Libya (Moreau-Benoit 1984; Massa and Moreau-Benoit 1985); Wenlockian?–Ludlovian, Emsian?–Frasnian?, Algerian Sahara (Jardiné *et al.* 1974); and Emsian–Frasnian, Ghana (Anan-Yorke 1974).

Genus *Tyligmasoma* Playford, 1977

Type species: *Tyligmasoma alargadum* (Cramer, 1964) Playford, 1977 [OD].

Tyligmasoma alargada (Cramer, 1964) Playford, 1977
Plate 4, Fig. 14

1964 *Triangulina alargada* Cramer, pp. 334-335, pl. 6, figs. 1, 4, text-fig. 39.

1973 *Triangulina* sp. cf. *T. alargada* Cramer; Legault, p. 58, pl. 11, figs. 11, 12.

1977 *Tyligmasoma alargadum* (Cramer, 1964) Playford, p. 38, pl. 19, figs. 1-6.

For additional synonymy, see Wicander and Wood (1981, p. 61).

Remarks. Although specifically identifiable specimens of *Tyligmasoma alargada* (Cramer, 1964) Playford, 1977 from the Hungry Hollow locality are not well preserved (see Plate 4, Fig. 14), they are sufficiently distinct for confident attribution.

Occurrence. Samples HH1, HH7, HH8, HH12.

Previous records. *Tyligmasoma alargada* (Cramer, 1964) Playford, 1977 has a wide palaeogeographic distribution. Occurrences and stratigraphic ranges are as follows: Givetian, Ontario (Legault 1973); Emsian–Eifelian, Ontario (Playford 1977); Givetian, Ohio (Wicander and Wood 1981); late Givetian, Iowa (Wicander and Wood 1997); Middle Devonian, Ohio (Wicander and Wright 1983); Pragian, northern Bolivia (Vavrdová *et al.* 1996); Early Devonian (= Zones R and S), Maranhão Basin, Brazil (Brito 1967a, b, c, 1969); Emsian, Uruguay (Pöthe de Baldis 1977); Silurian, France (Moreau-Benoit 1974); Lochkovian, Finistere, France (Deunff 1980); Ludlovian, Pragian–Emsian (in part) northwest Spain (Cramer 1964; Cramer and Díez 1976); late Famennian–Mississippian, South Wales (McNestry 1988); ?Late Devonian, Siberia (Sheshegova 1971); Givetian, western Libya (Moreau-Benoit 1984); Emsian, Algerian Sahara (Jardiné 1972; Jardiné and Yapaudjian 1968; Jardiné *et al.* 1972, 1974); Emsian–Frasnian, Ghana (Anan-Yorke 1974); and Eifelian, China (Zhu Huaicheng *et al.* 2008).

Genus *Uncinisphaera* Wicander, 1974

Type species: *Uncinisphaera lappa* Wicander, 1974 [OD; M].

Uncinisphaera acantha Wicander and Wood, 1981 Plate 3, Figs. 12, 13

1981 *Uncinisphaera acantha* Wicander and Wood, p. 63, pl. 16, figs. 5, 6.

Occurrence. Sample HH1, HH7, HH8.

Previous records. *Uncinisphaera acantha* Wicander and Wood, 1981 has previously been reported only from the Givetian, Ohio (Wicander and Wood 1981).

Genus *Veryhachium* Deunff, 1959 ex Downie, 1959

Type species: *Veryhachium trisulcum* (Deunff, 1954) Deunff 1959 [SD; Downie 1959, p. 62].

Veryhachium europaeum Stockmans and Willièrè, 1960 Plate 4, Fig. 8

1960 *Veryhachium europaeum* Stockmans and Willièrè, p. 3, pl. 2, fig. 25.

1962a *Veryhachium legrandi* Stockmans and Willièrè, p. 54, pl. 1, figs. 3, 4, text-figs. 11a, b.

See Wicander and Wood (1981, pp. 64-65) for an extensive synonymy.

Occurrence. Samples HH1-HH13.

Previous records. *Veryhachium europaeum* Stockmans and Willièrè, 1960 is a cosmopolitan species with a stratigraphic range of Silurian–Famennian (Lu Li-chang and Wicander, 1988).

Veryhachium lairdii (Deflandre, 1946) ex Deunff, 1959 Plate 4, Fig. 7

1946 *Hystrichosphaeridium lairdi* Deflandre, fichier 1112, 2 figs. (*nom. nud.*).

1959 *Veryhachium lairdi* (Deflandre, 1946) Deunff, p. 28, pl. 8, figs. 75-79.

1970 *Veryhachium lairdii* (Deflandre, 1946) ex Deunff; Loeblich, pp. 741-742.

For other synonymy, see Wicander and Wood (1981, pp. 65-66).

Remarks. We agree with Loeblich (1970, pp. 741-742) concerning the history of the naming and subsequent taxonomy of *Veryhachium lairdii* (Deflandre, 1946) ex Deunff, 1959.

Occurrence. Samples HH1-HH4, HH6-HH13.

Previous records. *Veryhachium lairdii* (Deflandre, 1946) ex Deunff, 1959, a predominantly northern hemisphere species, ranges from Ordovician through Devonian (Playford, 1977; Wicander and Wood 1981).

Veryhachium pastoris Deunff, 1966b Plate 4, Fig. 10

1966b *Veryhachium pastoris* Deunff, p. 22, fig. 4.

1997 *Veryhachium pastore* Deunff; Wicander and Wood, p. 137, pl. 3, fig. 12.

Occurrence. Samples HH2, HH4, HH7-HH9, HH12, HH13.

Previous records. *Veryhachium pastoris* Deunff, 1966 has been recorded from the Givetian, Ohio (Wicander and Wood 1981); late Givetian, Iowa (Wicander and Wood 1997); Middle Devonian, Ohio (Wicander and Wright 1983); undifferentiated Devonian, Tunisia (Deunff 1966b); Givetian, western Libya (Moreau-Benoit 1984); and Emsian–Frasnian, Ghana (Anan-Yorke 1974).

Veryhachium polyaster Staplin, 1961
Plate 4, Fig. 11

1961 *Veryhachium polyaster* Staplin, p. 413, pl. 49, fig. 20.
1961 *Veryhachium polyaster* var. *hexaster* Staplin, p. 413, pl. 49, fig. 19.

Occurrence. Samples HH1-HH10, HH12, HH13.

Previous records. *Veryhachium polyaster* Staplin, 1961 is a cosmopolitan species with a stratigraphic range of Pragian–Famennian (Playford and McGregor 1993; Ottone 1996). Heal and Clayton's (2008) unillustrated report is from the Lower Mississippian Hannibal Shale, Illinois.

Veryhachium trispinosum (Eisenack, 1938)
Stockmans and Willièrè, 1962a "complex"
Plate 4, Fig. 9

1938 *Hystriosphæridium trispinosum* Eisenack, pp. 14, 16, text-figs. 2, 3.
1962a *Veryhachium trispinosum* (Eisenack, 1938) Stockmans and Willièrè, pp. 46-47, pl. 2, figs. 25, 26, text-fig. 1.

See Wicander and Wood (1981, pp. 67-70 and Servais *et al.* (2007, pp. 191-203) for an extensive synonymy and discussion of this morpho-taxonomic "complex."

Occurrence. Samples HH1-HH13.

Previous records. The *Veryhachium trispinosum* (Eisenack, 1938) Stockmans and Willièrè, 1962a "complex" is cosmopolitan and ranges from Ordovician through Permian (Wicander and Wood 1981).

Genus *Villosacapsula* Loeblich and Tappan, 1976

Type species: *Villosacapsula setosapelllicula* (Loeblich, 1970) Loeblich and Tappan, 1976 [OD].

Villosacapsula compta Wicander and Wood, 1997
Plate 4, Fig. 12

1997 *Villosacapsula compta* Wicander and Wood, p. 147, pl. III, figs. 8-11.

Occurrence. Samples HH2-4, HH6-HH10, HH12, HH13.

Previous records. *Villosacapsula compta* Wicander and Wood, 1997 has previously been reported exclusively from the late Givetian, Iowa (Wicander and Wood 1997).

Villosacapsula rosendae (Cramer, 1964) Loeblich and Tappan, 1976
Plate 4, Fig. 13

1963 *Veryhachium rosendae* Cramer, pp. 215-216, pl. 1, figs. 4-6 (*nom. nud.*).

1964 *Veryhachium rosendae* Cramer, p. 313, pl. 13, figs. 6-9.

1976 *Villosacapsula rosendae* (Cramer, 1964) Loeblich and Tappan, p. 307.

Occurrence. Samples HH3, HH4, HH7, HH8, HH10-HH12.

Previous records. *Villosacapsula rosendae* (Cramer, 1964) Loeblich and Tappan, 1976 is known from the Givetian, Ohio (Wicander and Wood 1981); Devonian, Bolivia (Kimyai 1983); Givetian–Frasnian, northern Bolivia (Vavrdová *et al.* 1996); Ludlovian–Emsian (in part), northwest Spain (Cramer 1963, 1964, 1967, 1971); and Frasnian, east-central Iran (Hashemi and Playford 1998).

Chitinozoa

Order Operculatifera Eisenack, 1931
Family Desmochitinidae Eisenack, 1931, emend.
Paris, 1981
Subfamily Desmochitininae Paris, 1981

Genus *Hoegisphaera* Staplin, 1961, emend. Paris,
Grahm, Nestor and Lakova, 1999

Type species: *Hoegisphaera glabra* Staplin, 1961
[OD].

Hoegisphaera glabra Staplin, 1961
Plate 4, Figs. 16, 17

1961 *Hoegisphaera glabra* Staplin, pp. 419-420, pl. 50, figs. 5-7.

1964 *Hoegisphaera glabra* Staplin; Jansonius, p. 912, pl. 2, fig. 18 (holotype re-illustrated).

Occurrence. Samples HH1-HH14.

Previous records. *Hoegisphaera glabra* Staplin, 1961 is a commonly occurring and widespread species with a stratigraphic range of Middle–Late Devonian (Staplin 1961; Urban 1972; Legault 1973; Wood 1974; Wood and Clendening 1985).

Group	HAMILTON													
	Formation	ARKONA			HUNGRY HOLLOW			WIDDER						
Sample number	HH1	HH2	HH3	HH4	HH5	HH6	HH7	HH8	HH9	HH10	HH11	HH12	HH13	HH14
Prasinophyte species														
<i>Arkonites bilixus</i>		R		R	R				R					
<i>Cymatiosphaera canadense</i>			R	R			R	R	C	R		R	R	
<i>Cymatiosphaera cornifera</i>	R			R								R		
<i>Cymatiosphaera winderi</i>	R	C		R		R	R	R	R			R	R	
<i>Dictyotidium variatum</i>		R		R										
<i>Duvernaysphaera angelae</i>	A	VA	C	C	R	R	C	C	C	VA		VA	C	
<i>Duvernaysphaera tenuicingulata</i>	C	A	VA	VA	R	C	C	C	A	VA	R	VA	A	R
<i>Leiosphaeridia</i> sp.	R	VA	C	C	R	R	R	R	R	VA	R	VA	VA	VA
<i>Muraticavea munifica</i>	R	R	R	R	R	R	R	R	C		R	R	C	
<i>Polyedryxium ambitum</i>		R				R	R	R	R				R	
<i>Polyedryxium decorum</i>	C													
<i>Polyedryxium embudum</i>		R					R	R	R	R	R		C	
<i>Polyedryxium fragosulum</i>	R	R		R			R	R	R				R	
<i>Polyedryxium pharaone</i>	C	VA	C	VA	R	R	C	A	VA	R	R	C	VA	R
<i>Staplinium cuboides</i>	R	R		R	R	R	R	R	C			R	R	
<i>Tasmanites</i> sp.	R	VA	C	VA	C	R	R	R	R	VA	R	A	VA	C
Acritarch species														
<i>Ammonidium</i> sp. A	R	R	R	C	R	R	R	R	C	R		R	C	
<i>Baltisphaeridium distentum</i>	R	C	R	C	R	R	C	C	A	C	R	C	R	
<i>Daillydium pentaster</i>	R	R		A		R	R	R		R	R	R	R	
<i>Diexallophasis simplex</i>	R					R							R	
<i>Eisenackidium appendiculum</i>	C	C	R	A		C			R			R	R	
<i>Estiastra rhytidia</i>	R								R				R	
<i>Exochoderma arca</i>	A	VA	R	A	R	C	C	C	C	A	C	R	R	
<i>Gorgonisphaeridium inflatum</i>	A	R					R	R				R		
<i>Hapsidopalla chela</i>	C	R		R		R	R	R	R	R		C	R	
<i>Leiofusa pyrena</i>	R	R		R					R			R	R	
<i>Micrhystridium stellatum</i>	R	C	R	C	R		C	C	A	C	R	A	R	R
<i>Micrhystridium</i> sp. A	R	R		R			R	R	R	R		R		
<i>Multiplicisphaeridium ramusculosum</i>	A	VA	VA	A	R	R	VA	VA	VA	C	R	VA	A	R
<i>Multiplicisphaeridium</i> sp. A		R	R	C	R		C	C	A	R		C	C	
<i>Navifusa bacilla</i>	VA	VA	C	VA	R	C	A	A	VA	A	A	A	A	R
<i>Oppilatala sparsa</i>	R	R	R	R			R	R	R	R	R	R		
<i>Ozotobranchion furcillatus</i>	R			R	R		R	R	R			R		
<i>Palacanthus ledanoisii</i>	R	C	R	VA	R		C	C	C	C	R	C	R	
<i>Polygonium</i> sp. A			R			R	R	R	C			R		
<i>Solisphaeridium</i> sp. A				R			R	R				R		
<i>Stellinium comptum</i>	C	R	R				R	R	C	R		C	C	
<i>Stellinium micropolygonale</i>	C	C	R	R	R		C	C	VA	R	R	C	C	R
<i>Tunispheridium tentaculaferum</i>	C	C	R	C	R	R	C	C	C	R	R	R	C	R
<i>Tyligmasoma alargada</i>	R						R	R				R		
<i>Uncinisphaera acantha</i>	C						R	R						
<i>Veryhachium europaeum</i>	C	A	R	C	R	R	C	C	VA	A	R	C	R	
<i>Veryhachium lairdii</i>	R	A	R	C		R	R	R	C	C	R	VA	R	
<i>Veryhachium pastoris</i>		R		C			R	R	R			C	R	
<i>Veryhachium polyaster</i>	R	VA	C	A	R	R	A	A	C	A		VA	R	
<i>Veryhachium trispinosum</i> "complex"	C	VA	C	VA	R	R	C	C	C	A	C	R	R	
<i>Villosacapsula compta</i>		R	R	R		R	C	C	R	R		C	R	
<i>Villosacapsula rosendae</i>			R	R			R	R		R	R	R		
Chitinozoan species														
<i>Hoegisphaera glabra</i>	R	VA	C	VA	R	R	R	R	R	A	C	A	A	R

Table 1. Distribution of microphytoplankton taxa within the sampled Arkona, Hungry Hollow and Widder formations at Hungry Hollow, Ontario, Canada. Relative abundance of taxa is based on counts from three > 50 µm and three 20–50 µm slides, or three > 20 µm slides (see Materials and methods section). VA (very abundant) = > 100 specimens; A (abundant) = 51–100 specimens; C (common) = 11–50 specimens and R (rare) = 10 or fewer specimens. The taxa are arranged alphabetically within the prasinophytes, acritarchs and chitinozoans.

Tabla 1. Distribución de los taxones de microfitorplácton a lo largo de las formaciones Arkona, Hungry Hollow y Widder, Ontario, Canadá. La abundancia relativa de taxones está basada en conteos de tres láminas con residuos >50 µm y tres con residuos de 20-50 µm, o tres con residuos >20 µm (ver la sección de materiales y métodos). VA (muy abundante) = > 100 especímenes; A (abundante) = 51-100 especímenes; C (común) = 11-50 especímenes y R (raro) = 10 o menos especímenes. Los taxones están ordenados alfabéticamente considerando cada una de las tres categorías estudiadas: prasinofitos, acritarcos y quitinozoos.

Composition of the palynoflora

The palynoflora of the Middle Devonian (Givetian) Arkona, Hungry Hollow and Widder formations consists of prasinophyte phycmata, acritarchs, chitinozoans, scolecodonts and some miospores. The organic-walled microphytoplankton component includes 16 prasinophyte species (two of which are designated informally) that are distributed among nine genera. Acritarchs comprise 27 identified species and five informally named species; these are allocated to 25 genera. One chitinozoan species is also described. In addition, other chitinozoans and a few miospores and scolecodonts are also present, but unnamed.

Excluding the single named chitinozoan taxon (Plate 4, Figs. 16, 17), acritarchs dominate the palynoflora at both generic and specific levels (83% and 67% respectively). With the exception of sample HH14, where diversity and abundance significantly decrease, the most common taxa occur regularly throughout the sampled section (Table 1).

Disregarding *Leiosphaeridia* sp. and *Tasmanites* sp., the five most abundant species are, in decreasing order: *Multiplicisphaeridium ramusculosum*, *Navifusa bacilla*, *Duvernaysphaera tenuicingulata*, *Polyedryxium pharaone* and *D. angelae*. The least abundant species, having only two–four occurrences throughout the section and a rare abundance level per sample are, in decreasing quantitative order: *Arkonites bilixus*, *Solisphaeridium* sp. A, *Tyligmasoma alargada*, *Cymatiosphaera cornifera*, *Diexallophasis simplex*, *Estiastra rhytidoa* and *Dictyotidium variatum*. The remaining taxa fluctuate in their occurrences through the section, ranging from rare to very abundant (Table 1).

Chitinozoans, scolecodonts and indifferently preserved miospores also occur in the Arkona/Hungry Hollow/Widder assemblage, although in much lesser proportions than the acritarchs and prasinophytes. Overall, the marine component of the palynoflora is predominant, with the terrestrial (miospore) contribution being very minor.

Palynostratigraphic correlations and age

The palynoflora retrieved from the Hungry Hollow locality is characterized by a diverse and abundant acritarch/prasinophyte assemblage (Table 1) including many cosmopolitan species, together with taxa restricted to North America or the northern hemisphere. Although no new species are described herein, several taxa that are left in open nomenclature are probably new species, but poor preservation and/or



Figure 4. Geographic occurrences of well-dated Middle Devonian organic-walled microphytoplankton assemblages in North America. Star symbol denotes Hungry Hollow collecting site in southwestern Ontario (Arkona, Hungry Hollow and Widder formations of present study); W.Va = West Virginia; Qué = Québec. Key to numbered locations (generalized) and data sources: 1, Eifelian–Givetian Kwataboahagan, Moose River, Murray Island and Williams Island formations, Moose River Basin, Ontario (Playford 1977); 2, Middle Devonian Hamilton Group, southwestern Ontario (Legault 1973); 3, Givetian Silica Formation, Ohio (Wicander and Wood 1981); 4, Middle Devonian Columbus and Delaware limestones, Ohio (Wicander and Wright 1983); 5, Givetian Boyle Dolomite, Kentucky (Wood and Clendening 1985); 6, Givetian Rapid Member of Cedar Valley Formation, Iowa (Wicander and Wood 1997).

Figura 4. Situación geográfica de los puntos en donde se han encontrado asociaciones microplanctónicas de pared orgánica en Norte América. La estrella indica la zona de toma de muestras de la localidad de Hungry Hollow en el suroeste de Ontario (Arkona, Hungry Hollow y Widder de este estudio); W.Va = Oeste de Virginia; Qué = Québec. Clave de numeración de las localidades mencionadas en el texto y fuente de datos: 1, Eiffeliense-Givetiense de Kwataboahagan, Río Moose, formaciones Murray Island y Williams Island, Cuenca del Río Moose, Ontario (Playford 1977); 2, Devónico Medio del Grupo Hamilton Group, suroeste de Ontario (Legault 1973); 3, Givetiense de Silica Shale, Ohio (Wicander and Wood 1981); 4, devónico Medio de los limestones de Columbus y Delaware, Ohio (Wicander and Wright 1983); 5, Givetiense de Boyle Dolomite, Kentucky (Wood and Clendening 1985); 6, Givetiense del Miembro Rapid de la Formación Cedar Valley, Iowa (Wicander and Wood 1997).

lack of sufficient specimens preclude their formal designation. As discussed below, the assemblage, as a whole, corroborates the Middle Devonian (Givetian)

age for the Arkona, Hungry Hollow and Widder formations that has hitherto been based on lithostratigraphy and their contained marine invertebrate fauna (e.g. Stumm *et al.* 1956; Driscoll *et al.* 1965; Winder and Stanford 1972; Landing and Brett 1987).

A close similarity is evident in terms of species shared among Middle Devonian organic-walled microphytoplankton assemblages within North America (Fig. 4), and to a lesser extent elsewhere. Detailed comparison of the Arkona/Hungry Hollow/Widder palynoflora with correspondingly abundant, diverse and well-preserved Middle Devonian acritarch/prasinophyte assemblages from Laurentia and other palaeocontinents is provided in a subsequent section.

As cited earlier, there have been 17 publications describing Middle Devonian acritarch/prasinophyte assemblages or occurrences within North America. However, only six papers are of interest here (Fig. 4). These six assemblages show a degree of similarity between 59–96% commonality with the palynoflora of the present study. As would be expected from the close geographic proximity, a high percentage (89%)

of taxa recorded herein are shared with the Hamilton Group from southwestern Ontario (Legault 1973). An even higher percentage (96%) of co-occurring species link the present assemblage with that of the Givetian Boyle Dolomite from Kentucky (Wood and Clendening 1985).

Based on the high number of common species among the six Middle Devonian acritarch/prasinophyte assemblages from North America, it is clear that the palynofloras represent a distinct palynostratigraphic entity, incorporating both short- and long-ranging species, thereby facilitating stratigraphic correlation within the Laurentian palaeocontinent. In addition, many of the organic-walled microphytoplankton taxa from the Hungry Hollow locality, including several with restricted stratigraphic ranges, are globally distributed, allowing for intercontinental correlation and recognition of open oceanic connections.

Four distinctive species, occurring only in Laurentia and restricted there to the Eifelian–Givetian (*Gorgonisphaeridium inflatum* and *Hapsidopalla chela*) and Givetian (*Uncinisphaera acantha* and *Villosacapsula compta*), are biostratigraphically effi-

Taxa	DEVONIAN						
	LOWER			MIDDLE		UPPER	
	Lochkovian	Pragian	Emsian	Eifelian	Givetian	Frasnian	Famennian
Prasinophyte species							
<i>Arkonites bilixus</i>			—				---
<i>Cymatiosphaera canadense</i>		—				—	---
<i>Cymatiosphaera cornifera</i>		—				—	---
<i>Cymatiosphaera winderi</i>		—				---	
<i>Dictyotidium variatum</i>		—					
<i>Muraticavea munifica</i>				—			—
<i>Polyedryxium ambitum</i>				—			
<i>Polyedryxium fragosulum</i>		—					
Acritarch species							
<i>Dixallophasis simplex</i>		—					
<i>Estiastra rhytidia</i>		—					
<i>Exochoderma arca</i>		—					—
<i>Gorgonisphaeridium inflatum</i>				—			
<i>Hapsidopalla chela</i>				—			
<i>Leiofusa pyrena</i>					—		
<i>Oppilatata sparsa</i>					—		
<i>Uncinisphaera acantha</i>					—		
<i>Villosacapsula compta</i>					—		

Figure 5. Chronostratigraphic ranges of selected prasinophyte and acritarch species present in the Arkona, Hungry Hollow and Widder formations, southwestern Ontario. Taxa and ranges are based on illustrated specimens from stratigraphically documented occurrences. See Systematic palaeontology section for sources of data. Solid lines indicate known stratigraphical ranges; dashed lines are probable occurrences.

Figura 5. Rangos cronoestratigráficos de especies seleccionadas de prasinofitos y acritarcos presentes en las formaciones Arkona, Hungry Hollow y Widder, suroeste de Ontario. Los taxones y sus rangos estratigráficos están basados en especímenes ilustrados a partir de apariciones estratigráficamente bien documentadas. Ver la sección de Paleontología Sistemática para consultar la fuente de los datos. Las líneas continuas indican rangos estratigráficos bien conocidos; las líneas discontinuas señalan apariciones probables.

caceous (Fig. 5). Two species – *Leiofusa pyrena* and *Oppilatala sparsa* – are constrained to the Givetian in North America, and are also reported respectively from Givetian–Frasnian boundary beds in Argentina (Barreda 1986) and possibly Eifelian of China (Zhu Huaicheng *et al.* 2008 as *Oppilatala cf. O. sparsa*) (Fig. 5). Both *Estiastra rhytidoa* and *Polyedryxium ambitum* occur in the Eifelian–Givetian of North America, with *E. rhytidoa* present in the Givetian–early Frasnian in Argentina (Barreda 1986; Rubinstein 1999, 2000) and *P. ambitum* restricted to the late Givetian–early Frasnian in Argentina (Barreda 1986; Ottone 1996) (Fig. 5).

The high percentage of co-occurring Givetian or undifferentiated Middle Devonian acritarch/prasinophyte species recorded from the aforementioned six North American localities, corroborate a Givetian age for the Arkona, Hungry Hollow and Widder formations, and are in agreement with Middle Devonian lithostratigraphic and invertebrate faunal studies. This palynoflora, *in toto*, also enables palynologic correlation between Laurentia and other palaeocontinents during the Middle Devonian.

Paleoenvironmental synthesis

Interpreting palaeoenvironments involves the application of modern principles of sedimentology, biology, complex physico–chemical seawater relationships and hydrodynamic factors affecting water masses and circulation, to name a few. Sedimentary facies and the accompanying association of mega- and micro-invertebrates, phytoplankton and dispersed spores-pollen can all facilitate interpretation of past depositional and environmental conditions. In particular, the minute size and durability of microphytoplankton enhance their usefulness in palaeoenvironmental reconstructions.

Fluctuations in the inverse relationship between marine microphytoplankton and land-derived spores-pollen is well established and has been used for determining proximity to palaeoshorelines and the recognition of transgressive/regressive cycles (Sarmiento 1957; Upshaw 1964; Gray and Boucot 1972; Wicander and Wood 1997).

Various models based on microphytoplankton diversity, assemblage composition, morphotype and form-classes have been proposed for identifying and interpreting palaeoshorelines, inshore–offshore environments and water depths. Staplin (1961) was the first to show a relationship between acritarch morphotypes and diversity, on the one hand, and distance from a Devonian reef on the other. Subsequent stu-

dies confirming the value of applying the above methods to palaeoenvironmental syntheses include papers by such authors as Smith and Saunders (1970), Thusu (1972), Jacobson (1979), Colbath (1980), Dorning (1981), Al-Ameri (1982), Vecoli (2000), Li Jun *et al.* (2004) and Stricanne *et al.* (2004).

Jacobson (1979) constituted the first semi-quantitative attempt at palaeoenvironmental interpretation by means of acritarch diversity and abundance. He divided the acritarchs from Middle and Upper Ordovician rocks of the Cincinnati and New York regions into seven morphologically-defined classes. He graphically plotted the relative abundance of the classes in the sections studied, showing that the proportions and composition of the classes relate to facies differences in both regions. Jacobson (1979) concluded that by grouping some of the classes together, three distinct palaeoenvironmental settings could be recognized. The leiosphaerid class represented a shallow, nearshore environment; the peteinospaerid-*Dicommopalla* class reflected a shoal environment; and the remainder of the classes (baltisphaerid-veryhachid-*Polygonium*-micrhystridid) signified an offshore, open-marine situation. Furthermore, the acritarch abundance fluctuations closely mirrored the variations in relative abundances of chitinozoans and conodonts from the same studied sections.

Dorning (1981) adopted a different semi-quantitative technique to establish a relationship between acritarch diversity and morphotype variation *vis-à-vis* palaeoenvironment. He examined these variables for rocks from the Silurian (Ludlovian) shelf of South Wales and the Welsh borderland, and recognized three assemblages indicative of increasing depth and distance from the palaeoshoreline: viz. a nearshore environment characterized by low diversity and abundant sphaeromorphs; an offshore, shelf assemblage with high diversity and no dominant taxon; and a deeper water assemblage, also of low diversity, and with a preponderance of sphaeromorphs.

Al-Ameri (1983) qualitatively defined ‘palynofacies’ as being symptomatic of distance from palaeoshorelines in Silurian strata of the Rhadames Basin, Libya. The palynofacies were based on the presence, diversity, abundance and morphologies of miospores, acritarchs and chitinozoans.

Vecoli (2000) applied fluctuations in acritarch diversity, relative abundances and morphotype classes to reconstruct changing palaeoenvironmental conditions for Cambrian–Ordovician sedimentary successions of the northern Sahara Platform. He concluded that these three variable factors were influenced by changes in depositional facies; and moreover, that

certain stratigraphically important acritarch taxa appeared to be facies-sensitive.

Inshore-offshore models of microphytoplankton distribution have been proposed and applied to palaeoenvironmental syntheses of Palaeozoic sedimentary sequences by such authors as Li Jun *et al.* (2004) and Stricanne *et al.* (2004). Although recognizing that nearshore-offshore models might be somewhat simplistic and affected by a host of variables, they appear nonetheless to allow a first-order level of analysis. Using the above principles, many authors have applied these models to adduce palaeoenvironmental changes and to recognize transgressive/regressive cycles (e.g. Wicander and Wood 1997).

Applying the general principles of palaeoenvironmental interpretation, the lithologies and associated shelly faunas (e.g. corals, brachiopods, trilobites, crinoids) of the Arkona, Hungry Hollow and Widder formations, as reported by Mitchell (1967) and Wright and Wright (1961), indicate a normal, low-energy, offshore, marine environment. The prasinophyte and acritarch assemblages reported here, are also clearly in accord with that interpretation.

In terms of relative abundance of the palynomorph taxa recovered from the 14 samples at the Hungry Hollow location (Table 1), the following designations per sample are used: rare (10 or fewer specimens); common (11–50 specimens); abundant (51–100 specimens) and very abundant (> 100 specimens).

The diversity of the assemblage ranges from a low of 10 species (sample HH14) to a high of 41 species (samples HH7 and HH8), with five samples each containing between 38 and 40 species per sample (Table 1). As expected, the higher diversities recorded (28 to 41 taxa per sample) correspond to the shale, calcareous shale, and argillaceous, fine-grained limestone lithofacies (samples HH1, 3, 7, 8, 9, 10, 13). Conversely, two of the lower-diversity samples (HH5, 11), both limestones, yielded 23 and 21 species respectively. There were also exceptions to the generally accepted high-diversity/fine-grained sediment and low-diversity/coarser grained or crystalline rocks model. For example, samples HH2, 4 and 12, all collected from limestone layers, had some of the highest diversities (38, 39, 40 respectively), whereas the lowest-diversity sample (10 species) was an argillaceous limestone (HH14).

In terms of morphotypes, the most consistently high-abundance taxa are, in order of decreasing abundance: *Multiplicisphaeridium ramusculosum*, *Leiosphaeridia* sp., *Navifusa bacilla*, *Duvernaysphaera tenuicingulata*, *Polyedryxium pharaone*, *D. angelae*, *Exochoderma arca*, *Micrhystridium stellatum*, *Veryhachium trispinosum* "complex," *V.*

polyaster, *Stellinium micropolygonale*, *Baltisphaeridium distentum* and *Tunisphaeridium tentaculaferum*.

The Arkona/Hungry Hollow/Widder assemblage complies with the baltisphaerid-veryhachid-*Polygonium*-micrhystridid morphological class that Jacobson (1979) associated with an offshore, open-marine environment. Furthermore, Dorning (1981) concluded that offshore, shelf assemblages display high diversity (typically 25–60 species) and moderate abundance with no one taxon dominating. Common genera include: *Cymatiosphaera*, *Diexallophasis*, *Micrhystridium*, *Multiplicisphaeridium* and *Leiosphaeridia*. All of Dorning's criteria for an offshore, open-marine environment are exemplified by the palynologic assemblage documented herein.

Various authors (e.g. Hashemi and Playford 1998; Wicander *et al.* 1999; Vecoli 2000; Stricanne *et al.* 2004; Playford and Wicander 2006; Yan Kui *et al.* 2013; Wicander and Playford 2013) have applied similar palynologic criteria – i.e. variation in abundance, diversity and morphotypes of the organic-walled microphytoplankton – to palaeoenvironmental syntheses of marine successions. Our findings and interpretations with respect to the Arkona/Hungry Hollow/Widder assemblage essentially mirror and complement the conclusions reached in those previous studies.

In addition to prasinophytes and acritarchs, chitinozoans were also encountered in the studied samples, although not approaching the abundance or diversity of the organic-walled microphytoplankton taxa. The co-occurring miospores constitute only a very small portion of the overall palynomorph cohort. Their defective preservation very likely reflects degradation during transportation to the offshore environment.

In summary, application of all the factors previously discussed indicate that the sediments of the Arkona, Hungry Hollow and Widder formations accumulated in a well-oxygenated, marine, offshore, shelf environment, as embodied by the fine-grained sediment hosting the palynologic assemblage, with periodic regressions favouring the development of a reef-type environment that produced coarser-grained, coralline limestones.

Comparison with other Middle Devonian organic-walled microphytoplankton assemblages

Published accounts of Middle Devonian organic-walled microphytoplankton assemblages are not as extensive, stratigraphically definitive, or palaeogeographically widespread as might be expected. Many

reports, especially early ones, dated the assemblages no more precisely than Middle Devonian (i.e. without attribution to the constituent Eifelian and/or Givetian stages). Most recent papers, however, are better documented stratigraphically, with enhanced emphasis on taxonomic identifications, thereby resulting in more refined biostratigraphic and palaeogeographic interpretations.

In the following two sub-sections, we compare our Givetian prasinophyte/acritarch suite to other Middle Devonian assemblages reported from, and beyond, North America. Because of some differences among authors – in particular, the degree of morphologic variation constituting species – comparison of commonality between assemblages tends to be rather more qualitative than quantitative.

It is noteworthy that a close similarity between assemblages does not necessarily connote stratigraphic equivalence. It could reflect, in part, mutual presence of long-ranging, cosmopolitan species. On the other hand, a low similarity expressed as a percentage in common between two assemblages might be a consequence of differences in palaeoecologic or palaeoenvironmental conditions, palaeogeographic distribution, or even taxonomic and nomenclatural differences among authors.

In determining the degree of similarity between our acritarch/prasinophyte assemblage and others, we counted the number of named species (including those designated cf.) in the assemblage if we considered them identical to our particular species. Furthermore, we counted as a single species those that a previous author considered as distinct species, but which we regard as conspecific.

Fourteen prasinophyte, 27 acritarch, and one named chitinozoan species comprise the Arkona/Hungry Hollow/Widder assemblage; i.e. a total of 42 identified organic-walled microphytoplankton species. For counting purposes, we excluded from our assemblage or the comparison assemblages, the informal species designations (sp. or sp. A). For purposes of external comparison, we refer only to diverse, well-preserved and well-dated Middle Devonian assemblages. Those papers that include descriptions of only a few selected species, or lack acceptable stratigraphic control, are not incorporated in our analysis (although they are noted in the systematics section).

North American assemblages

Six microphytoplankton assemblages from North America are comparable to our Arkona/Hungry

Hollow/Widder palynoflora (Fig. 4). Legault (1973) described an assemblage from the Middle Devonian Hamilton Group (which includes the Arkona, Hungry Hollow and Widder formations) in southwestern Ontario. She recorded nine named species, together with a number of informally named species. Not unexpectedly, because of close geographic proximity and lithostratigraphic equivalence, there is a high existential degree of congruence (eight of nine named species, equalling 89% co-occurrence) between the two assemblages.

Playford (1977) described an Early to Middle Devonian organic-walled microphytoplankton assemblage from the Moose River Basin, Ontario. Counting only those named species that occurred in the Eifelian–Givetian upper two-thirds of the Kwataboahagan Formation, and the overlying Moose River, Murray Island and Williams Island formations, there are 22 species (59%) shared with the section at Hungry Hollow. Although none of the taxa is restricted to North America, some have only a few extra-North American occurrences. These include: *Cymatiosphaera canadense* (late Pragian–late Famennian; predominately Givetian), *C. winderi* (Emsian–Givetian; most commonly Givetian), *Dictyotidium variatum* (Lochkovian–Givetian; one doubtful Tournaisian occurrence in Xizang/Tibet), *Polydrixium fragosulum* (Pragian–Frasnian; characteristically Givetian) and *Baltisphaeridium distentum* (Pragian–Famennian).

An extensive study of the Givetian Silica Formation, Ohio (Wicander and Wood 1981) yielded 37 of 48 species (77%) co-occurring. Given the nearness of the two locations, and a Givetian age for both formations, close similarity between the two assemblages is hardly unexpected. A number of species known to be restricted stratigraphically (late Eifelian–Givetian) and geographically (North America) are shared with the palynoflora of this study; viz. *Gorgonisphaeridium inflatum* (late Eifelian–Givetian), *Hapsidopalla chela* (Eifelian–Givetian), *Micrhystridium* sp. A (Eifelian–Givetian), *Uncinisphaera acantha* (Givetian) and *Villosacapsula compta* (Givetian).

Wicander and Wright (1983) described a Middle Devonian acritarch/prasinophyte assemblage from the Columbus and Delaware limestones of Ohio. Despite poor preservation, 38 species proved identifiable, of which 28 (74%) also occur in our Ontario assemblage. Wicander and Wright (1983) reported that the species from the limestone formations showed a high degree of similarity (60%) to the younger Silica Formation (Wicander and Wood, 1981), and also to the Moose River Basin strata (Playford, 1977) and

the Hamilton Group (Legault, 1973), both of which are in Ontario. Most of the species identified from the Columbus and Delaware limestones, are also components of the Silica Formation and the Arkona, Hungry Hollow and Widder formations, and require no citation here.

A 96% co-occurrence is evident between our Arkona/Hungry Hollow/Widder phytoplankton assemblage and that of the Middle Devonian (Givetian) Boyle Dolomite, Kentucky (Wood and Clendening, 1985). Of the 23 species reported from the Boyle Dolomite, only *Lophosphaeridium ochthos* Wicander and Wood, 1981 is unrepresented in our assemblage.

Wicander and Wood (1997) examined the organic-walled microphytoplankton from the upper Givetian Rapid Member of the Cedar Valley Formation, Iowa. Although their emphasis was on the use of acritarchs/prasinophytes and chitinozoans for interpreting transgressive/regressive cycles, 33 well-preserved species were identified. Of these, 21 species (64%) are shared with the Hungry Hollow sampled section.

As would be expected, very close similarity exists (59–96% commonality) between the Middle Devonian phytoplankton assemblage from the Hungry Hollow locale and coeval assemblages described from elsewhere in North America. Of shared occurrences are several stratigraphically long-ranging and palaeogeographically widespread forms such as *Micrhystridium stellatum*, *Multiplicisphaeridium ramusculosum*, *Navifusa bacilla*, *Veryhachium europaeum*, *V. lairdii* and *V. trispinosum* "complex." Also co-represented are many species that combine Devonian stratigraphic-limitation with extensive palaeogeographic distribution; e.g. *Duvernaysphaera angelae*, *D. tenuicinctulata*, *Muraticavea munifica*, *Polyedryxium embudum*, *P. pharaone*, *Daillyidium pentaster*, *Exochoderma arca*, *Stellinium comptum* and *S. micropolygonale*. Lastly, five Middle Devonian species (all but one confined to the Givetian) occur only in North America: viz. *Gorgonisphaeridium inflatum*, *Hapsidopalla chela*, *Micrhystridium* sp. A, *Uncinisphaera acantha* and *Villosacapsula compta*.

Extra-North American assemblages

As within North America, the Arkona/Hungry Hollow/Widder palynoflora of this study can be compared with assemblages from elsewhere that have been well documented, sufficiently preserved, adequately illustrated and identified and stratigraphically constrained. Comparable South American assemblages include those reported by Barreda (1986), Ottone

(1996), Rubinstein (1999, 2000) and Amenábar *et al.* (2006) from Argentina. Other studies, such as those of Brito (e.g. 1965, 1966, 1967a, b, c, 1976) from Brazil, are not included here because either the stratigraphy was insufficiently defined or the assemblage was not comprehensively or adequately documented. The same applies to the papers by Pöthe de Baldis (1974, 1979; Paraguay), Pöthe de Baldis (1977; Uruguay) and, from Bolivia, Vavrdová *et al.* (1996) and di Pasquo (2007).

An assemblage of 33 named acritarch/prasinophyte species was documented by Barreda (1986) from subsurface strata, dated as transitional Givetian–Frasnian, of the Salta province, Argentina. Eighteen of the species she identified are represented in the Hungry Hollow sampled collection (55% commonality). Several species known hitherto only from North America (*Baltisphaeridium distentum*, *Estiastra rhytidoia*, *Leiofusa pyrena*, *Muraticavea munifica* and *Polyedryxium ambitum*) were subsequently reported from Argentina by Ottone (1996), Rubinstein (1999, 2000) and Amenábar *et al.* (2006), and from Bolivia by Wicander *et al.* (2011). In addition, the characteristic Middle–Late Devonian Gondwanan species *Maranhites brasiliensis* and *Pterospermella pernambucensis* were present, but *Umbellasphaeridium deflandrei* and *U. saharicum* were unrecorded.

Ottone (1996) described a palynologic assemblage from the Los Monos Formation (late Givetian–early Frasnian), Tarija Basin, Argentina, consisting of 51 acritarch/prasinophyte species (40 binomially named). Nineteen of the named Los Monos Formation species are also present in the Arkona/Hungry Hollow/Widder assemblage; i.e. a similarity of 48%. It is also noteworthy that *Maranhites mosesii* and *Umbellasphaeridium deflandrei* – both components of Ottone's palynoflora – have not been encountered in our samples.

Rubinstein (1999) recorded an assemblage of 14 acritarch/prasinophyte species (seven named binomially, three cf. designations and four in open nomenclature) from two palynofloras (Eifelian–Givetian and Givetian–Frasnian boundary beds respectively = Eifelian–early Frasnian herein) of the Punta Negra Formation in the San Juan Precordillera, Argentina. Her subsequent paper (Rubinstein 2000) revised the age of the Punta Negra Formation as transitional Givetian–Frasnian based on additional sampling and chitinozoan data. Although indifferently preserved, seven of the 10 named and cf.-designated microphytoplankton species also occur in our Ontario assemblage (70%; albeit mostly long-ranging species). Additionally, Rubinstein recorded the Gondwanan form *Maranhites* cf. *M. mosesii*.

Twenty-eight acritarch/prasinophyte species were reported by Amenábar *et al.* (2006) from the Chavela Member of the Chigua Formation, Rio Blanco Basin, San Juan Province, Argentina. Three palynologic assemblages were recovered from two locations with an overall proposed age of late Emsian through the Givetian/Frasnian boundary. Of the 16 binomially named species recorded, 11 co-occur in the Arkona/Hungry Hollow/Widder assemblage (69%). These include such familiar North American taxa as *Arkonites bilixus*, *Cymatiosphaera canadense*, *Estiastra rhytidia*, *Exochoderma arca* and *Polyedryxium decorum*. Amenábar *et al.* (2006) did not report any representatives of either *Maranhites* or *Umbellasphaeridium*.

Certain African locations have yielded well-preserved and diverse Devonian assemblages, several dated wholly, or partially, as Middle Devonian, based on chitinozoan and acritarch content. Anan-Yorke

(1974) described 21 binomially named species from three wells that penetrated Ghana's shelf and coastal region. Twelve of these species are shared with our assemblage (57% co-occurrence). Most of the Ghanaian species are stratigraphically long ranging and geographically widespread; e.g. *Micrhystridium stellatum*, *Multiplicisphaeridium ramusculosum* and *Veryhachium lairdii*.

Jardiné (1972), Jardiné and Yapaudjian (1968) and Jardiné *et al.* (1972, 1974) described several assemblages from a series of Silurian–Devonian sections and wells in the Algerian Sahara of North Africa. The assemblage that includes Middle Devonian strata, and was reported by Jardiné and Yapaudjian (1968) from the Fort-Polignac Basin, is most representative of the lithostratigraphic units reported in the aforementioned papers. The Fort-Polignac assemblage contains 26 identified species, only eight of which are represented at Hungry Hollow. The shared species

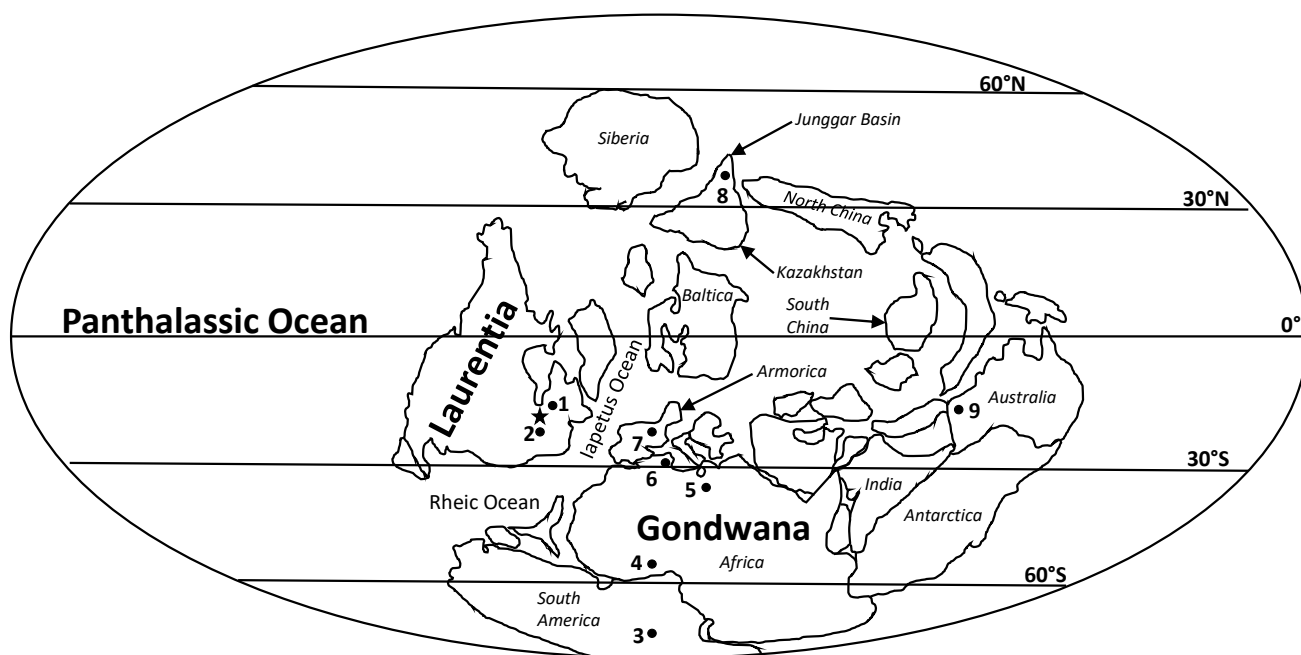


Figure 6. Palaeogeographic map for the Middle Devonian (modified from Scotese and McKerrow, 1990, p. 13, fig. 15 and Molyneux *et al.*, 2013, p. 381, fig. 23.10). Solid star denotes the Hungry Hollow locality (present study). Key to numbered locations (generalized and shown as solid circles) and respective data sources: 1, Moose River Basin, Ontario (Playford, 1977); southwestern Ontario (Legault, 1973); 2, Ohio (Wicander and Wood, 1981; Wicander and Wright, 1983); Kentucky (Wood and Clendening, 1985); Iowa (Wicander and Wood, 1997); 3, Argentina (Barreda, 1986; Ottone, 1996; Rubinstein, 1999; Amenábar *et al.*, 2006); 4, Ghana (Anan-Yorke, 1974); 5, Libya (Moreau-Benoit, 1984); 6, Algerian Sahara (Jardiné and Yapaudjian, 1968; Jardiné, 1972; Jardiné *et al.*, 1972, 1974); 7, Armórica, Francia (Turnau and Racki, 1999); 8, eastern Junggar Basin, Kazakhstan (Zhu Huaicheng *et al.*, 2008); 9, Canning Basin, Western Australia (Colbath, 1990).

Figura 6. Mapa paleogeográfico para el Devónico Medio (modificado de Scotese and McKerrow, 1990, p. 13, fig. 15 y Molyneux *et al.*, 2013, p. 381, fig. 23.10). La estrella indica la localidad de Hungry Hollow (estudio actual). Clave de localidades (señaladas por círculos) y fuentes de datos: 1, Cuenca del Río Moose, Ontario (Playford, 1977); suroeste de Ontario (Legault, 1973); 2, Ohio (Wicander and Wood, 1981; Wicander and Wright, 1983); Kentucky (Wood and Clendening, 1985); Iowa (Wicander and Wood, 1997); 3, Argentina (Barreda, 1986; Ottone, 1996; Rubinstein, 1999; Amenábar *et al.*, 2006); 4, Ghana (Anan-Yorke, 1974); 5, Libia (Moreau-Benoit, 1984); 6, Sahara argelino (Jardiné and Yapaudjian, 1968; Jardiné, 1972; Jardiné *et al.*, 1972, 1974); 7, Armórica, Francia (Turnau and Racki, 1999); 8, Este de la Cuenca de Junggar, Kazakhstan (Zhu Huaicheng *et al.*, 2008); 9, Cuenca de Canning, Oeste de Australia (Colbath, 1990).

(31% from two locations), like those reported by Anan-Yorke (1974), are stratigraphically long ranging and widely distributed palaeogeographically.

Core samples from three wells in western Libya (Moreau-Benoit 1984) yielded 37 species, 17 of which are found at Hungry Hollow (46%), including such low-latitude, typically northern hemisphere, Middle Devonian species as *Cymatiosphaera canadense*, *C. winderi*, *Polyedryxium decorum* and *P. fragosulum*. These were reportedly associated with a number of stratigraphically long ranging and widely distributed taxa, all of which have previously been mentioned. Additionally represented, are the characteristic Gondwana species *Maranhites brasiliensis*, *Umbellaspheeridium deflandrei* and *U. saharicum*, which do not appear in Laurentia until the Late Devonian.

A number of papers have been published that include Middle Devonian strata in Europe. Except for a Givetian assemblage described by Turnau and Racki (1999) from the Holy Cross Mountains in central Poland, none of the published literature from the European continent contains sufficiently diverse assemblages to warrant discussion in an extra-North American comparative context. Turnau and Racki's acritarch/prasinophyte assemblage contains 23 named species, 12 of which also occur in the Arkona/Hungry Hollow/Widder assemblage (52% commonality). Moreover, *Arkonites bilixus* and *Daillydium pentaster* are also found at this location.

Colbath (1990) documented a Givetian–Frasnian organic-walled microphytoplankton flora from the Canning Basin, Western Australia. This assemblage is composed of 66 named species, 34 of which were newly proposed and appear to be endemic to the region. Only eight species are common to the Arkona/Hungry Hill/Widder assemblage (12% shared taxa); all of these, with the exception of *Daillydium pentaster*, are palaeogeographically and stratigraphically widespread and long ranging.

The final assemblage meriting discussion here is from the Middle Devonian (Eifelian) Ulusubasite Formation, eastern Junggar Basin, Xinjiang, China (Zhu Huaicheng *et al.* 2008). As noted by those authors, Devonian palynologic studies from China have only been reported from scattered localities. Several reports are from the Upper Devonian, but prior to 2008, there were no published studies for the Middle Devonian. Although the Ulusubasite preservation is less than ideal, a miospore and organic-walled microphytoplankton palynoflora was recognized, consisting of 19 acritarch/prasinophyte species, 13 which were binomially named. There are 10 species in common with our Ontario assemblage, a similarity factor of 77%, and

all are stratigraphically long-ranging and cosmopolitan. Thus, the Junggar Basin phytoplankton assemblage evinces a marine connection between Laurentia, Baltica, Kazakhstan (Junggar Basin) and Gondwana.

Palaeogeographic implications

During the Middle Devonian, Laurentia occupied a low-latitude region, extending from ca 30° N to 30° S, and separated narrowly from Baltica on the east by progressive closure of the Iapetus Ocean (Fig. 6). By the end of the Devonian, Baltica and Laurentia effectively became a single landmass (Laurasia). During the Middle and Late Devonian, Laurentia (Laurasia) remained distinct from Gondwana by the intervening Rheic Ocean, which, like the Iapetus Ocean, was also decreasing in size, thus bringing the two continents in closer proximity (Fig. 6).

In terms of Devonian microphytoplankton, the Late Devonian has received the most attention, although a sizeable literature exists for the Middle Devonian, as discussed in the previous section. As mentioned elsewhere, a number of early studies involved poorly preserved or inadequately illustrated assemblages that lacked stratigraphic documentation and/or chronological calibration, thus limiting their applicability to stratal correlation, comparison of palynologic assemblages and palaeogeographic synthesis. Furthermore, the palaeogeographic coverage of microphytoplankton assemblages for the Middle Devonian is uneven (Molyneux *et al.* 2013).

Despite these limitations, analysis of those well-preserved and stratigraphically constrained Middle Devonian acritarch/prasinophyte assemblages previously discussed connotes a significant degree of cosmopolitanism. Palaeogeographically widespread taxa include *Arkonites bilixus*, *Cymatiosphaera cornifera*, *Duvernaysphaera angelae*, *D. tenuicingulata*, *Polyedryxium embudum*, *P. pharaone*, *Daillydium pentaster*, *Exochoderma arca*, *Micrhystridium stellatum*, *Multiplicisphaeridium ramusculosum*, *Navifusa bacilla*, *Ozotobranchion furcillatus*, *Palacanthus ledanoisii*, *Stellinium comptum*, *S. micropolygonale*, *Tunisphaeridium tentaculaferum*, *Tyligmasoma alargada*, *Veryhachium europaeum*, *V. lairdii*, *V. polyaster*, *V. trispinosum* "complex" and *Villosacapsula rosendae*.

A number of distinctive and commonly occurring species are seemingly restricted to Laurentia such as: *Eisenackidium appendiculum*, *Gorgonisphaeridium inflatum*, *Hapsidopalla chela*, *Uncinisphaera acantha* and *Villosacapsula comptata*.

The remainder of the Arkona/Hungry Hollow/Widder phytoplankton assemblage contains

taxa found predominately in Laurentia, but also reported from several extra-Laurentian localities. With few exceptions, the majority of species recorded from North America show dispersal to other locations during the Middle Devonian. However, certain species were endemic to high-latitude areas of Gondwana, in association with many low- to mid-latitude species. These Gondwanan high-latitude taxa include *Maranhites brasiliensis*, *M. mosesii*, *Pterospermella pernambucensis*, *Umbellasphaeridium deflandrei* and *U. saharicum* although some of these species may be misidentified (Alain Le Hérissé, personal communication).

Wood (1984) reviewed the palaeobiogeographic dispersal of *Umbellasphaeridium deflandrei*, *U. saharicum* and the "Maranhites brasiliensis complex" (the latter informally linking *M. brasiliensis* with *M. mosesii*). He noted that the first appearance in North America of these three taxonomic categories did not occur until the Late Devonian. His conclusion was that the post-Middle Devonian dispersal of these species from the high latitudes of Gondwana to the mid- to low-latitudes closely paralleled a seaway connection inferred previously from the distribution of coral and goniatite taxa. The distribution of Middle Devonian acritarchs/prasinophytes discussed in this paper, supports that scenario.

In summary, the Arkona/Hungry Hollow/Widder organic-walled microphytoplankton represent a low- to mid-palaeolatitude, warm-water, marine assemblage consisting of both stratigraphically short- and long-ranging, cosmopolitan taxa. Although many of the widespread species occur in the mid- to high-palaeolatitudes of Gondwana, a Middle Devonian endemic population of phytoplankton existed in the Gondwanan high latitudes, and did not migrate to Laurasia until the Late Devonian.

Conclusions

A diverse and well-preserved acritarch/prasinophyte assemblage is profusely represented in a 13.3-m exposure of the Middle Devonian (Givetian) Arkona, Hungry Hollow and Widder formations at Hungry Hollow in southwestern Ontario, Canada.

The palynoflora comprises 49 acritarch, prasinophyte and one chitinozoan species, 42 of which have previously been named, and seven left in open nomenclature. Additionally, other chitinozoans, scolecodonts and miospores also occur, albeit in lesser diversity and abundance, and are not identified taxonomically.

The assemblage's adduced Middle Devonian

(Givetian) age is based on the vertical ranges of certain acritarch and prasinophyte species as reported from biostratigraphically constrained assemblages in North America and elsewhere; and accords with the dating of associated marine invertebrate faunas.

The palynofloral composition signifies deposition in a well-oxygenated, marine, offshore shelf environment, with periodic regressions promoting the development of reef-type environments.

The Arkona/Hungry Hollow/Widder organic-walled microphytoplankton assemblage reflects a high degree of cosmopolitanism, as well as confirming an endemic high-latitude Gondwanan contribution, many species of which did not migrate into the low-middle-latitudes until the Late Devonian.

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Species	Pl./Fig. #	Sample #	Slide #	EF	Photo #	GSC type #
<i>Arkonites bilixus</i>	1/1	HH5	HH5 >20 μ 3	C30/3	HH-11A	138608
<i>Arkonites bilixus</i>	1/2	HH4	HH4 >20 μ 2	Q27/2	HH-12A	138609
<i>Cymatiosphaera canadense</i>	1/3	HH9	HH9 20–52 μ 2	D28/0	HH-15A	138610
<i>Cymatiosphaera canadense</i>	1/4	HH9	HH9 20–52 μ 3	Q37/2	HH-17A	138611
<i>Cymatiosphaera cornifera</i>	1/5	HH12	HH12 20–52 μ 3	T42/4	HH-17A	138612
<i>Cymatiosphaera cornifera</i>	1/6	HH4	HH4 >20 μ 2	S33/2	HH-18A	138613
<i>Cymatiosphaera winderi</i>	1/7	HH13	HH13 20–52 μ 3	E34/4	HH-21A	138614
<i>Dictyotidium variatum</i>	1/8	HH9	HH9 20–52 μ 3	M26/2	HH-24A	138615
<i>Duvernaysphaera angelae</i>	1/9	HH1	HH1 20–52 μ 1	H32/3	HH-28A	138616
<i>Duvernaysphaera tenuicingulata</i>	1/10	HH1	HH1 20–52 μ 2	R39/0	HH-35A	138617
<i>Duvernaysphaera tenuicingulata</i>	1/11	HH1	HH1 20–52 μ 1	J41/2	HH-30A	138618
<i>Duvernaysphaera tenuicingulata</i>	1/12	HH12	HH12 20–52 μ 4	U39/1	HH-31A	138619
<i>Leiosphaeridia</i> sp.	1/17	HH1	HH1 >52 μ 1	T39/2	HH-105A	138620
<i>Muraticavea munifica</i>	1/18	HH13	HH13 20–52 μ 1	H41/3	HH-56A	138621
<i>Muraticavea munifica</i>	1/19	HH13	HH13 20–52 μ 1	T38/1	HH-57A	138622
<i>Polyedryxium ambitum</i>	1/13	HH8	HH8 >52 μ 2	K32/0	HH-63A	138623
<i>Polyedryxium ambitum</i>	1/14	HH7	HH7 20–52 μ 2	K41/2	HH-65A	138624
<i>Polyedryxium decorum</i>	1/15	HH1	HH1 >52 μ 2	H39/1	HH-68A	138625
<i>Polyedryxium embudum</i>	1/16	HH8	HH8 20–52 μ 2	P45/3	HH-70A	138626
<i>Polyedryxium embudum</i>	2/1	HH8	HH8 >52 μ 2	S35/4	HH-71A	138627
<i>Polyedryxium fragosulum</i>	2/2	HH9	HH9 20–52 μ 3	J25/4	HH-73A	138628
<i>Polyedryxium fragosulum</i>	2/3	HH8	HH8 >52 μ 2	T45/2	HH-72A	138629
<i>Polyedryxium pharaone</i>	2/6	HH8	HH8 >52 μ 1	N44/2	HH-107A	138630
<i>Polyedryxium pharaone</i>	2/7	HH13	HH13 >52 μ 3	V29/0	HH-74A	138631
<i>Staplinium cuboides</i>	2/4	HH8	HH8 20–52 μ 2	Q48/3	HH-68A	138632
<i>Tasmanites</i> sp.	2/5	HH4	HH4 >20 μ 2	E31/0	HH-102A	138633
<i>Ammonidium</i> sp. A	2/8	HH13	HH13 20–52 μ 1	T35/0	HH-10A	138634
<i>Ammonidium</i> sp. A	2/9	HH13	HH13 20–52 μ 1	R31/3	HH-09BA	138635
<i>Baltisphaeridium distentum</i>	2/10	HH8	HH8 >52 μ 2	G29/4	HH-13A	138636
<i>Baltisphaeridium distentum</i>	2/11	HH8	HH8 20–2 μ 2	O46/2	HH-14A	138637
<i>Dailyidium pentaster</i>	2/12	HH11	HH11 >20 μ 1	L27/0	HH-22A	138638
<i>Diexallophosis simplex</i>	2/13	HH1	HH1 20–52 μ 2	N30/0	HH-26A	138639
<i>Eisenackidium appendiculum</i>	2/14	HH6	HH6 >20 μ 1	J42/2	HH-32A	138640
<i>Estiastra rhytidia</i>	2/15	HH1	HH1 20–52 μ 3	P36/3	HH34A	138641
<i>Exochoderma arca</i>	2/18	HH4	HH4 >20 μ 1	S22/1	HH-39A	138642
<i>Exochoderma arca</i>	2/19	HH4	HH4 >20 μ 3	Q37/2	HH-40A	138643
<i>Gorgonisphaeridium inflatum</i>	2/16	HH1	HH1 20–52 μ 1	V34/0	HH-41A	138644
<i>Gorgonisphaeridium inflatum</i>	2/17	HH1	HH1 20–52 μ 3	M42/0	HH-42A	138645
<i>Hapsidopalla chela</i>	3/1	HH1	HH1 >52 μ 1	T37/2	HH-44A	138646
<i>Hapsidopalla chela</i>	3/2	HH7	HH7 20–52 μ 2	W38/2	HH-43A	138647
<i>Leiofusa pyrena</i>	3/4	HH4	HH4 >20 μ 2	R25/3	HH-46A	138648
<i>Michrhystridium stellatum</i>	3/3	HH9	HH9 20–52 μ 4	T33/3	HH-48A	138649
<i>Michrhystridium</i> sp. A	3/7	HH12	HH12 20–52 μ 3	X36/4	HH-51A	138650
<i>Michrhystridium</i> sp. A	3/8	HH12	HH12 20–52 μ 2	Q31/3	HH-50A	138651
<i>Multiplicisphaeridium ramusculosum</i>	3/5	HH8	HH8 20–52 μ 2	P42/2	HH-52A	138652
<i>Multiplicisphaeridium</i> sp. A	3/6	HH13	HH13 20–52 μ 1	Q42/2	HH-55A	138653
<i>Navifusa bacilla</i>	3/15	HH1	HH1 >52 μ 2	Q37/0	HHa-05A	138654
<i>Navifusa bacilla</i>	3/16	HH8	HH8 >52 μ 1	G35/0	HH-06A	138655
<i>Oppilatala sparsa</i>	3/9	HH7	HH7 20–52 μ 2	Q32/0	HH-58A	138656
<i>Oppilatala sparsa</i>	3/10	HH8	HH8 20–52 μ 2	K35/2	HH-59A	138657
<i>Ozotobrachion furcillatus</i>	4/1	HH8	HH8 20–52 μ 3	E46/3	HH-60A	138658
<i>Palacanthus ledanoisii</i>	3/11	HH12	HH12 20–52 μ 3	K30/1	HH-07A	138659
<i>Polygonium</i> sp. A	4/2	HH7	HH7 20–52 μ 3	W35/2	HH-37A	138660
<i>Polygonium</i> sp. A	4/3	HH9	HH9 >52 μ 1	E29/3	HH-38A	138661
<i>Solisphaeridium</i> sp. A	3/14	HH4	HH4 >20 μ 3	P30/3	HH-76A	138662
<i>Stellinium comptum</i>	4/4	HH2	HH2 20–52 μ 1	U24/0	HH-78A	138663
<i>Stellinium micropolygonale</i>	4/5	HH9	HH9 20–52 μ 4	V38/2	HH-80A	138664
<i>Tunisphaeridium tentaculaferum</i>	4/6	HH9	HH9 >52 μ 1	X32/1	HH-83A	138665
<i>Tyligmasoma alargada</i>	4/14	HH1	HH1 >52 μ 1	K43/3	HH-85A	138666
<i>Uncinisphaera acantha</i>	3/12	HH1	HH1 20–52 μ 1	U26/0	HH-88A	138667
<i>Uncinisphaera acantha</i>	3/13	HH1	HH1 20–52 μ 1	L42/1	HH-87A	138668
<i>Veryhachium europaeum</i>	4/8	HH12	HH12 20–52 μ 2	S36/1	HH-89A	138669
<i>Veryhachium lairdii</i>	4/7	HH8	HH8 20–52 μ 1	K42/2	HH-02A	138670
<i>Veryhachium pastoris</i>	4/10	HH8	HH8 20–52 μ 2	S37/1	HH-90A	138671
<i>Veryhachium polyaster</i>	4/11	HH2	HH2 20–52 μ 3	E37/4	HH-92A	138672
<i>Veryhachium trispinosum</i> "complex"	4/9	HH12	HH12 20–52 μ 4	E44/1	HH-93A	138673
<i>Villosacapsula compta</i>	4/12	HH12	HH12 20–52 μ 2	E36/4	HH-97A	138674
<i>Villosacapsula rosendae</i>	4/13	HH3	HH3 20–52 μ 2	J42/4	HH-96A	138675
<i>Scolecodont</i>	4/15	HH6	HH6 >20 μ 1	P38/3	HH-103A	138676
<i>Hoegisphaera glabra</i>	4/16	HH8	HH8 >52 μ 2	T41/0	HH-114A	138677
<i>Hoegisphaera glabra</i>	4/17	HH8	HH8 >52 μ 1	G33/2	HH-111A	138678

Appendix 1. Inventory of illustrated specimens (hypotypes). Slide locations of individual specimens are specified by coordinates derived from a standard England Finder™ (EF) slide. Specimen catalogue numbers (GSCType 138608 to GSCType 138678 inclusive) are those of the permanent repository: Geological Survey of Canada, National Invertebrate and Plant Type Fossil Collection, 601 Booth Street, Ottawa, Ontario, Canada.