

Palynostratigraphy of the Sarhlef Series (Mississippian), Jebilet Massif, Morocco

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ABSTRACT: The Jebilet Massif, located in the southern part of the Moroccan Western Meseta, includes a sequence known as the Sarhlef Series, which comprises mostly black shales with subordinate volcanic rocks and hosts several massive sulfide deposits. Hitherto, the Sarhlef Series has received only scant biostratigraphic attention. Accordingly, a detailed palynological analysis of the shaly Sarhlef strata that embrace the massive sulfide deposit of Draa Sfar, ca. 20km north of Marrakech, is presented herein. The palynoflora consists predominantly of moderately well preserved miospores, together with quantitatively subordinate marine palynomorphs (acritarchs, prasinophyte phycomata) and scolecodonts. The miospore content, documented systematically herein, comprises 19 genera including 29 species, five of which (*Cristatisporites mixtus*, *Densosporites dissonus*, *Indotriradites immutabilis*, *Vallatisporites extensivus* and *Endoculeospora marrakechensis*) are newly established. The Sarhlef miospore assemblage closely resembles those reported from late Viséan-early Serpukhovian strata elsewhere in North Africa and adjacent regions. Some similarities are also evident with Western Gondwanan assemblages (viz., from the Parnaíba, Solimões and Amazonas basins of northern Brazil). The palynological data, in conjunction with published faunal evidence accrued from the overlying lithostratigraphic unit, demonstrate that the age of the black shales of the Sarhlef Series hosting the Draa Sfar sulfide deposit can be constrained to the late Viséan (Asbian); this, moreover, is corroborated by radiometric determinations from associated volcanic rocks.

INTRODUCTION

The number and detail of studies and consequently the level of understanding achieved among the Variscan provinces vary considerably. Knowledge of those terranes, located in southernmost Europe and along the northwestern African margin (i.e., the Moroccan Variscan Domain), is still incomplete. As a result, in the classic paleogeographic reconstructions generally accepted by the scientific community (i.e., Matte 1986, 1991; Ziegler 1989), the southernmost Variscan domains remain vaguely defined or have simply been omitted. This applies particularly to the Moroccan Variscan Domain, despite the high number and quality of local studies undertaken. This region, generally excluded from consideration of European Variscan terranes, is also sometimes studied as a fringe of the West African craton. As a result, this domain is commonly analyzed within an ambiguous geologic context.

One of the main factors inhibiting adequate understanding of the northwestern African margin is an insufficiency of biostratigraphic, chronostratigraphic and paleoenvironmental information. Such data are crucial not only for the accuracy of tectonic and regional syntheses, but also for targeting areas of economic mineral potential.

The present study focuses on the Jebilet Massif, an E-W extension of the southern part of the Western Meseta Domain, Moroccan Variscan Orogen. The Massif is subdivided into three tectono-stratigraphic units disposed perpendicularly to the maximum dimension (Huvelin 1977; Bordonaro et al. 1979). The central unit, termed the Central Zone, consists mainly of a sequence of black shales and subordinate volcanic rocks known as the Sarhlef Series (Huvelin 1977). A particularly distinctive feature of the Sarhlef Series is the presence of several massive

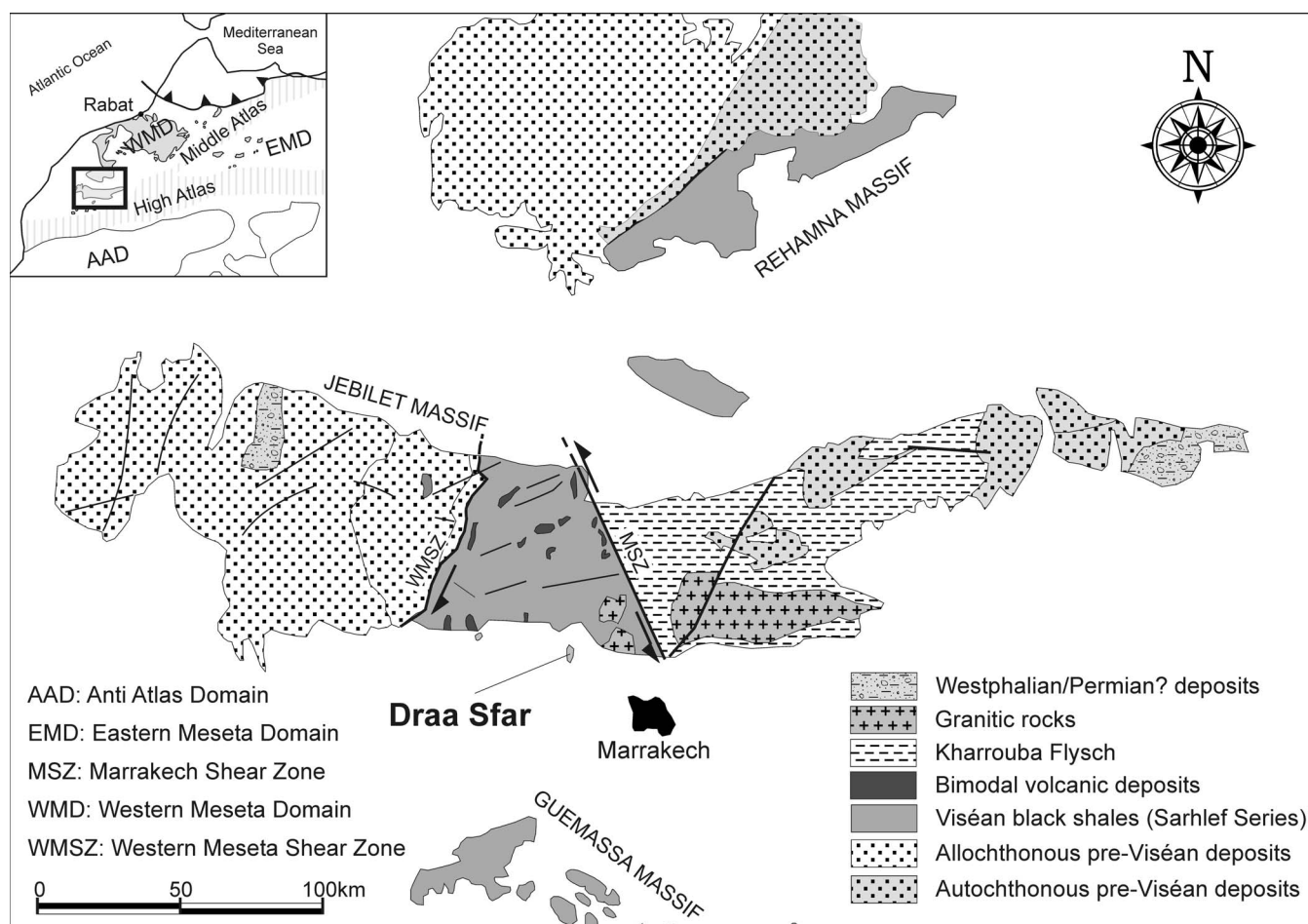
sulfide deposits intercalated with the shales. Those deposits form part of the massive sulfide Moroccan Variscan Province. They are represented in the Jebilet Massif by the mineralizations of Draa Sfar, Kettara and numerous other minor occurrences.

Due to the paucity of faunal evidence, biostratigraphic/chronostratigraphic knowledge of the economically important Sarhlef Series has been very limited. In fact, dating of the entire sequence has hitherto been founded on very sparse occurrences of the late Viséan bivalve *Posidonia becheri* Bronn, which is occasionally associated with biostratigraphically unimportant brachiopods and crinoids (Huvelin 1961; Hollard et al. 1977). Apart from these records, the chronostratigraphy of the Sarhlef Series has been based on correlation with laterally equivalent stratal sequences.

The present study focuses on a borehole that penetrated the Sarhlef Series near the southern border of the Jebilet Massif and intersected the massive sulphide deposit of Draa Sfar. The primary objective is to provide a sound biostratigraphic base for the Sarhlef Series by means of a detailed taxonomic and chronostratigraphic analysis of the palynomorphs recovered.

GEOLOGIC SETTING AND STRATIGRAPHY

The Moroccan Meseta represents the most extensive and representative geologic domain of the deformed North African Palaeozoic. Located immediately south of the Rift Domain, it occupies an extensive area of northwestern Morocco, extending eastward to Algeria as a row of small, disconnected exposures. It is subdivided by the Mesozoic mountains of the Middle Atlas into the Eastern and Western Meseta domains (text-fig. 1).



TEXT-FIGURE 1

Simplified map of Morocco (upper left corner) indicating the Variscan outcrops, in pale gray, and the study area; and geologic map of the Jebilet Massif including the location of Draa Sfar.

The Jebilet Massif is a well-defined, E-W trending sector of the Western Meseta. It is 170km long and 20km wide, and is located ca. 20km north of Marrakech. The massif, whose northern and southern boundaries are faulted and mostly covered by Pliocene-Quaternary alluvial deposits, comprises three tectono-stratigraphic, N-S oriented units – the Eastern, Central and Western units. These are delimited by two major shear zones: the Western Meseta Shear Zone, dividing the Western and Central units (Piqué et al. 1980); and the Marrakech Shear Zone, between the Central and Eastern units (Lagarde and Choukroune 1982; see text-fig. 1 herein).

The Central Zone is mostly composed of the Sarhlef Series (Huvelin, 1977), a detrital Carboniferous succession hosting several massive sulfide deposits that have been affected by strong and continuous syn- and post-sedimentary magmatic activity. Informally defined by Huvelin (1977), the series consists of black shales with thin beds of fine-grained sandstone and volcanic/volcanoclastic rocks of felsic and mafic composition. From economic and social perspectives, the most important feature of the Sarhlef Series is the presence of polymetallic sulfide deposits like that of Draa Sfar, Kettara and several lesser occurrences, all belonging to the Variscan massive sulfide province of Jebilet, Haouz and Gemassa. The basement rocks of the

Sarhlef Series are not exposed anywhere in the Jebilet Massif. Conformably overlying the series is the lutitic-carbonate Teksim Formation, which accumulated in a shallow marine basin during late Viséan times (Hollard et al. 1977). The stratigraphic architecture of the Sarhlef Series (text-fig. 2) is complex, being characterized by frequent facies changes throughout its known extent (Moreno et al. in press).

The Sarhlef Series has been traditionally dated as Viséan-Serpukhovian. This is based on correlation with the Kharrouba Flysch in the Eastern Jebilet (see below), and on Huvelin's (1961) identification of *Posidonia becheri* Bronn in the western part of the Central Jebilet. This species was subsequently reported by Hollard et al. (1977) from other localities in the Central Jebilet, together with undetermined species of the brachiopod genera *Productus* Sowerby, *Punctospirifer* North and *Spirifer* Sowerby, and of the crinoid genus *Poteriocrinus* Miller. Those records represent the only paleontological data reported thus far from the Sarhlef Series.

The Eastern Zone is constituted mainly by the Kharrouba Flysch (Huvelin 1972), a shaly-sandy unit that comprises over 2000m of turbidites and tidal/wave-dominated shallow marine deposits indicative of a deep basin to shallow platform transition (Graham 1982a, b). The succession has been dated as late

Viséan from megafaunal evidence presented by Permingeat (1954) and Huvelin (1977). They reported abundant crinoids, brachiopods and a few trilobites, and considered the bivalve *Posidonia becheri* Bronn, the ammonoid *Goniatites crenistria* Phillips and the articulate brachiopod *Productus costatus* Sowerby as the most stratigraphically important species. The Kharrouba Flysch is succeeded gradationally by the Teksim Formation. In the easternmost part of the Eastern Zone, the Kharrouba Flysch includes a series of mainly Ordovician blocks.

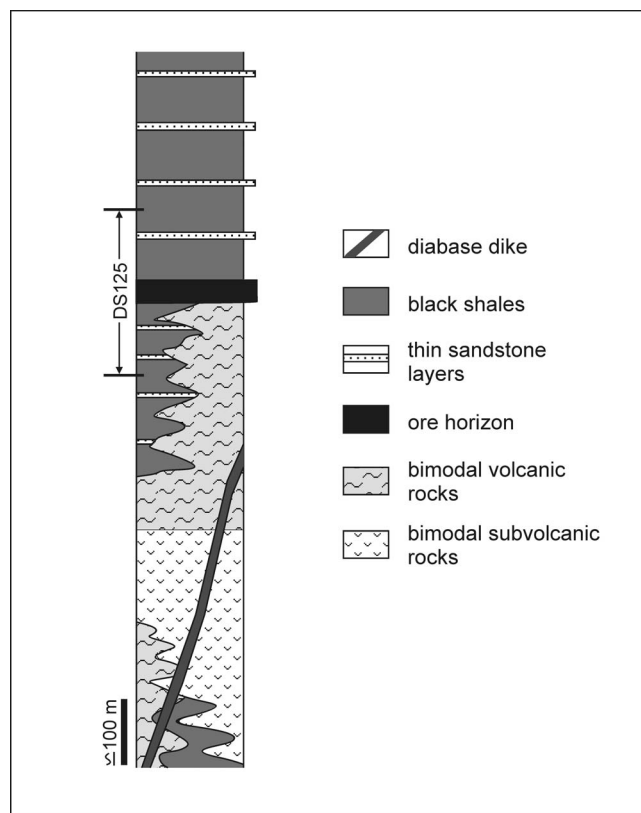
The relationship between the Kharrouba Flysch (characterizing the Eastern Zone) and the Sarhlef Series (of the Central Zone) remains unclear, owing to dislocation of the contact by the Marrakech Shear Zone. Some authors (El Hassani et al. 1983) considered the relationship as purely tectonic; others (e.g., Bordonaro et al. 1979; Gaillet 1979), however, have suggested that they occupy a similar stratigraphic position, and signify a facies change between autochthonous and turbiditic deposits.

The foraminiferal contents of the Teksim Formation (which conformably overlies both the Sarhlef Series and the Kharrouba Flysch), and of bioclastic sandstones transitional downwards to the Kharrouba Flysch in the Eastern Jebilet, have been studied by Hollard et al. (1977). They listed abundant and diverse foraminifers including such species as *Archaeodiscus karrieri* aut. non Brady, *Endothyranopsis crassa* (Brady) emend. Cumming and *Palaeotextularia* spp. Accordingly, they correlated the host strata with the lower part of Foraminiferal zone 15, which Mamet (1962, 1974) had dated as late Viséan (Vb3 in terms of the Belgian succession).

The Western Zone of the Jebilet Massif comprises a thick succession of Cambrian and Ordovician strata representing the southerly extension of the autochthonous coastal block, which crops out more extensively to the north in the Rehamna and Central Meseta massifs (Huvelin 1977; Piqué and Michard 1989).

Paleogeographic reconstructions of the Jebilet Massif depict a complex basin where tectonism and sedimentation occurred synchronously in a system of horsts and grabens delimited to the east and west by emergent land masses (Bordonaro et al. 1979; Beauchamp and Izart 1987). Subsequent interpretations suggested a foreland-type basin delimited by shear zones (Bouabdelli and Piqué 1996) or a transtensive pull-apart basin bounded by strike-slip faults (Houari and Hoepffner 2003; Hoepffner et al. 2005). In accordance with the principal Variscan trend, this basin has its equivalent in the northern Central Massif, in the Sidi-Bettache Basin (Mayol and Muller 1985; Piqué and Michard 1989).

All these rocks were deformed in the Pennsylvanian, during the major compressive phase of the Variscan Orogeny in Morocco (Michard 1976; Piqué and Michard 1989). This complex and polyphased deformation produced compressed folds and multi-directional faults, developing schistosity and lineations that conform to the regional N-S Variscan trend (Huvelin 1977; Bordonaro 1983; Mayol 1987). The manifestations of deformation in the Jebilet Massif are heterogeneous. The weak deformation evinced by the Eastern and Western zones contrasts with the intensive compression observed in the Central Jebilet, where gently deformed bands alternate with N-S shear zones, reproducing the same deformational pattern on a smaller scale. These shear zones, together with the two major shears delimiting the Central Jebilet, canalized most of the deformation, and



TEXT-FIGURE 2
Stratigraphic section of the Sarhlef Series at Sidi M'Barek ore body of
Draa Sfar showing the sequence intersected by the borehole DS125.
Modified from Bernand et al. (1988) and, Ministère de l'Energie et des
Mines (1997), and Moreno et al. (in press).

facilitated the intrusion of syntectonic granodiorite plutons (Piqué et al. 1980; Piqué and Michard 1989).

The Draa Sfar sulphide deposit, mined by MANAGEM (subsidiary of ONA), is located 16km north of Marrakech, near the southern border of the Jebilet Massif (text-fig. 1). It is made up of lenticular ore bodies hosted by the black shales and volcanic rocks of the Sarhlef Series (Dagbert and Harfi 2002). The main ore mineral is pyrrhotite, although sphalerite, chalcopyrite, galena, arsenopyrite and pyrite are also common. The deposit is subdivided into two main ore bodies, each consisting of one or several mineralized horizons. The ore bodies are Tazakourt in the south; and Sidi M'Barek, in the north, the latter providing the material for the present study.

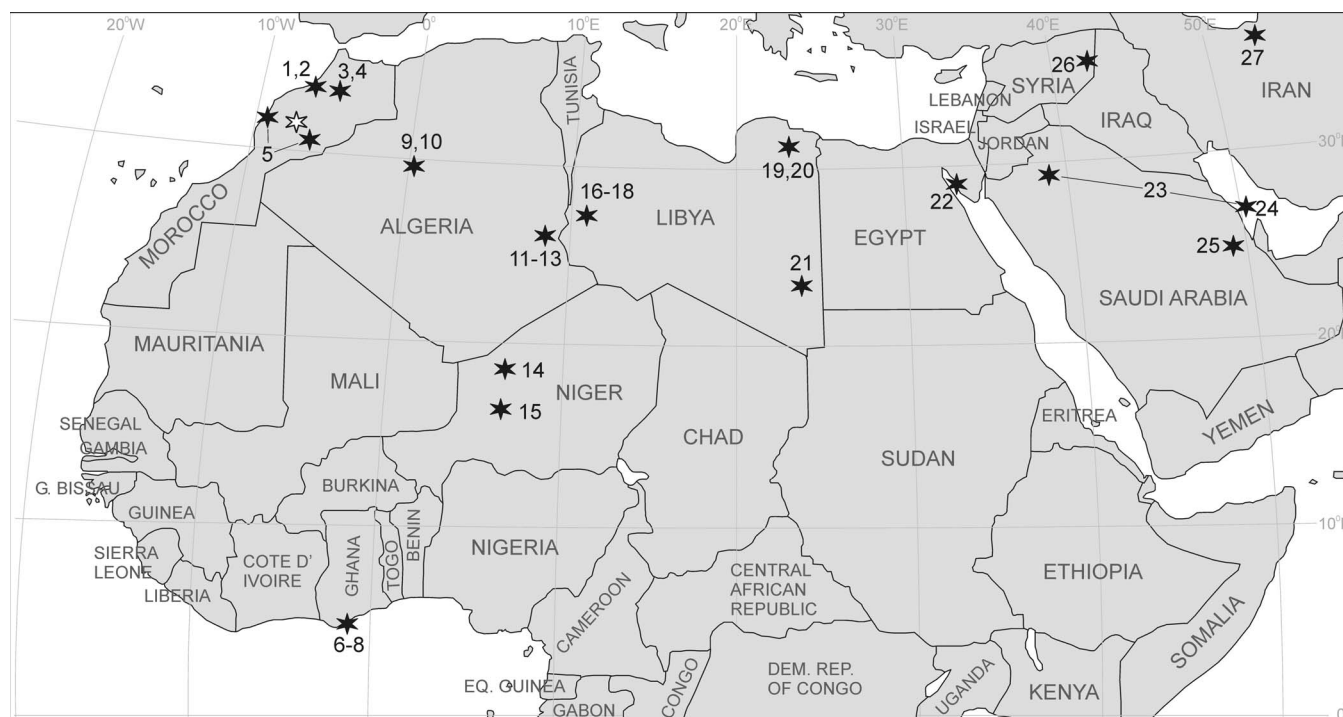
PREVIOUS PALYNOLOGICAL STUDIES ON THE MISSISSIPPIAN OF NORTH AFRICA AND NEIGHBORING GONDWANAN REGIONS

Palynological studies of Mississippian strata in Northern Gondwana have been less intensive than in many other Paleozoic regions, due in part to limited exposures. Oil exploration in the North African region has provided an incentive for palynological investigations of subsurface successions since the 1950s, but relatively little attention has been accorded Carboniferous strata, compared to other economically more attractive Paleozoic and Mesozoic targets. Furthermore, the palynozonal schemes that have been proposed for Mississippian sections in the region mostly lack rigorous taxonomic foundations. Hence,

Locality numbers	Authors and dates	Country	Location	Lithostratigraphic units (descending order)	Inferred age
1	Marhoumi et al. (1984)	Morocco	Mdakra Massif. Sidi Bettache Basin	Mechra, Korifla and Akrech fms.	Tournaisian-middle Viséan
2	Loboziak et al. (1990)	Morocco	Mdakra Massif	Sidi Sebâa Formation	late Tournaisian and late Viséan
3	Bouabdelli and Doubinger (1990)	Morocco	Central Moroccan Massif	Migoumess Formation	Tournaisian
4	Ouarache et al. (1991)	Morocco	Adarouch area	unspecified	late Viséan
5	Rahmani-Antari and Lachkar (2001)	Morocco	Doukkala and Essaouira Basins. Erfoud region	unspecified	Tournaisian-early Viséan
6	Bär and Riegel (1974)	Ghana	South Ghana	Sekondi Group	Tournaisian
7	Atta-Peters (1996)	Ghana	South Ghana	Sekondi Group	Tournaisian
8	Atta-Peters and Anan-Yorke (2003)*	Ghana	South Ghana	Sekondi Group	Tournaisian
9	Lanzoni and Magloire (1969)	Algeria	Mac-Mahon, Béchar, Benoud and Timimoun basins. Grand Erg Occidental	Bahmer, Ahrlad, Timimoun and Kahla fms.	Tournaisian-late Viséan
10	Coquel and Abdesselam-Rouighi (2000)	Algeria	Béchar Basin. Grand Erg Occidental	Kebir, Archipel, Goumriat and Ioucha fms.	Tournaisian-late Viséan
11	Attar et al. (1980)	Algeria	Illizi Basin	Illerène, Issendjel, Assekaïf, Oubarakat and El Adeb Arache fms.	Tournaisian-Serpukhovian
12	Coquel and Latreche (1989)	Algeria	Illizi Basin	Illerène Formation	Tournaisian-Viséan
13	Abdesselam-Rouighi and Coquel (1997)	Algeria	Illizi Basin	Assékaïf and Issendjel fms.	Tournaisian-Serpukhovian
14	Coquel et al. (1995)	Niger	Tim Mersoï sub-basin. Agadès Basin	Tarat, Tchinezogue, Guézouman and Talak fms.	Viséan- possibly Bashkirian
15	Loboziak and Alpern (1978)*	Niger	Agadès Basin	unspecified	late Viséan
16	Massa et al. (1980)	Libya	Rhadamès Basin	Tiguentourine, Dembaba, Assedjefar and M'Rar fms.	Tournaisian-Middle Pennsylvanian
17	Coquel and Moreau-Benoit (1986)*	Libya	Rhadamès Basin	M'Rar Formation	Tournaisian
18	Coquel et al. (1988)	Libya	Rhadamès Basin	Dembaba and Assedjefar fms.	late Viséan-Moscovian
19	Clayton and Loboziak (1985)	Libya	Cyrenaica	unspecified	earliest Viséan and Serpukhovian
20	Loboziak and Clayton (1988)*	Libya	Cyrenaica	unspecified	Middle Mississippian-earliest Cisuralian
21	Grignani et al. (1991)	Libya	Kafrah Basin	Dalma Formation	Tournaisian-middle Viséan
22	Kora (1993)	Egypt	West-central Sinai	Abu Thora Formation	Viséan and Bashkirian-early Moscovian
23	Clayton (1995)	Saudi Arabia	East Saudi Arabia	Berwath Formation	Tournaisian, late Viséan and early Serpukhovian
24	Clayton et al. (2000)	Saudi Arabia	East Saudi Arabia	Berwath Formation	Tournaisian and late Viséan-early Serpukhovian
25	Owens et al. (2000)	Saudi Arabia	East-central Saudi Arabia	Berwath Formation	early Serpukhovian
26	Ravn et al. (1994)*	Syria	West Syria	Doubayat Group	Tournaisian? and Viséan?
27	Coquel et al. (1977)	Iran	East Elburz Mountains	Mobarak and Khosh-Yeilagh fms.	Tournaisian and Viséan

TEXT-FIGURE 3

Compilation of the most relevant literature on Mississippian palynology of the North Gondwanan region. Notes: (a) for numbered localities see text-fig. 4; (b) asterisk indicates publications that include descriptions of palynomorphs; (c) “inferred age” is that stated originally in the cited literature.



TEXT-FIGURE 4

Locations of principal palynological studies of the Mississippian of Northern Gondwana. The present study is indicated by a white star. For authors of those studies represented by black stars see text-figure 3.

such correlations that have been attempted with independent (faunal) biostratigraphic markers have generally proven controversial. Thus, the efficacy of Mississippian palynostratigraphy of North Africa is currently more of potential than actual substance. The follow paragraphs (see also text-figs. 3 and 4) summarize the most relevant investigations that have been conducted in the Mississippian of North Africa and adjacent regions.

Morocco

Palynological studies focused on the Mississippian of Morocco are fewer than in other North African Paleozoic areas. Furthermore, the publications cited below are based largely on the chronostratigraphic potentiality of the miospores, with scant supporting systematic-descriptive documentation.

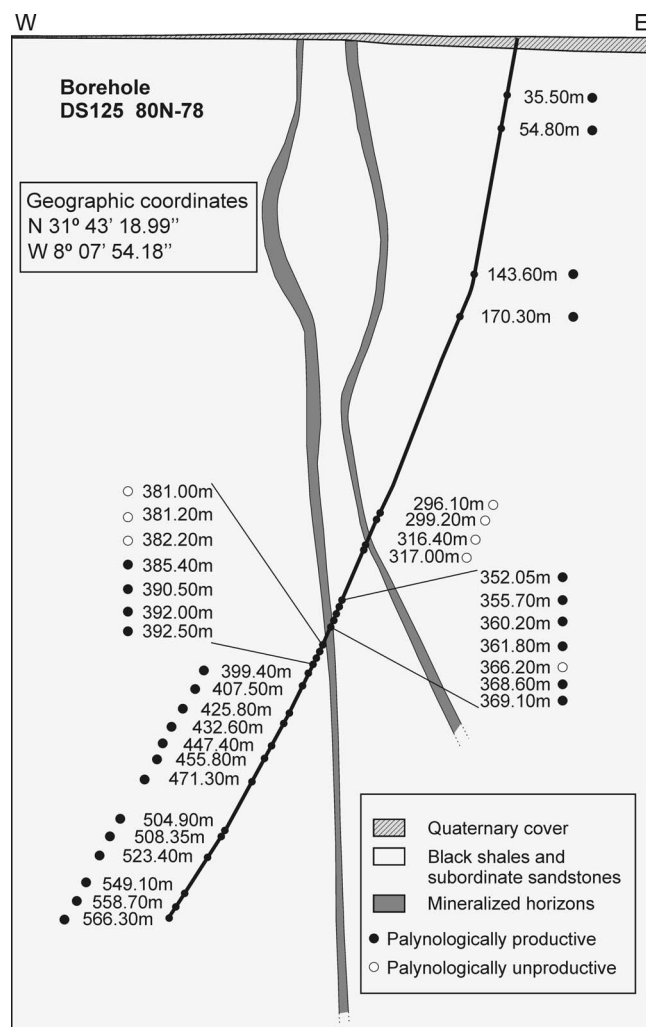
The initial publication dealing with the Mississippian palynoflora of Morocco is that of Marhoumi et al. (1984). They sampled the Hallauf and Korifla formations in the Sidi-Bettache Basin, Mdakra Massif, and recognized five assemblages consecutively ascribed to the early Tournaisian-early Viséan PL, NV, PC, CM and Pu miospore biozones of the Western European zonation (Clayton et al. 1977). Marhoumi et al. (1984) represents a part of Marhoumi's (1984) unpublished PhD thesis, which embraces more comprehensively the systematic description and biostratigraphy of Ordovician, Devonian and Mississippian palynomorphs from the northwestern and central Moroccan Meseta. Also from the Mdakra Massif, but in the Sidi Sebâa Formation, Loboziak et al. (1990) recorded miospores together with foraminifers of reputedly late Tournaisian and middle Viséan age.

The eastern part of the Central Moroccan Massif was investigated by Bouabdelli and Doubinger (1990). From the Migoumess Formation these authors obtained an assemblage of miospores and subordinate organic-walled microphytoplankton that they dated as Tournaisian. Subsequently, Ouarhache et al. (1991) studied the foraminifers of a carbonate lens at the base of the same formation and suggested a late Viséan age. In the same paper, these authors obtained both foraminifers and palynomorphs, also ascribed to the late Viséan, from a carbonate-shaly sequence cropping out northeast of the Central Moroccan Massif.

The only paper attempting a miospore zonation of the Devonian-Carboniferous of Morocco is that of Rahmani-Antari and Lachkar (2001). These authors analyzed core samples from two basins located in the Western Meseta Domain, and outcrop samples from the Tafilalt region, eastern Anti-Atlas. They proposed 12 miospore biozones intermittently spanning the Lower Devonian (Pragian) through Mississippian (lower Viséan). Nine of these zones could be correlated with Devonian miospore zones established by Richardson and McGregor (1986) in the Old Red Sandstone region, and the other three had their counterparts in the Western European scheme of Clayton et al. (1977; modified by Higgs et al. 1988).

Algeria

The first miospore zonation of the Devonian-Carboniferous of North Africa was proposed by Lanzoni and Magloire (1969) in the Grand Erg Occidental, Algerian Sahara. These authors studied several core samples from 20 oil exploration wells penetrating the Mac-Mahon, Béchar, Benoud and Timimoun basins. They reported numerous miospore and acritarch species, the



TEXT-FIGURE 5
DS125 borehole section indicating the palynological sampling levels.

stratigraphic ranges of which were used to define four palynozones. Collectively embracing the late Famennian-late Viséan, these zones were designated, in ascending stratigraphic order, as follows: *Hymenozonotriletes lepidophytus* (*Retispora lepidophyta* in current terminology); *Convolutispora*; Spore monolète zonale n° 2874; and *Densosporites* et *Verrucosiporites*. The oldest zone was subdivided into four subunits and the succeeding zones comprised two subzones each. This scheme has served as a useful reference for subsequent papers dealing with the Upper Paleozoic palynostratigraphy of North Africa, despite the essentially informal taxonomic documentation.

Coquel and Abdesselam-Rouighi (2000) studied seven boreholes in the Béchar Basin, four of which had previously been investigated by Lanzoni and Magloire (1969). They highlighted the biostratigraphic relevance of some species not reported by Lanzoni and Magloire (1969), and revised the dating of subzone M4 as late Viséan.

The next miospore zonation proposed for the Algerian Devonian-Carboniferous succession was that of Attar et al. (1980). They utilized over 300 core and cuttings samples from 17 bore-

holes penetrating the Illerène, Issendjel, Assekaïf, Oubarakat and El Adeb Arache formations of the Illizi Basin, thereby establishing six zones (I-VI). In a subsequent palynological study of the Illerène Formation, Coquel and Latreche (1989) examined 240 samples from 20 boreholes, and divided Biozone II of Attar et al. (1980) into subunits IIa, IIb and IIc. Abdesselam-Rouighi and Coquel (1997) analyzed 71 samples from two exploration wells also in the Illizi Basin. They corroborated the miospore zonation of Attar et al. (1980), identifying representatives of five of the six original zones in the uppermost Devonian-Mississippian succession.

Libya

In palynostratigraphic terms, the Rhadamès Basin, which is an extension of the Algerian Illizi Basin, is one of the most intensively investigated basins in Northern Gondwana. Massa et al. (1980) initiated Carboniferous palynological studies of the Rhadamès Basin in western Libya. They examined the palynological contents of three oil exploration wells (A1-49, B1-49 and C1-49) intersecting the Tahara, M'Rar, Assedjefar, Dembaba and Tiguentourine formations, and recognized seven successive miospore zones (from XI through XVII) in the latest Devonian-Middle Pennsylvanian interval. In a complementary publication, Coquel and Moreau-Benoit (1986) revised the miospore zonations established previously in western Libya; namely, that of Massa et al. (1980), as above, and also that of Massa and Moreau-Benoit (1976). Coquel and Moreau-Benoit (1986) compared the Devonian-Carboniferous palynofloras of the Rhadamès Basin with published and unpublished miospore data from adjacent regions of Libya and from Algeria, Morocco, Iran and Western Europe. Furthermore, they systematically described and illustrated 14 miospore species (six new), documented the local stratigraphic ranges of 136 species within the upper Famennian-Tournaisian zones XI and XII, and provided brief notes on the synonymy of selected species. Coquel et al. (1988) revised Biozones XII-XVII of Massa et al. (1980) and compared the Mississippian palynoflora of the Rhadamès Basin with those reported from adjacent areas of North Africa and from Western Europe. In Cyrenaica, northeastern Libya, Clayton and Loboziak (1985) and Loboziak and Clayton (1988) reported a Mississippian palynoflora recovered from seven boreholes. In the 1985 paper they defined two miospore assemblages of earliest Viséan and Serpukhovian age respectively, illustrating the most representative species. Later, Loboziak and Clayton (1988) established a miospore zonation for the Middle Mississippian-earliest Cisuralian of northwestern Libya. Four successive zones were proposed and compared with the palynofloras of other Gondwanan regions. They also included notes on the more stratigraphically significant species and instituted three new species.

In the Kafrah Basin of southeastern Libya, Grignani et al. (1991) investigated samples from three oil exploration wells. They proposed 19 miospore zones, ranging in age from latest Ordovician to Early Triassic. Three successive biozones (designated 12, 13 and 14) covered the Tournaisian-middle Viséan interval, represented by the Dalma Formation.

Other Northern Gondwanan and neighboring regions

The Lower Mississippian palynoflora of southeastern Ghana, at the southern margin of the West African Craton, has been studied by Bär and Riegel (1974), Atta-Peters (1996) and Atta-Peters and Anan-Yorke (2003). These authors observed, in particular, a distinct similarity between their lower Tournaisian

miospore assemblages and those reported from other regions of Gondwana and from Laurasia.

Loboziak and Alpern (1978) obtained a late Viséan assemblage from coal samples from several boreholes located in the Agadès Basin of central northwestern Niger, at the eastern margin of the West African Craton. Although these authors did not provide a comprehensive taxonomic listing, they included notes on selected species and genera, and instituted two new species (*Vallatisporites agadesensis* and *Spelaeotriletes owensii*). Coquel et al. (1995) recorded abundant, well-preserved Mississippian palynomorphs from a succession of four formations also in the Agadès Basin (Tim Mersoï sub-basin). By reference to published ranges of particular spore species in North Africa, they dated the succession as Viséan-possibly Bashkirian.

Kora (1993) summarized palynological knowledge of the Egyptian Carboniferous, and reported two miospore assemblages of Viséan and Bashkirian-early Moscovian age from the Abu Thora Formation in the west-central Sinai. Both palynofloras included forms known from the Mississippian of North Africa, Western Europe, North America and Western Australia.

Mississippian palynostratigraphic studies of Saudi Arabia were initiated by Clayton (1995). He reported the miospore content of 11 core samples from three oil exploration wells (ABSF-29, AR'AR n°1 and ST-8) intersecting the Berwath Formation, and compared the palynoflora with the miospore contents of zones erected in Algeria and Libya by Massa et al. (1980) and Loboziak and Clayton (1988), respectively. A single sample from the ABSF-29 well was dated as Tournaisian; four samples from AR'AR n°1 as transitional Viséan-Serpukhovian; and the other six samples, from ST-8, were dated somewhat broadly as late Viséan-early Serpukhovian. Samples from the HRML-51 well and additional material from ABSF-29 were subsequently investigated by Clayton et al. (2000). From 19 samples they described two assemblages in the Devonian Jubah Formation and two others in the Carboniferous Berwath Formation. The Devonian assemblages, named the *Verruciretusispora famenensis* Assemblage and the *Retispora lepidophyta* Assemblage, were dated respectively as late and latest Famennian. The oldest Carboniferous palynoflora, the *Indotriradites explanatus* Assemblage, was dated as early Tournaisian; the younger suite was assigned to the late Viséan-early Serpukhovian RT miospore zone of Loboziak and Clayton (1988). Further samples from the Berwath Formation penetrated by the HRDH-601 well were analyzed by Owens et al. (2000), who recovered a poorly preserved palynoflora interpreted as early Serpukhovian in age.

The single study of Upper Devonian-Mississippian palynofloras of Syria was conducted by Ravn et al. (1994). Analyzing cuttings samples from four boreholes intersecting the Doubayat Group, eastern Syria, these authors recognized one Devonian (upper Famennian) and two Carboniferous (Tournaisian? and Viséan?) assemblages with a clear Gondwanan affinity. An appendix provided brief taxonomic notes and definition of a new species; however, the stated intention to present more biostratigraphic documentation has yet to be realized.

In northeastern Iran, Coquel et al. (1977) investigated palynomorphs of an Upper Devonian-Mississippian succession in the eastern Elburz Mountains. They recognized three palynological assemblages, dated respectively as late Famennian, Tournaisian and Viséan. Whereas the two older assemblages showed a cosmopolitan complexion, the Viséan assemblage was considered

closely affiliated with the similarly dated North African palynoflora.

Two papers, concerned primarily with systematic descriptions of Mississippian miospores from Northern Gondwana, are noteworthy. Loboziak et al. (1986) erected *Aratrisporites saharaensis*, a distinctive form seemingly omnipresent in the North African Tournaisian-Viséan. Coquel and Moreau-Benoit (1989) described 14 cavate miospores from Upper Devonian-Mississippian strata of Algerian Sahara and Libya.

In addition to the works cited above, useful comparisons, reassessments and commentaries dealing, at least in part, with the Upper Paleozoic palynostratigraphy of Northern Gondwana have appeared. These include Coquel (1985), Coquel and Massa (1993), Streel and Loboziak (1994), Abdesselam-Rouighi et al. (1998), Loboziak et al. (1998), Coquel and Abdesselam-Rouighi (1999) and Loboziak et al. (2000a, b).

MATERIAL AND METHODS

The present study is based on 35 core samples from DS125, a borehole that penetrated 567m of an overturned shaly sequence of the Sarhlef Series at Draa Sfar and intersected two mineralized horizons of the Sidi M'Barek ore body (text-fig. 5). Twenty-seven samples proved to contain palynomorphs in fair to good states of preservation. Whereas all the samples collected from the basal and upper part of the intersected sequence were productive, those from the central sector, in the vicinity of the massive sulfides, yielded dissimilar results. The samples from the near proximity of the lower mineralized horizon yielded, at best, unidentifiable (highly fragmented, carbonized) palynomorphs, whereas those hosting the upper horizon were mostly productive. This is shown in text-fig. 5, which depicts the stratigraphic position of each sample, and the location of the massive sulfides, in the DS125 borehole.

Laboratory procedures used for the extraction and concentration of the palynomorphs followed those described by Wood et al. (1996). Approximately 30g of each sample were carefully cleaned and disaggregated prior to removal of carbonates by immersion in cold hydrochloric acid (36%). Silicates were then dissolved with hydrofluoric acid (40%), and fluorides and any remaining carbonates were eliminated by further immersion in hot hydrochloric acid (36%). The organic residue so obtained was oxidized with fuming Schulze solution for times varying, as appropriate, from 15 to 35 minutes. Following washing and neutralization with distilled water, the palynomorphs were concentrated using a 20µm sieve. For identification and quantitative analysis, a minimum of two permanent slides per sample were mounted using "Cellosize" as dispersing agent and "Elvacite" as mounting medium. In addition, palynomorphs from the best-preserved and more productive residues were picked and mounted individually in glycerine jelly for taxonomic identification under light microscopy (LM). These residues were also used for single-specimen picking for scanning electron microscopy (SEM).

LM was performed at the Department of Geology, University of Huelva, Spain, and the Department of Earth Sciences, The University of Queensland, Australia, using Nikon Labaphot-2 and Olympus BH-2 microscopes, respectively. Photomicrographs were taken with a Nikon Digital Coolpix 995 and a Leica DFC Twain 320. SEM was performed at the University of Huelva using a JEOL JSM-5410 instrument.

All type and other figured specimens are to be permanently deposited in the Museo Geominero del Instituto Geológico y Minero de España, Madrid. For curatorial details, see Appendix 1.

SYSTEMATIC PALEONTOLOGY

The miospore genera and species are morphotaxa constituted under provisions of the International Code of Botanical Nomenclature (I.C.B.N.; McNeill et al. 2006). Suprageneric classification follows the scheme initiated by Potonié and Kremp (1954) and subsequently modified by Dettmann (1963), Richardson (1965), Potonié (1966, 1970, 1975) and Smith and Butterworth (1967). Morphological terminology accords with glossaries provided by Dettmann (1963), Kremp (1965), Smith and Butterworth (1967), and Playford and Dettmann (1996). Measurements of miospore equatorial diameter (excluding the size of any projecting sculptural elements) are given by the lowest and highest values, generally with the arithmetic mean in brackets, e.g., 35 (42) 54µm. New species are instituted on the basis of at least 12 adequately preserved specimens. Where definitive assignment of one or several specimens to a previously instituted species is uncertain, the abbreviation “cf.” precedes the trivial epithet. Where only a limited number of specimens of a possibly new species are available, an informal letter-designation is used, e.g., “sp. A.” Slide locations of all type and other figured specimens are specified in the systematic descriptions and Appendix 1.

Descriptive systematics

Anteturma PROXIMEGERMINANTES R. Potonié 1970

Turma TRILETES Reinsch 1881 emend. Dettmann 1963

Suprasubturma ACAVATITRILETES Dettmann 1963

Subturma AZONOTRILETES Lubér 1935 emend. Dettmann
1963

Genus *Leiotriletes* Naumova 1939 ex Ishchenko 1952 emend. R. Potonié and Kremp 1954

Type species: Leiotriletes sphaerotriangulus (Loose 1932) R. Potonié and Kremp 1954, by subsequent designation of Potonié and Kremp (1954, p. 120).

Leiotriletes inermis (Waltz 1938) Ishchenko 1952

Plate 1, figures 1, 2

Azonotriletes inermis Waltz in LUBER and WALTZ 1938, p. 11, pl. 1, fig. 3, pl. 5, fig. 58, pl. A, fig. 2.

Leiotriletes inermis (Waltz 1938) ISHCENKO 1952, p. 9, pl. 1, figs. 2, 3.

For further synonymy see Playford (1962, p. 574).

Description: Spores radial, trilete; amb subtriangular with slightly concave sides and rounded apices. Laesurae distinct, simple, straight, almost reaching equatorial margin. Exine 1-1.5µm thick, laevigate.

Dimensions (14 specimens): Equatorial diameter 42 (45) 57 μm .

Previous records: Mainly reported from Eastern Europe in Devonian-lower Pennsylvanian rocks; also from Northern Gondwana (Viséan of Niger: Loboziak and Alpern 1978).

Genus *Punctatisporites* Ibrahim 1933 emend. R. Potonié and Kremp 1954

Type species: Punctatisporites punctatus (Ibrahim 1932) Ibrahim 1933, by original designation.

[illegible]

TEXT-FIGURE 6

Occurrence of miospore species in the palyniferous samples which are specified by respective depths (in meters) in borehole DS125 and laboratory preparation numbers. Relative abundances of individual species, based mainly on counts of 250 specimens per sample, are denoted as follows: r, rare, <1%; u, uncommon, >1-5%; c, common, >5-10%; a, abundant, >10-25%; v, very abundant, >25%. Notes: (a) asterisks indicate samples in which counting was based on <250 specimens; (b) presence of a particular (rare) species, but not in actual count is italicized (*r*).

Punctatisporites spp.

Remarks: Most of the analyzed samples include numerous simple, laevigate to scabrate, circular-subcircular trilete miospores attributable to *Punctatisporites* Ibrahim 1933 emend. R. Potonié and Kremp 1954. Specific segregation of many of these forms was not attempted due to their negligible stratigraphic value.

However, the following previously instituted species, all known from Carboniferous strata, proved identifiable.

Punctatisporites glaber (Naumova in Luber and Waltz 1938) Playford 1962 (pp. 576-577, pl. 78, figs. 15, 16); Plate 1, figure 3 herein

Punctatisporites irrasus Hacquebard 1957 (p. 308, pl. 1, figs. 7, 8); Plate 1, figures 4, 5

Punctatisporites minutus Kosanke 1950 (pp. 15-16, pl. 16, fig. 3); Plate 1, figures 6-8

Punctatisporites planus Hacquebard 1957 (p. 308, pl. 1, figs. 12); Plate 1, figures 9, 10

Infraturma **RETUSOTRILETI** Streel in Becker, Bless, Streel and Thorez 1974

Genus ***Retusotriletes*** Naumova 1953 emend. Streel 1964

Type species: Retusotriletes simplex Naumova 1953, by subsequent designation of Potonié (1958, p. 13).

Retusotriletes crassus Clayton 1980
Plate 2, figures 1-3

Phyllothescotriletes sp. n° 840 of LANZONI and MAGLOIRE 1969, pl. I, figs. 3, 4. [no description]

Retusotriletes sp. A of HIGGS 1975, p. 395, pl. 1, figs. 9-13.

Retusotriletes crassus CLAYTON in CLAYTON, JOHNSTON, SEVASTOPULO and SMITH 1980, p. 97, pl. 3, figs. D-H.

Description: Spores radial, trilete; amb subcircular to rounded subtriangular. Laesurae distinct, simple, straight, extending ca. three-quarters of distance to equator, terminating in well-defined curvaturae perfectae. Exine 1-1.5µm thick, laevigate, scabrate (corrosion effect?) or slightly granulate. Contact areas thickened, polumbra extending one-half to four-fifths equator-wards from proximal pole.

Dimensions (20 specimens): Equatorial diameter 41 (49) 59µm.

Previous records: This species has been recorded commonly from the uppermost Famennian and Tournaisian of Ireland (Higgs 1975; Keegan 1977; Clayton et al. 1980; Van der Zwan 1980; Keegan and Feehan 1981; Higgs et al. 1988; Graham and Clayton 1994); England (Higgs and Clayton 1984); Germany (Higgs and Streel 1984); Belgium (Higgs 1996); Portugal (Pereira et al. 1994; Pereira 1999); Spain (González et al. 2002, 2005, 2006); Colombia (Dueñas and Césari 2005, 2006); Canada (Utting 1987; Utting et al. 1989); Libya (Coquel and Moreau-Benoit 1986); Saudi Arabia (Clayton et al. 2000); and Ghana (Atta-Peters and Anan-Yorke 2003). However, younger occurrences of this species have also been reported, especially in Northern Gondwana; viz., Viséan of Syria (Ravn et al. 1994); upper Viséan of northeastern Libya (Clayton and Loboziak 1985); and upper Viséan-lower Serpukhovian of Saudi Arabia (Clayton 1995).

Retusotriletes incohatus Sullivan 1964
Plate 1, figures 11, 12

Retusotriletes incohatus SULLIVAN 1964, p. 1251, pl. 1, figs. 5-7.

Aneurospora incohata (Sullivan 1964) Streel in BECKER et al. 1974, p. 24, pl. 16, fig. 4.

Dimensions (10 specimens): Equatorial diameter 41 (48) 69µm.

Previous records: Widely distributed, mainly in the northern hemisphere, within the Upper Devonian through Mississippian interval.

Infraturma **APICULATI** Bennie and Kidston 1886 emend. R. Potonié 1956

Subinfraturma **GRANULATI** Dybová and Jachowicz 1957

Genus ***Waltzisporea*** Staplin 1960

Type species: Waltzisporea lobophora (Waltz 1938) Staplin 1960, by original designation.

Waltzisporea polita (Hoffmeister, Staplin and Malloy 1955) Smith and Butterworth 1967

Plate 2, figure 4

Granulati-sporites politus HOFFMEISTER, STAPLIN and MALLOY 1955, p. 389, pl. 36, fig. 13.

Waltzisporea polita (Hoffmeister, Staplin and Malloy 1955) SMITH and BUTTERWORTH 1967, pp. 159-160, pl. 6, fig. 14.

For further synonymy see Playford and Powis (1979, p. 380).

Dimensions (1 specimen): Equatorial diameter 33µm.

Previous records: Reported worldwide from Viséan-Namurian strata (see Playford 1991, p. 93; Dino and Playford 2002, p. 342). In Northern Gondwana, the species has been recorded from the middle-upper Viséan of Morocco (Loboziak et al. 1990; Ouarhache et al. 1991) and upper Viséan-lower Serpukhovian of Saudi Arabia (Clayton 1995) and northeast Libya (Clayton and Loboziak 1985; Loboziak and Clayton 1988).

Subinfraturma **VERRUCATI** Dybová and Jachowicz 1957

Genus ***Verrucosisporites*** Ibrahim 1933 emend. Smith and Butterworth 1967

Type species: Verrucosisporites verrucosus (Ibrahim 1932) Ibrahim 1933, by original designation.

Verrucosisporites* sp. cf. *V. aspratilis Playford and Helby 1968
Plate 2, figures 5, 6

cf. *Verrucosisporites aspratilis* PLAYFORD and HELBY 1968, p. 108, pl. 9, figs. 3-5.

Description: Spores radial, trilete. Amb subcircular. Laesurae distinct to barely perceptible, simple, straight, at least three-quarters of spore radius in length. Exine 1-2.5µm thick, comprehensively sculptured with discrete or rarely fused verrucae, 1-6µm in basal diameter, 2-5µm high, up to 4µm apart. Verrucae variable in shape and size on a given specimen; rounded in profile and subcircular to highly irregular in basal outline. Sculpture reduced in contact areas.

Dimensions (12 specimens): Equatorial diameter 24 (33) 43µm.

Comparison: These specimens closely resemble *Verrucosisporites aspratilis* Playford and Helby 1968 but differ in being somewhat smaller and possessing verrucae with more irregular basal outlines.

Previous records: *Verrucosisporites aspratilis* was originally recorded per se from New South Wales (Playford and Helby 1968) in rocks now dated as late Viséan (Jones 1996).

MIOPORE SPECIES \ GEOGRAPHIC REGIONS	Morocco	Algeria	Niger	Libya	Egypt	Saudi Arabia	Syria	Iran
<i>Leiotriletes inermis</i>	✓		✓					
<i>Punctatisporites</i> spp.	✓	✓	✓	✓	✓	✓	✓	✓
<i>Retusotriletes crassus</i>	✓			✓		✓	✓	
<i>Retusotriletes incohatus</i>	✓	✓	✓	✓	✓	✓		
<i>Waltzispota polita</i>	✓			✓		✓		
<i>Verrucosisporites aspratilis</i>	✓,cf.							
<i>Lycospora pusilla</i>	✓	✓	✓	✓	✓	✓		✓
<i>Vallatisporites agadesensis</i>	✓,cf.	✓	✓	✓		✓	✓	✓
<i>Vallatisporites galearis</i>	✓					✓		
<i>Vallatisporites vallatus</i>	✓					✓	✓	
<i>Vallatisporites verrucosus</i>	✓			✓		✓	✓	✓
<i>Auroraspora solisorta</i>	✓		✓		✓	✓		
<i>Endosporites micromanifestus</i>	✓			✓				
<i>Spelaetriletes arenaceus</i>	✓	✓	✓	✓	✓	✓		✓
<i>Spelaetriletes owensii</i>	✓,cf.	✓	✓	✓	✓	✓	✓	✓
<i>Laevigatosporites vulgaris</i>	✓		✓		✓			
<i>Monoletes ellipsoides</i>	✓	✓		✓		✓		
Sources of published data	1-6	7-11	12,13	14-19	20	21-23	24	25

TEXT-FIGURE 7

Mississippian-age occurrences of miospore species as recorded herein from the Draa Sfar samples and in other Northern Gondwanan and neighboring areas. Ticks and “cf.” notations indicate respectively positive and “comparative” occurrences of individual species. Key to data sources: 1, present study; 2, Marhoumi et al. (1984); 3, Loboziak et al. (1990); 4, Bouabdelli and Doubinger (1990); 5, Ouarhache et al. (1991); 6, Rahmani-Antari and Lachkar (2001); 7, Lanzoni and Magloire (1969); 8, Attar et al. (1980); 9, Coquel and Latreche (1989); 10, Abdesselam-Rouighi and Coquel (1997); 11, Coquel and Abdesselam-Rouighi (2000); 12, Loboziak and Alpern (1978); 13, Coquel et al. (1995); 14, Massa et al. (1980); 15, Clayton and Loboziak (1985); 16, Coquel and Moreau-Benoit (1986); 17, Coquel et al. (1988); 18, Loboziak and Clayton (1988); 19, Grignani et al. (1991); 20, Kora (1993); 21, Clayton (1995); 22, Clayton et al. (2000); 23, Owens et al. (2000); 24, Ravn et al. (1994); 25, Coquel et al. (1977).

Subinfraturma NODATI Dybová and Jachowicz 1957

Genus *Anapiculatisporites* R. Potonié and Kremp 1954

Type species: Anapiculatisporites isselburgensis R. Potonié and Kremp 1954, by original designation.

Anapiculatisporites sp. A

Plate 2, figures 7, 8

Description: Spores radial, trilete. Amb subtriangular, sides concave or slightly convex, apices rounded. Laesurae distinct, straight, simple, almost reaching equatorial margin. Exine thin (ca. 0.7µm thick). Much of distal exine (i.e., apart from outer interradian regions) sculptured with regularly distributed coni ca. 1µm in basal diameter and height, up to 1.2µm apart. Sculpture absent equatorially and proximally.

Dimensions (2 specimens): Equatorial diameter 25, 26µm.

Comparison: *Anapiculatisporites concinnus* Playford 1962 (pp. 587-588, pl. 80, figs. 9-12) has a slightly more rounded amb; larger, more widely spaced coni; and generally shorter laesurae.

Genus *Diatomozonotriletes* Naumova 1939 emend. Playford 1963

Type species: Diatomozonotriletes saetosus (Hacquebard and Barss 1957) Hughes and Playford 1961; by subsequent designation of Playford (1963, p. 646).

Diatomozonotriletes sp. A

Plate 2, figures 9, 10

Description: Spores radial, trilete. Amb subtriangular with rounded apices and straight to slightly concave sides. Laesurae distinct, almost straight, extending nearly to equatorial margin, accompanied by narrow lips up to 1.5µm high. Exine 1.2-2µm thick; contact areas laevigate. Distal exine bearing coni and spinae 1.2-2µm in basal diameter, 2-3µm high, 1-1.2µm apart. Larger elements, consisting mainly of spinae with circular bases (1-2µm broad basally, 3.5-4.5µm long), developed along equatorial interradian. Sculpture slightly finer and sparser on apical regions.

Dimensions (3 specimens): Equatorial diameter 34, 36, 45µm.

Comparison: *Diatomozonotriletes rarus* Playford 1963 (pp. 649-650, pl. 93, figs. 15, 16, text-fig. 11e) is comparable to *D.* sp. A, but differs in having smaller and more widely spaced distal coni. *Tricidarispites phippisae* Playford and Satterthwait

SYSTEM	SUBSYSTEM	STAGE	Lanzoni and Magloire (1969)	Attar et al. (1980)	Massa et al. (1980)	Loboziak and Clayton (1988)	Selected miospore species
Carboniferous (part)	Pennsylvanian (part)	Bashkirian		VI	XVI	MJ	
	Mississippian	Serpukhovian					
		Viséan	M7	V	XV	RT	<i>R. crassus</i>
			M6	IV	XIV	OA	<i>V. verrucosus</i>
			M5		?	PO	<i>V. galearis</i>
			M4		XIII	?	<i>V. vallatus</i>
			?		?	VP	<i>V. agadesensis</i>
		Tournaisian	M3	III	XII	?	<i>A. solisorta</i>
			?				<i>S. owensii</i>
			M2				<i>W. polita</i>
							<i>L. pusilla</i>
							<i>S. arenaceus</i>
							<i>M. ellipsoides</i>

TEXT-FIGURE 8

Stratigraphic ranges in Northern Gondwanan strata of selected miospore species recorded herein from the Sarhlef Series at Draa Sfar Mine, with reference to the palynological zonal schemes of Lanzoni and Magloire (1969; Algeria), Attar et al. (1980; Algeria), Massa et al. (1980; Libya) and Loboziak and Clayton (1988; Libya).

1986 (pp. 14-15, pl. 5, figs. 8-14) is similarly sculptured distally, but is somewhat larger and lacks longer spinae along the equatorial interradii.

Infraturma MURORNATI R. Potonié and Kremp 1954

Genus *Reticulatisporites* Ibrahim 1933 emend. R. Potonié and Kremp 1954

Type species: *Reticulatisporites reticulatus* (Ibrahim 1932) Ibrahim 1933, by original designation.

Reticulatisporites? sp. A

Plate 2, figures 11, 12; Plate 3, figures 1a, b

Description: Spores with circular to subcircular amb. Laesurae not evident. Exine 2.5-4µm thick, comprehensively and uniformly reticulate. Reticulum perfectae consisting of coarse, laevigate, acutely crested muri, 2-4.5µm in basal diameter, 3-6.5µm high, enclosing polygonal lumina 13-20µm in maximum dimension. Exine within lumina microrugulate.

Dimensions (11 specimens): Equatorial diameter 34 (47) 63µm

Remarks: Positive assignment of these forms to *Reticulatisporites* Ibrahim 1933 emend. R. Potonié and Kremp 1954 is withheld because no haptotypic marks or structures were detected on any of the specimens. In that respect, they are possibly attributable to *Maculatasporites* Tiwari 1964. The microgranulate lumina floors are evident only by SEM.

Suprasubturma LAMINATITRILETES Smith and Butterworth 1967

Subturma ZONOLAMINATITRILETES Smith and Butterworth 1967

Infraturma CINGULICAVATI Smith and Butterworth 1967

Genus *Cristatisporites* R. Potonié and Kremp 1954 emend. Butterworth et al. in Staplin and Jansonius 1964

Type species: *Cristatisporites indignabundus* (Loose 1932) R. Potonié and Kremp 1954, by original designation.

Cristatisporites mixtus Playford, González and Moreno n. sp.

Plate 3, figures 2-6

Diagnosis: Spores radial, trilete, cingulicavate; amb subtriangular with serrate margin due to projecting spinae. Lae-

surae distinct to obscure, straight or slightly curved, generally accompanied by narrow lips, up to 1µm in overall width, extending to, or almost to, equatorial margin. Exine two-layered, cavate. Intexine distinct to obscure, laevigate, proximally attached to exoexine, up to 1µm thick, diameter ca. one-half to three-quarters of total spore diameter; outline conformable with amb or slightly more rounded. Exoexine extended equatorially to form zona. Distal exoexine sculptured with freely terminating or anastomosing muri, 2-5µm wide, enclosing irregular to rounded lumina up to 5µm in maximum dimension. Muri surmounted by rounded, bulbous-based spinae, discrete or fused basally, 1-3µm high, 0.5-3µm (usually <1.5µm) in basal diameter. Zona 3-7µm wide, commonly darker than remainder of exoexine, sculptured distally with flattened spinae, 1-5µm high, 1-3.5µm in basal diameter, commonly fused at bases. Non-spinose zona laevigate; remainder of unsculptured exoexine laevigate to punctate.

Dimensions (21 specimens): Overall equatorial diameter 35 (44) 58µm; diameter of intexine (polar view) 18 (29) 38µm.

Holotype: Preparation k693/a, L52/0; Plate 3, figures 5a, b. Amb subtriangular, margin serrate; overall equatorial diameter 51µm, intexine diameter 20µm. Laesurae hardly perceptible, narrowly lipped, extending almost to equatorial margin. Intexine perceptible, closely appressed to exoexine, occupying two-fifths of overall spore diameter; outline slightly more rounded than amb. Zona 4µm wide. Distal non-zonate exoexine bearing anastomosing muri, 2-5µm wide, enclosing irregular lumina; muri with rounded spinae 1-2µm high. Zona sculptured distally with flattened spinae 1-1.5µm wide and high. Proximal exoexine unsculptured.

Name derivation: Latin, *mixtus*, mixed; referring to the varied nature of the cristae.

Remarks and comparison: Attribution of this new species to *Cristatisporites* R. Potonié and Kremp 1954 emend. Butterworth et al. in Staplin and Jansonius 1964 (p. 108) is somewhat tentative because its distal sculpture is not clearly cristate. *Cristatisporites mixtus* Playford, González and Moreno n. sp. is comparable to *Cristicavatispora dispersa* González, Playford and Moreno 2005 (p. 26, pl. 5, figs. 9-12), but the latter is non-zonate and features cristate sculpture topped with smaller apiculate elements. A Western Gondwanan Pennsylvanian-Lower Permian species, *Cristatisporites lestai* Archangel-

sky and Gamarro 1979 (pp. 437-438, pl. VI, figs. 1-3), slightly resembles *C. mixtus*, but differs in having generally larger apiculate elements, a wider zona, and a more conspicuously indented equatorial margin.

Genus *Densosporites* Berry 1937 emend. Butterworth, Jansonius, Smith and Staplin 1964

Type species: *Densosporites covensis* Berry 1937, by original designation.

Densosporites dissonus Playford, González and Moreno n. sp.

Plate 3, figures 7-9; Plate 4, figure 1

Diagnosis: Spores radial, trilete, cingulicavate; amb rounded subtriangular. Laesurae distinct to perceptible, slightly sinuous, extending to inner margin of cingulum; commonly accompanied by narrow lips, ca. 1µm in overall width. Exine two-layered; intexine distinct to barely perceptible, thin (0.5-1µm thick), laevigate, commonly folded equatorially; outline, in polar aspect, conformable with amb or slightly more rounded. Cingulum well-developed and fairly uniform on a given specimen, 5-10µm in overall width, tapering gently to equator; bearing dispersed, small spinae, 1-2.5µm in basal diameter, 1-3µm high, usually projecting equatorially. Proximal exoexine laevigate to scabrate or bearing minute spinae <1µm broad basally and high. Distal non-cingulate exoexine sculptured irregularly with verrucae, spinae and grana, 0.5-3µm in basal diameter, 0.5-3.5µm high, discrete (up to 6µm apart) or basally fused.

Dimensions (18 specimens): Overall equatorial diameter 31 (45) 53µm; spore cavity diameter (polar view) 23 (26) 32µm.

Holotype: Preparation k688/a, J59/4. Plate 3, figure 7. Amb rounded subtriangular; equatorial diameter 38µm. Laesurae perceptible, narrowly lipped, slightly sinuous, reaching inner margin of cingulum. Equatorially tapering cingulum ca. 6µm wide; spinae up to 1.5µm high, projecting equatorially. Distal non-cingulate exoexine bearing verrucae and grana, 0.5-2µm wide and high, rarely fused basally. Remainder of non-cingulate exoexine scabrate. Intexine ca. 0.5µm thick, outline conformable with amb, equatorially folded.

Name derivation: Latin, *dissonus*, inharmonious, dissonant; referring to the irregular distribution of sculptural elements.

PLATE 1

1,2 *Leiotriletes inermis* (Waltz 1938) Ishchenko 1952; proximal foci. 1, ×1000. 2, ×1100.

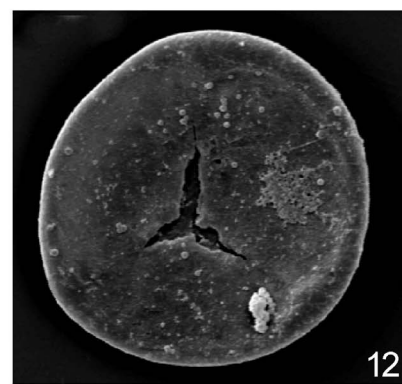
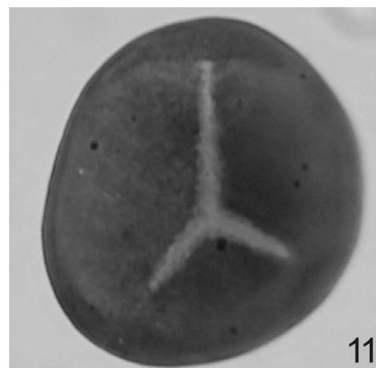
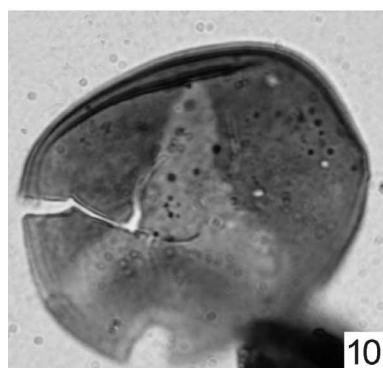
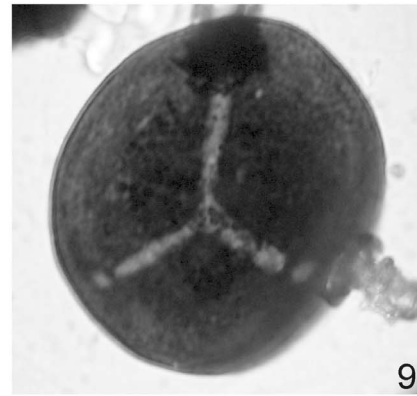
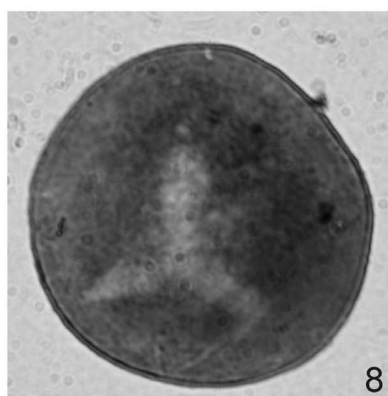
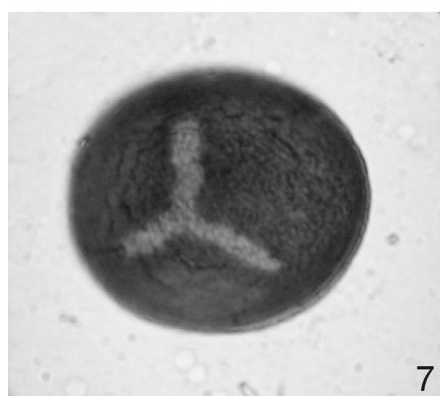
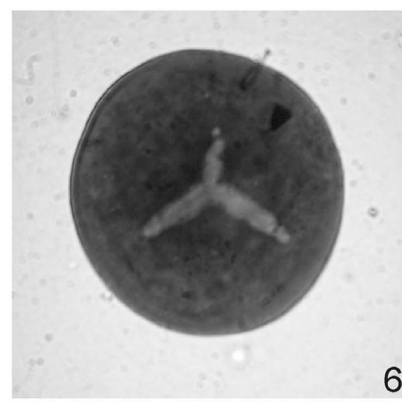
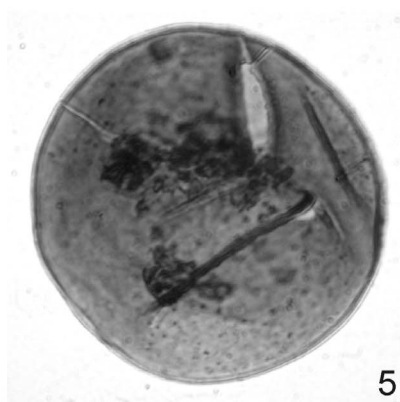
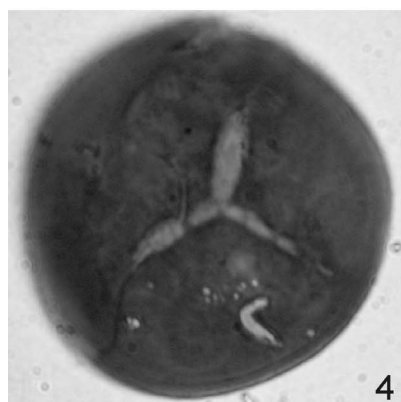
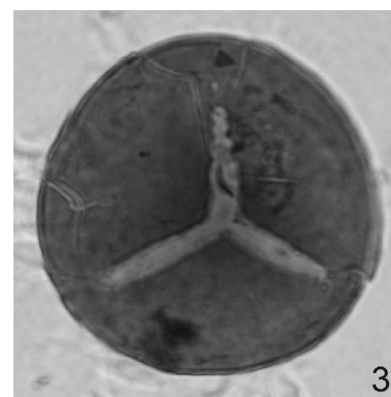
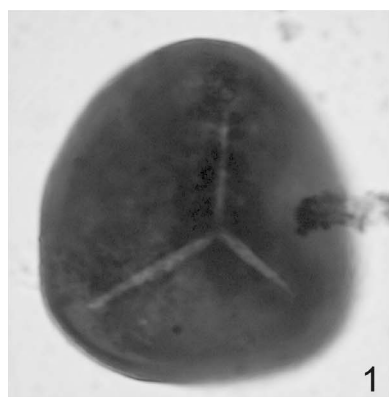
3 *Punctatisporites glaber* (Naumova in Lubert and Waltz 1938) Playford 1962; proximal focus, ×1100.

4,5 *Punctatisporites irrasus* Hacquebard 1957; proximal foci, ×800.

6,8 *Punctatisporites minutus* Kossanke 1950; proximal foci. 6, ×1000. 7, 8, ×1100.

9,10 *Punctatisporites planus* Hacquebard 1957; proximal foci. 9 ×1000. 10, ×1100.

11,12 *Retusotriletes incohatus* Sullivan 1964; ×1000. 11, proximal focus. 12, proximal surface.



Comparison: *Densosporites dissonus* Playford, González and Moreno n. sp. is comparable to *D. rarispinosus* Playford 1963 (pp. 630-631, pl. 89, figs. 18-21, text-fig. 10d) but features a narrower cingulum and more irregular distal sculpture. *Densosporites spitsbergensis* Playford 1963 (pp. 627-628, pl. 89, figs. 1-5) is larger and its cingulum is more densely sculptured with coarser spinae. *Densosporites regalis* (Bharadwaj and Venkatachala 1962) Smith and Butterworth 1967 (p. 242, pl. 19, figs. 13-15) is also larger, and possesses a wider, more densely and coarsely sculptured cingulum, which is generally more conspicuously developed in radial positions.

Genus *Lycospora* Schopf, Wilson and Bental 1944 emend. R. Potonié and Kremp 1954

Type species: *Lycospora micropapillata* (Wilson and Coe 1940) Schopf, Wilson and Bental 1944, by original designation.

Lycospora pusilla (Ibrahim 1932) Schopf, Wilson and Bental 1944 Plate 4, figures 2, 3

Sporonites pusillus Ibrahim in R. POTONIÉ, IBRAHIM and LOOSE 1932, p. 448, pl. 15, fig. 19.

Lycospora pusilla (Ibrahim 1932) SCHOPF, WILSON and BENTALL 1944, p. 54.

Description: Spores radial, trilete, cingulicavate. Amb rounded subtriangular; margin entire or minutely indented. Laesurae distinct, straight, extending to, or slightly beyond, inner margin of cingulum; generally accompanied by narrow lips ca. 1µm in overall width. Exine two-layered. Intexine indiscernible or barely perceptible, closely appressed to exoexine, occasionally folded equatorially. Cingulum 2.5-3µm wide, tapering equatorially; inner part darker colored, up to 1.5µm wide. Non-cingulate exoexine thin, minutely granulate distally and proximally. Sculpture very fine or absent on cingulum.

Dimensions (5 specimens): Overall equatorial diameter 25-27µm; spore cavity diameter (polar view) 20-22µm.

Comparison: *Lycospora uber* (Hoffmeister, Staplin and Malloy 1955) Staplin 1960 (p. 20, pl. 4, figs. 13, 17, 18, 20) is closely comparable to *L. pusilla* (Ibrahim 1932) Schopf, Wilson and Bental 1944, but features a generally wider cingulum.

Remarks: The first appearance of *L. pusilla* was adopted by Neves et al. (1973) to define the base of their *Lycospora pusilla* (Pu) Biozone in Britain. Subsequently, assemblages containing this species and correlative with the Pu Biozone have been reported from the Viséan of many Laurasian localities. Despite

the inadequate biostratigraphic control, there is little doubt that initial appearances of *L. pusilla* in Western and Eastern Europe (excluding the Volga-Urals region) are close to the Tournaisian/Viséan boundary (Turnau et al. 1997). The latter authors conceded that "the first appearance of *L. pusilla* is not a global event." This is supported by later inceptions of this distinctive species in Western and Northern Gondwana, where the much-discussed incoming of *L. pusilla* (e.g., Coquel and Massa 1993; Streel and Loboziak 1994; Loboziak et al. 1998, 2000a, b; Coquel and Abdesselam-Rouighi 1999) apparently does not predate the late Viséan. But this may well be a consequence of earlier Viséan strata being strongly condensed or absent in Western and Northern Gondwanan regions (Loboziak et al. 2000a, b; Coquel and Abdesselam-Rouighi 2000).

Previous records: In North Africa and adjacent regions, *L. pusilla* has been reported from the upper Viséan-Gzhelian of Libya (Massa et al. 1980; Clayton and Loboziak 1985; Coquel et al. 1988; Brugman et al. 1988); upper Viséan-Bashkirian of Algeria (Abdesselam-Rouighi et al. 1998; Coquel and Abdesselam-Rouighi 2000); upper Viséan of Niger (Loboziak and Alpern 1978; Coquel et al. 1995); upper Viséan-upper Bashkirian of Egypt (Kora 1993); and Serpukhovian of Saudi Arabia (Owens et al. 2000).

Genus *Indotriradites* Tiwari 1964 emend. Foster 1979

Type species: *Indotriradites korbaensis* Tiwari 1964, by original designation.

Indotriradites immutabilis Playford, González and Moreno n. sp. Plate 4, figures 4-6

Diagnosis: Spores radial, trilete, cingulicavate. Amb triangular to rounded subtriangular. Laesurae distinct to perceptible, ± straight, accompanied by narrow lips, 1-1.5µm in overall width, tapering toward inner margin of zona. Exine two-layered. Intexine up to 0.5µm thick, outline slightly more rounded than amb, occupying ca. one-half to two-thirds of total spore diameter, sometimes excentrically disposed, uncommonly folded equatorially. Exoexine extended equatorially as a zona 5-8µm wide (fairly constant on a given specimen), displaying a relatively thick and dark-colored inner border; zona bearing small, scattered spinae, up to 1.5µm basally and 2µm high, rarely fused at bases, occasionally projecting beyond equator. Non-zonate distal exoexine sculptured with small, discrete or rarely fused verrucae and grana with circular to irregular bases, 0.5-1.5µm wide and high, up to 4µm apart. Proximal exoexine, excluding zona, laevigate, uncommonly sculptured with few,

PLATE 2

1-3 *Retusotriletes crassus* Clayton 1980; proximal foci, ×1000.

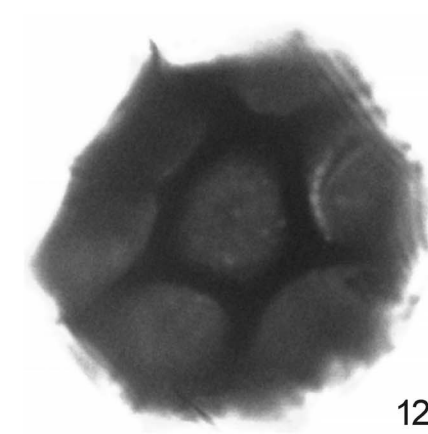
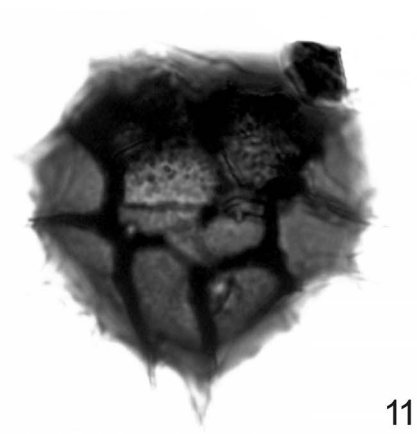
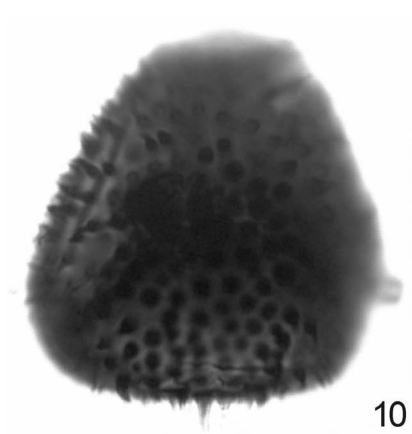
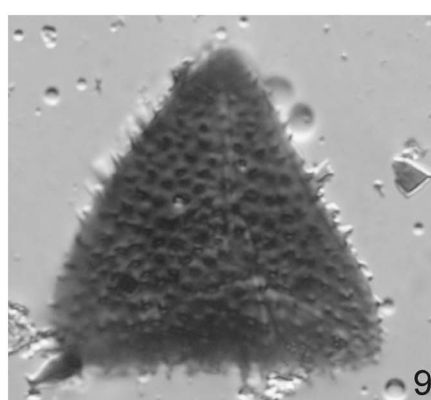
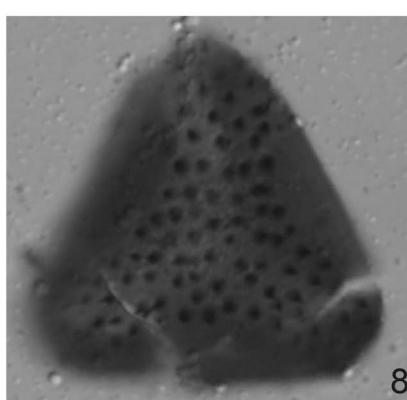
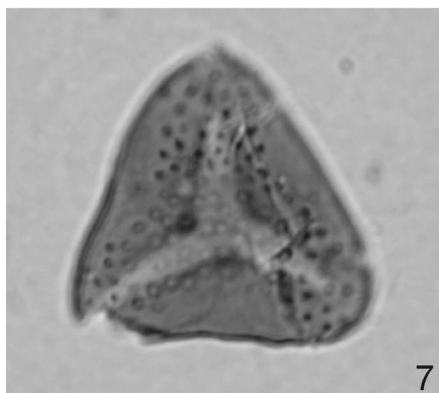
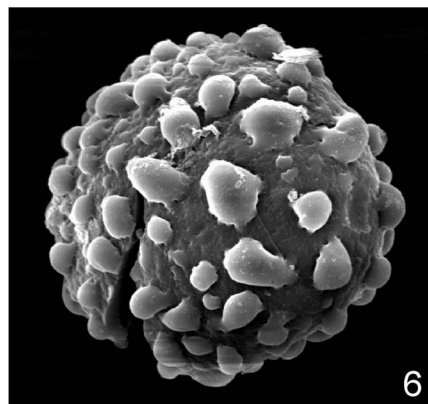
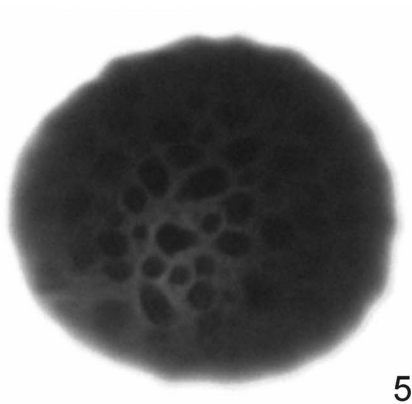
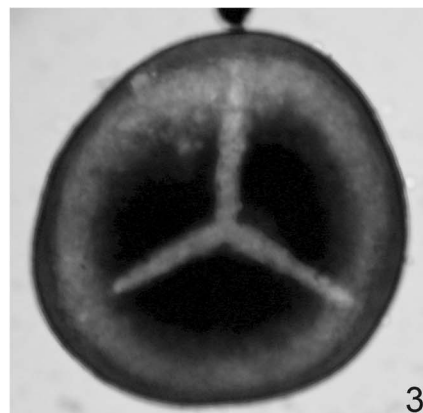
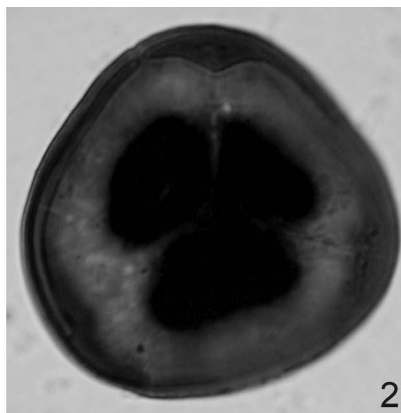
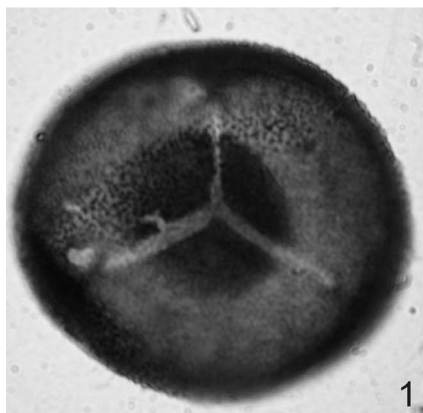
4 *Waltzispota polita* (Hoffmeister, Staplin and Malloy 1955) Smith and Butterworth 1967; median focus, ×1300.

5,6 *Verrucosporites* sp. cf. *V. aspratilis* Playford and Helby 1968. 5, distal focus, ×1400. 6, distal surface, ×1300.

7,8 *Anapiculatisporites* sp. A; ×1400. 7, median focus. 8, distal focus.

9,10 *Diatomozonotriletes* sp. A; ×1200. 9, median focus. 10, distal focus.

11,12 *Reticulatisporites?* sp. A; distal foci. 11, ×900. 12, ×1000.



discrete, irregularly distributed spinae, 0.5-1.5µm in basal diameter, 2-3µm in height.

Dimensions (12 specimens): Overall equatorial diameter 35 (46) 52µm; diameter of intexine (polar aspect) 19 (26) 30µm.

Holotype: Preparation k689/b, L52/1. Plate 4, figure 4. Amb rounded subtriangular; overall equatorial diameter 52µm. Laesurae distinct, extending to inner margin of zona. Intexine ca. 0.3µm thick, ± excentrically disposed and equatorially folded. Exoexine zonate; zona 6µm wide, bearing slender, radially oriented spinae up to 2.5µm high. Distal non-zonate exoexine with discrete or rarely fused grana and verrucae, 0.5-1µm wide and high. Proximal exoexine with scattered spinae, 0.5-1µm wide, up to 3µm high.

Name derivation: Latin, *immutabilis*, unchangeable; referring to the generally constant aspect of the species in the study material.

Comparison: *Indotriradites immutabilis* Playford, González and Moreno n. sp. is comparable to the cosmopolitan Upper Devonian-Mississippian *I. explanatus* (Luber 1941) Playford 1991 (pp. 103-104, pl. 3, figs. 17, 18), but is generally smaller, with a narrower zona, and lacks pointed sculptural elements on the distal non-zonate exoexine. *Indotriradites dolianitii* (Daemon 1974) Loboziak, Melo, Playford and Streel 1999 (pp. 18-20, pl. I, figs. 6-14) is generally larger, equatorially undulant and more coarsely sculptured on distal non-zonate exoexine, and features a plicated zona with larger elements on its inner margin. *Indotriradites daemonii* Loboziak, Melo, Playford and Streel 1999 (p. 20, pl. I, figs. 1-5) is also larger and has a conspicuously undulant zona with a narrower thickened inner margin bearing longer sculptural elements.

Genus *Vallatisporites* Hacquebard 1957

Type species: *Vallatisporites vallatus* Hacquebard 1957, by original designation.

Vallatisporites agadesensis Loboziak and Alpern 1978
Plate 4, figures 7-10

Vallatisporites n° 3324 of LANZONI and MAGLOIRE 1969, pl. III, figs. 7, 8.

Vallatisporites sp. A of COQUEL, LOBOZIAK, STAMPFLI and STAMPFLI-VUILLE 1977, pl. 3, fig. 1.

Vallatisporites agadesii LOBOZIAK and ALPERN 1978, pp. 58-59, pl. 2, figs. 9-12.

Vallatisporites sp. A of MASSA, COQUEL, LOBOZIAK and TAUGOURDEAU-LANTZ 1980, pl. V, figs. 13, 14.

Vallatisporites agadesensis Loboziak and Alpern 1978 nom. corr. MELO and LOBOZIAK 2000, pp. 155-156, pl.II, 17.

Description: Spores radial, trilete, cingulicavate. Amb rounded subtriangular. Laesurae distinct to perceptible, straight or

slightly curved, attaining inner margin of zona, accompanied by narrow lips 0.5-2.5µm in overall width. Exine two-layered, cavate; intexine perceptible to indistinct, 0.3-0.5µm thick, laevigate, slightly more rounded than amb, closely appressed to exoexine. Exoexine extended equatorially as a zona 5-9µm wide; fairly uniform on a given specimen, although slightly wider at amb apices. Inner margin of zona bearing a row of elongate to rounded, commonly coalescent, radially oriented vacuoles, 1-3µm in maximum dimension, length one-third to one-half of zona width. Outer non-vacuolate zona bearing minute (0.5-1µm high), scattered, discrete spinae, rarely projecting beyond equator. Distal non-zonate exoexine sculptured with apiculate elements, mainly verrucae and coni, 0.5-2µm broad basally, up to 2.5µm high, mostly coalescing basally to form irregular, ill-defined rugulae freely terminating or, less commonly, anastomosing. Proximal exoexine laevigate.

Dimensions (8 specimens): Overall equatorial diameter 40 (49) 65µm; diameter of intexinal body, in polar view, 27 (34) 44µm.

Remarks: The present specimens of *Vallatisporites agadesensis* have a lower size range, but are otherwise in close morphological agreement with Loboziak and Alpern's (1978) diagnosis of the species. Other Moroccan representatives of *V. agadesensis*, illustrated by Marhoumi (1984) and Rahmani-Antari and Lachkar (2001), show similar size disparity.

Previous records: In Northern Gondwana, *Vallatisporites agadesensis* has been recorded from the Tournaisian-Viséan of Morocco (Marhoumi 1984; Rahmani-Antari and Lachkar 2001); Tournaisian-Serpukhovian of Libya (Massa et al. 1980; Clayton and Loboziak 1985; Coquel and Moreau-Benoit 1986; Coquel et al. 1988; Loboziak and Clayton 1988); upper Viséan of Niger (Loboziak and Alpern 1978); and upper Viséan-lower Serpukhovian of Saudi Arabia (Clayton 1995; Clayton et al. 2000; Owens et al. 2000) and Algeria (Lanzoni and Magloire 1969; Attar et al. 1980; Coquel and Latreche 1989; Coquel et al. 1995; Coquel and Abdesselam-Rouighi 2000).

Vallatisporites extensivus Playford, González and Moreno n. sp.
Plate 4, figure 11; Plate 5, figures 1-5

Diagnosis: Spores radial, trilete, cingulicavate. Amb rounded subtriangular, commonly with serrate margin due to corrosion. Laesurae distinct, straight, commonly gaping, extending to inner margin of zona. Exine two-layered, cavate. Intexine distinct to perceptible, thin, laevigate, occupying one-half to one-third of overall spore diameter; outline, in polar aspect, slightly more rounded than amb, commonly distorted by large-scale compression folds. Exoexine zonate; zona tapering equatorially, width 30-50% of overall spore diameter. Inner one-half to four-fifths of zona bearing a row of radially elongate vacuoles up to 13µm in maximum dimension. Vacuole surface 0.5-1.5µm thick; ra-

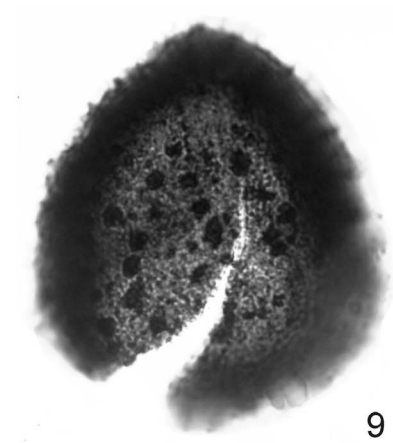
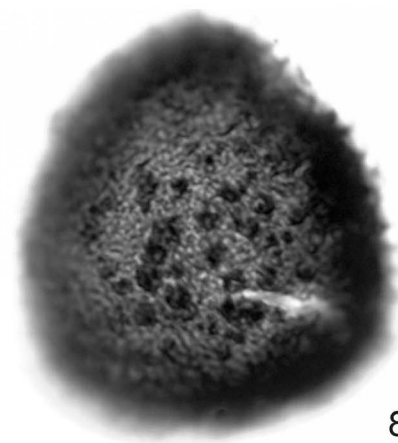
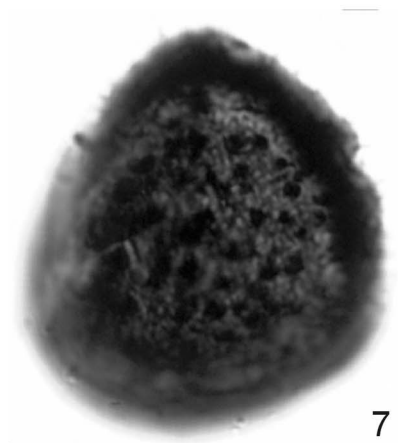
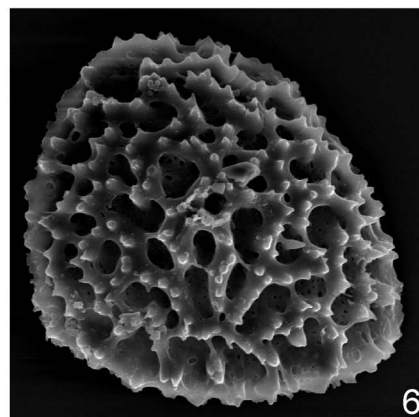
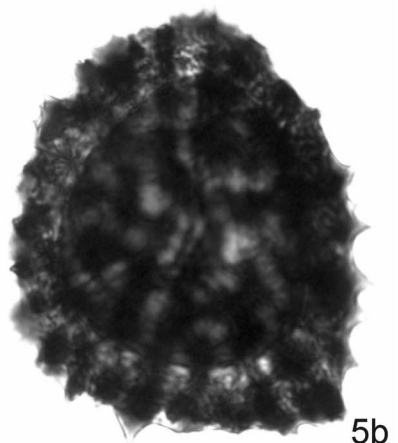
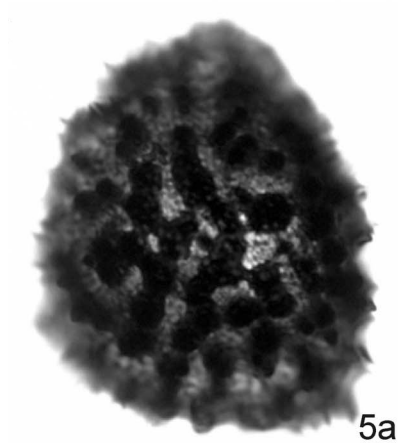
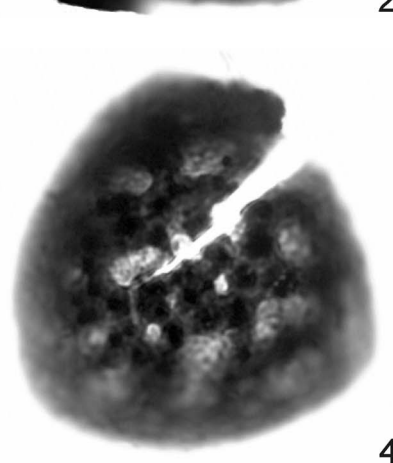
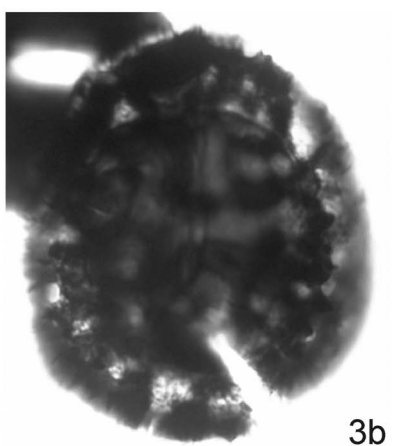
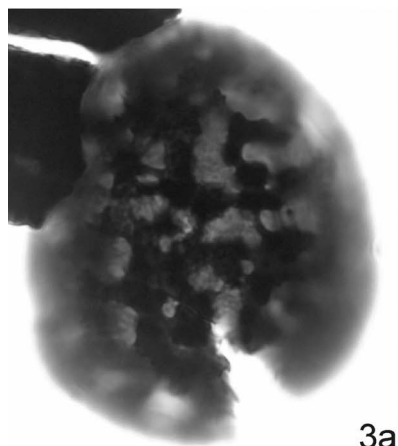
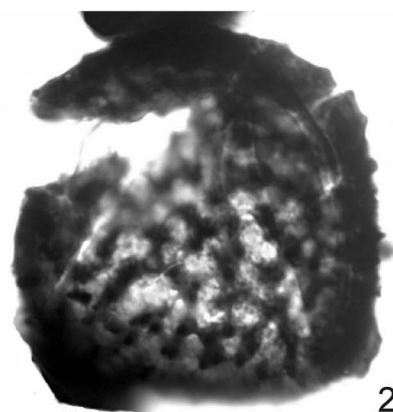
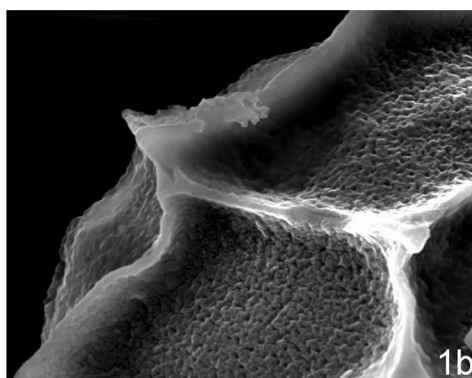
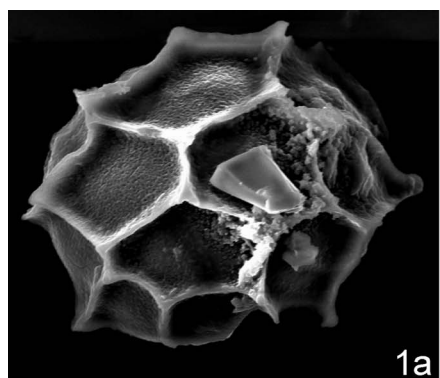
PLATE 3

1a,b *Reticulatisporites?* sp. A; distal surface. 1a, ×1000.
1b, sculptural detail, ×2200.

2-6 *Cristatisporites mixtus* n. sp. 2, distal focus, ×900. 3a,
b, distal and proximal foci, ×900. 4, distal focus,

×1200. 5a, b, holotype, distal and proximal foci,
×1000. 6, distal surface, ×1100.

7-9 *Densosporites dissonus* n. sp.; distal foci. 7, holotype,
×1200. 8, ×1000. 9, ×900.



dial conjunction of vacuoles resembling straight to slightly arched ridges. Non-vacuolate zona thinner and laevigate. The entire distal zona, including vacuolate inner margin, bearing minute, scattered spinae and coni up to 1µm high, sometimes projecting equatorially. Non-zonate distal exoexine infrapunctate to infrarugulate, sculptured with discrete or rarely fused, broad-based spinae, coni and verrucae 1-3.5µm wide basally and high, highly variable in number among specimens. Proximal exoexine laevigate to infrapunctate, with or without discrete, irregularly disposed spinae up to 1.5µm high.

Dimensions (28 specimens): Overall equatorial diameter 45 (59) 79µm; diameter of intexinal body, in polar view, 30 (38) 50µm.

Holotype: Preparation k693/5, Q33/0. Plate 5, figures 2a, b. Amb rounded subtriangular; overall equatorial diameter 70µm. Simple, straight laesurae extending to inner margin of zona. Intexine ca. 0.3µm thick, outline slightly more rounded than amb, equatorially folded. Exoexine zonate; zona 11µm wide, with radially elongate vacuoles, 2.5-4µm wide, 8-10µm long, occupying zona's inner portion. Non-vacuolate outer part of zona distinctly thinner, laevigate, with scattered spinae up to 0.5µm high. Distal non-zonate exoexine infrarugulate, sculptured with rarely fused verrucae and coni 1-2.5µm wide and high.

Name derivation: Latin, *extensivus*, extensive; referring to the elongate vacuolae.

Remarks and comparison: Although some specimens are somewhat defectively preserved, *Vallatisporites extensivus* Playford, González and Moreno n. sp. is clearly assignable to Hacquebard's (1957) genus on the basis of its distinctly vacuolate zona. *Radiizonates arcuatus* Loboziak, Playford and Melo 2000 (pp. 272-275, pl. I, figs. 1-18), from the Mississippian of Western Gondwana, is closely comparable to *V. extensivus*, aside from lacking spinose sculpture on its zona and infrapunctuation/infrarugulation on its non-zonate distal exoexine. The main difference between these two species relates to the morphology of their respective zones. Whereas *V. extensivus* possesses large, radially oriented vacuoles, the diagnosis of *R. arcuatus* specifies "curved ribs, radiating from inner margin of zona, connected to form arches almost at equatorial margin." However, some poorly preserved specimens of *V. extensivus*, displaying partially broken vacuoles, are scarcely distinguishable from *R. arcuatus*.

Vallatisporites galearis Sullivan 1964
Plate 5, figures 6-8

Vallatisporites galearis SULLIVAN 1964, p. 372, pl. 59, figs. 17-19.

Description: Spores radial, trilete, cingulicavate. Amb rounded subtriangular. Laesurae perceptible to obscure, straight, narrowly lipped (lips up to 1µm in overall width), extending to, or almost to, inner margin of zona. Exine two-layered, cavate. Intexine distinct, thin (ca. 0.4µm thick), laevigate, outline slightly more rounded than amb and mostly appressed to exoexine. Large compression folds commonly distorting intexine outline. Exoexine extended equatorially to form zona 5-9µm wide, gently tapering equatorially. Inner 15-50% of zona with a row of rounded to radially elongate, partly coalescent vacuoles up to 5µm in maximum length. Non-vacuolate outer zona bearing small, scattered spinae up to 3.5µm high and 3µm in basal breadth; some may project equatorially. Distal exoexine over spore cavity minutely punctate, sculptured with basally expanded spinae to galeae, 1-6µm broad at base, 3.5-7µm high. Sculptural elements discrete (up to 3µm apart), uncommonly fused basally to form ill-defined, incipient cristae. Proximal exoexine laevigate to infrapunctate.

Dimensions (8 specimens): Overall equatorial diameter 45 (54) 65µm; diameter of intexinal body, in polar view, 33 (41) 49µm.

Previous records: This distinctive species has been recorded previously from the upper Famennian and upper Tournaisian of Canada (Utting 1987; Playford and McGregor 1993); upper Viséan of England (Sullivan 1964); and lower Serpukhovian of Saudi Arabia (Owens et al. 2000).

Vallatisporites vallatus Hacquebard 1957
Plate 5, figures 9, 10

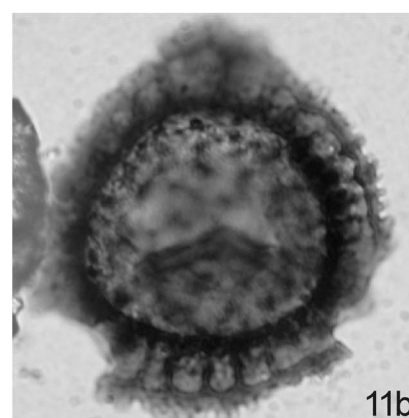
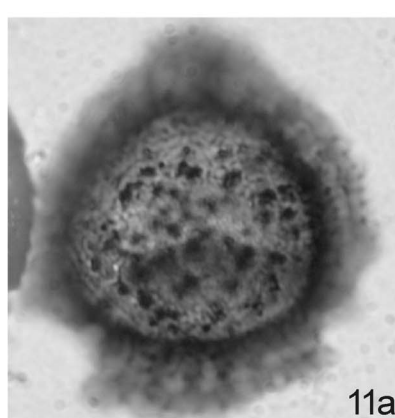
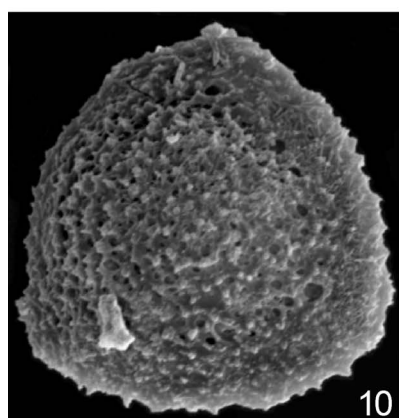
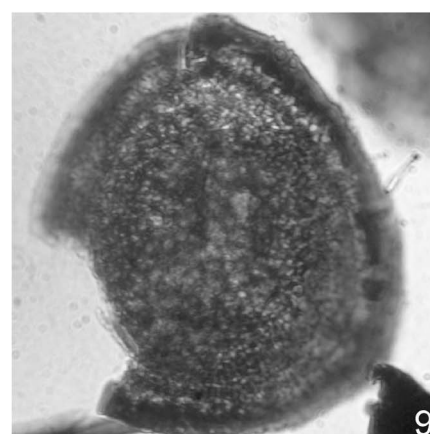
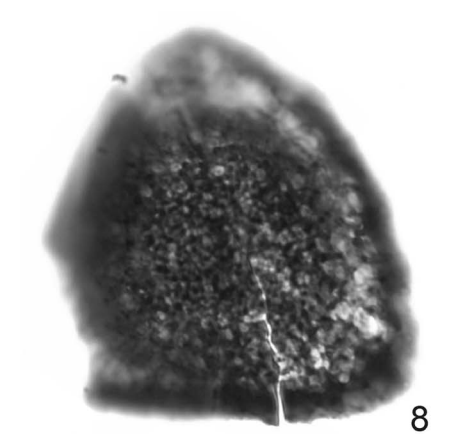
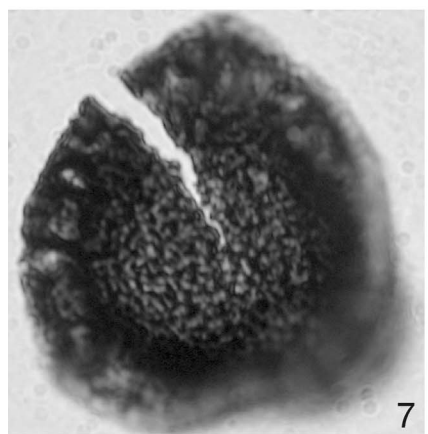
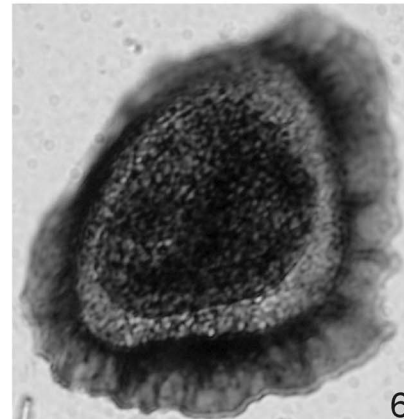
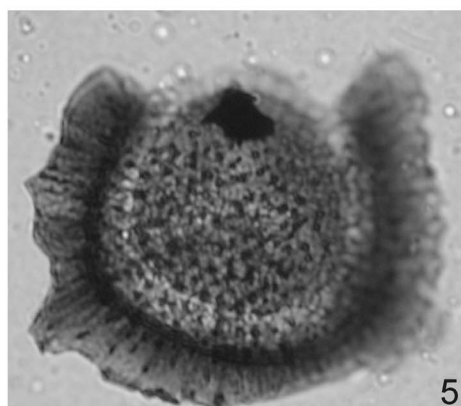
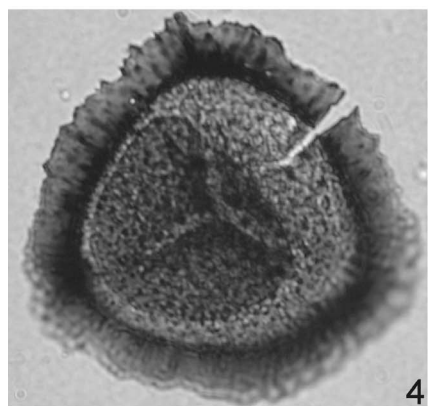
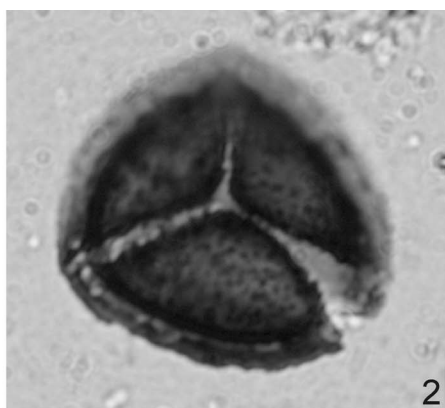
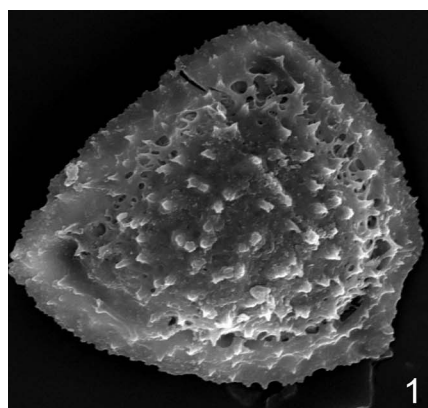
Vallatisporites vallatus HACQUEBARD 1957, pp. 312-313, pl. 2, fig. 12.

Remarks: A few specimens consonant with Hacquebard's (1957) definition of *Vallatisporites vallatus* have been recovered from the studied material. They exhibit an infrapunctate, non-zonate distal exoexine bearing discrete (up to 3µm apart) or rarely fused spinae and coni, 1-2.5µm wide and high, together with minor grana. The slightly tapering zona occupies one-quarter to one-third of the spore radius, and has a single row of rounded vacuoles on its inner part; scattered, minute spinae and coni up to 1µm wide and high are borne on the outer (non-vacuolate) part.

Dimensions (6 specimens): Overall equatorial diameter 40 (45) 52µm; diameter of intexinal body, in polar view, 31 (34) 42µm.

PLATE 4

- 1 *Densosporites dissonus* n. sp.; distal surface, ×1200.
- 2,3 *Lycospora pusilla* (Ibrahim 1932) Schopf, Wilson and Bentall 1944; proximal foci, ×1600.
- 4,6 *Indotriradites immutabilis* n. sp.; median foci. 4, holotype, ×900. 5, 6, ×1000.
- 7-10 *Vallatisporites agadesensis* Loboziak and Alpern 1978. 7, distal focus, ×1100. 8, distal focus, ×1000. 9, median focus, ×800. 10, distal surface, ×1000.
- 11 *Vallatisporites extensivus* n. sp. 11a, b, distal and proximal foci. ×800.



Previous records: Widely reported from the upper Famennian through upper Tournaisian of the northern hemisphere (see Playford and McGregor 1993, p. 35). In Northern Gondwana, the species has been recorded from the upper Famennian-Tournaisian of Algeria (Attar et al. 1980; Coquel and Latreche 1989; Moreau-Benoit et al. 1993; Coquel and Abdesselam-Rouighi 2000); upper Famennian-lower Viséan of Morocco (Marhoumi et al. 1984; Bouabdelli and Doubinger 1990; Rahmani-Antari and Lachkar 2001); Tournaisian-lower Viséan of Libya (Massa et al. 1980; Clayton and Loboziak 1985; Coquel and Moreau-Benoit 1986; Coquel et al. 1988; Loboziak and Clayton 1988); and Tournaisian-lower Serpukhovian of Saudi Arabia (Clayton 1995; Clayton et al. 2000; Owens et al. 2000).

Vallatisporites verrucosus Hacquebard 1957
Plate 5, figure 11

Vallatisporites verrucosus HACQUEBARD 1957, p. 313, pl. 2, fig. 13.

Description: Spores radial, trilete, cingulicavate. Amb rounded subtriangular. Laesurae distinct to perceptible, accompanied by straight to slightly sinuous lips, up to 2µm in overall width, extending to inner margin of zona. Exine two-layered, cavate. Intexine distinct, laevigate, very thin (0.4µm thick), closely appressed to exoexine, conformable with, or somewhat more rounded than amb, uncommonly with coarse equatorial compression folds. Exoexine zonate; zona 4-5µm wide; inner margin marked by a single row of rounded to radially elongate, mainly coalescent vacuolae, 1.5-2.5µm in maximum dimension. Non-vacuolate distal surface of zona with minute, scattered spinae up to 1µm high, commonly projecting equatorially. Non-zonate distal exoexine sculptured with discrete or rarely coalescent verrucae, 1-2.5µm broad basally and high. Proximal exoexine laevigate to scabrate.

Dimensions (7 specimens): Overall equatorial diameter 32 (37) 48µm; diameter of intexinal body, in polar view, 23 (28) 39µm.

Previous records: Widely reported from the upper Famennian-Tournaisian of the northern hemisphere (see González et al. 2005, p. 23). In Northern Gondwana, this species is known from the Tournaisian-lower Viséan of Morocco (Rahmani-Antari and Lachkar 2001); upper Viséan of Egypt (Kora 1993); upper Famennian-lower Serpukhovian of Libya (Clayton and Loboziak 1985; Coquel and Moreau-Benoit 1986; Loboziak and Clayton 1988); and Tournaisian-lower Serpukhovian of Saudi Arabia (Clayton 1995; Clayton et al. 2000; Owens et al. 2000).

Suprasubturma PSEUDOSACCITITRILETES Richardson 1965

Infraturma MONOPSEUDOSACCITI Smith and Butterworth 1967

Genus ***Auroraspora*** Hoffmeister, Staplin and Malloy 1955

Type species: *Auroraspora solisorta* Hoffmeister, Staplin and Malloy 1955, by original designation.

Auroraspora solisorta Hoffmeister, Staplin and Malloy 1955
Plate 6, figures 1, 2

Auroraspora solisortus HOFFMEISTER, STAPLIN and MALLOY 1955, p. 381, pl. 37, fig. 3.

Auroraspora cf. *solisortus* HOFFMEISTER, STAPLIN and MALLOY 1955. – TURNAU 1978, pp. 10-11, pl. 4, figs. 17, 18.

Dimensions (6 specimens): Overall equatorial diameter 40 (48) 57µm; diameter of intexine (in polar aspect) 23 (27) 30µm.

Remarks: Although somewhat smaller than the Upper Mississippian type material from Illinois and Kentucky described by Hoffmeister et al. (1955), the Moroccan specimens are otherwise consonant with their species.

Previous records: From the Famennian of Belgium (Becker et al. 1974; Maziane et al. 1999) and France (Loboziak and Streel 1981, 1988); upper Famennian of Germany (Higgs and Streel 1984; Hartkopf-Fröder and Streel 1994); upper Famennian-Viséan of Ireland (Higgs et al. 1988; McPhilemy 1988); upper Famennian-lower Serpukhovian of the British Isles (Butterworth and Williams 1958; Sullivan 1964; Higgs and Clayton 1984; McNestry 1988; Brindley and Spinner 1989; Mahdi and Butterworth 1994; Turner et al. 1994); upper Famennian-Serpukhovian of USA (Hoffmeister et al. 1955; Wiggins 1961; Felix and Burbridge 1967; Streel and Traverse 1978; Owens et al. 1984; Ravn 1991; Clayton et al. 1998); Tournaisian-Viséan of Colombia (Dueñas and Césari 2005, 2006); upper Tournaisian-Viséan of Poland (Turnau 1978); upper Famennian-upper Viséan of Brazil (Loboziak et al. 1991, 1992, 1998; Melo and Loboziak 2003); Viséan of Australia (Playford 1971; Playford and Satterthwait 1988); middle to upper Viséan of Spain (Rodríguez González et al. 2007); upper Viséan-Serpukhovian of Canada (Staplin 1960; Utting 1987) and Denmark (Bertelsen 1972, 1978); and lower Serpukhovian of Ukraine (Teteriuk 1976). In Northern Gondwana, the species is known from the upper Viséan-lower Serpukhovian of Libya (Massa et al. 1980; Coquel et al. 1988) and Saudi Arabia (Clayton 1995; Owens et al. 2000); and upper Viséan-Bashkirian of Egypt (Kora 1993).

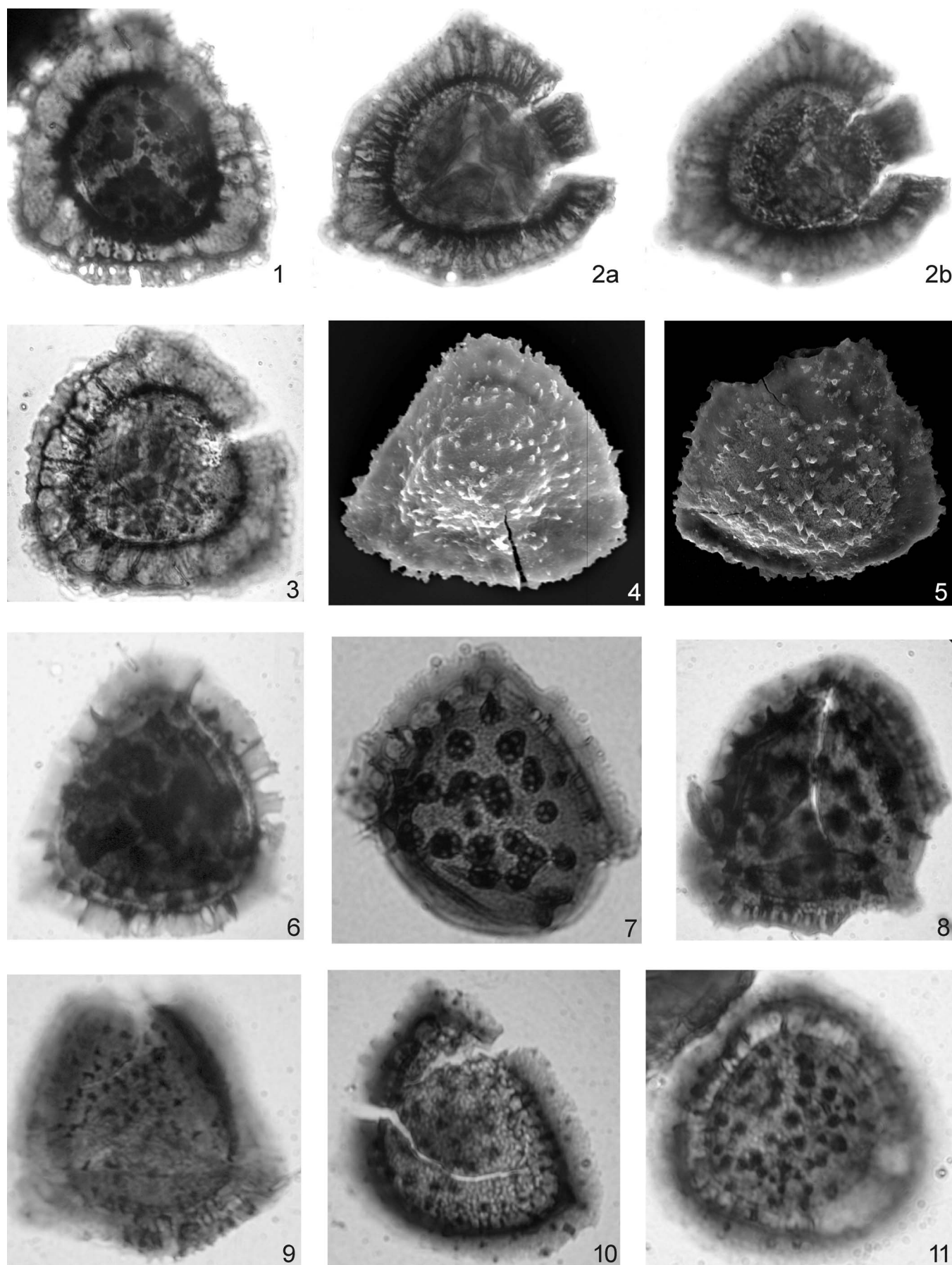
PLATE 5

1-5 *Vallatisporites extensivus* n. sp. 1, distal focus, ×700. 2a, b, holotype, proximal and distal foci, ×700. 3, median focus, ×700. 4, 5, distal surface, ×1000.

6-8 *Vallatisporites galearis* Sullivan 1964; distal foci. 6, 7, ×1000. 8, ×900.

9, 10 *Vallatisporites vallatus* Hacquebard 1957; distal foci. 9, ×1000. 10, ×1100.

11 *Vallatisporites verrucosus* Hacquebard 1957; distal focus, ×1500.



Genus *Endoculeospora* Staplin 1960 emend. Turnau 1975

Type species: *Endoculeospora rarigranulata* Staplin 1960, by original designation.

Endoculeospora marrakechensis Playford, González and Moreno n. sp.

Plate 6, figures 3-9

Diagnosis: Spores radial, trilete. Amb subcircular to rounded subtriangular. Laesurae distinct, simple, straight, length ca. one-half to two-thirds of spore radius. Contact areas bounded by curvaturae perfectae, frequently invaginated in radial positions. Exine two-layered, cavate. Intexine distinct, ca. 1µm thick, laevigate, occupying ca. 75-90% of overall spore diameter; outline, in polar view, conformable with amb. Exoexine 1-1.5µm thick; distal surface, equatorial margin and proximo-equatorial radial regions densely sculptured with discrete (up to 2µm apart) or rarely fused grana and coni up to 1.2µm in basal diameter and 1.4µm high. Contact areas laevigate to scabrate.

Dimensions (43 specimens): Overall equatorial diameter 27 (45) 65µm; diameter of intexine (polar aspect) 21 (39) 54µm.

Holotype: Preparation k656/c, S50/4. Plate 6, figure 3. Amb subcircular, 46µm in diameter. Laesurae one-half of spore radius in length, terminating in curvaturae perfectae. Exoexine 1.5µm thick. Distal, equatorial and proximo-equatorial inter-radial exoexine bearing discrete or rarely fused coni and subordinate grana (basal diameter ca. 0.5µm, height 0.5-1µm, up to 1.5µm apart). Intexine ca. 1µm thick, laevigate, subcircular in polar view.

Name derivation: From Marrakech, the closest city to the type area of this species.

Comparison: *Endoculeospora marrakechensis* Playford, González and Moreno n. sp. superficially resembles *Apiculiretusispora granulata*, described by Owens (1971, pp. 15-16, pl. III, figs. 2, 3, 6, 8) and figured by Higgs (1975, pl. 1, fig. 26), but differs sculpturally (i.e., bearing mixed granulate-conate elements) and in its stratified exine and appreciably smaller size. *Spelaeotriletes crustatus* Higgs 1975 (p. 399, pl. 6, figs. 4-6) is somewhat larger and features a thicker, more coarsely sculptured exoexine.

Genus *Endosporites* Wilson and Coe 1940 ex Schopf, Wilson and Bentall 1944

Type species: *Endosporites ornatus* Wilson and Coe 1940, by subsequent designation of Schopf, Wilson and Bentall (1944, p. 45).

Endosporites micromanifestus Hacquebard 1957

Plate 7, figures 1-3

Endosporites micromanifestus HACQUEBARD 1957, p. 317, pl. 3, fig. 16.

For further synonymy see Playford (1971, p. 52) and Byvscheva (1985, p. 146).

Dimensions (15 specimens): Overall equatorial diameter 45 (59) 75µm; diameter of intexine (polar aspect) 32 (37) 45µm.

Remarks: The present specimens are positively assignable to *Endosporites micromanifestus* Hacquebard 1957, although some show conspicuous distal plication of the exoexine, as in the type material of *E. macromanifestus* Hacquebard 1957 (p. 317, pl. 3, figs. 14, 15). However, the latter differs from *E. micromanifestus* in its considerably larger size.

Previous records: Widely reported, on a virtually cosmopolitan scale, from upper Famennian through Bashkirian strata. In Northern Gondwana, *E. micromanifestus* has been recorded from the upper Famennian-Tournaisian of Iran (Coquel et al. 1977); Tournaisian-Viséan of Morocco (Marhoumi et al. 1984; Rahmani-Antari and Lachkar 2001); Famennian-lower Serpukhovian of Libya (Massa et al. 1980; Coquel and Moreau-Benoit 1986); and Famennian-Bashkirian of Algeria (Lanzoni and Magloire 1969; Attar et al. 1980; Coquel and Latreche 1989).

Genus *Spelaeotriletes* Neves and Owens 1966

Type species: *Spelaeotriletes triangulus* Neves and Owens 1966, by original designation.

Spelaeotriletes arenaceus Neves and Owens 1966

Plate 7, figures 4-9

Spelaeotriletes arenaceus NEVES and OWENS 1966, pp. 345-346, pl. II, figs. 1-3.

For further synonymy see Playford et al. (2001, p. 596).

Description: Spores radial, trilete, cavate. Amb rounded subtriangular. Laesurae distinct to perceptible, ± straight, extending almost to equatorial margin, commonly bordered by narrow lips 0.5-2µm in overall width. Exine two-layered, cavate. Intexine distinct, thin, laevigate, proximally attached to exoexine, occupying 50-70% of overall spore diameter; outline conformable to, or slightly more rounded than amb, commonly folded peripherally. Exoexine 1-1.5µm thick; contact areas laevigate; proximo-equatorially and distally scabrate, bearing discrete or rarely fused verrucae, coni, spinae and grana, 0.5-2µm broad at base, 0.5-1.5µm high. Sculptural elements irregularly distributed, up to 3.5µm apart, generally smaller and sparser towards equator (i.e., beyond intexine margin).

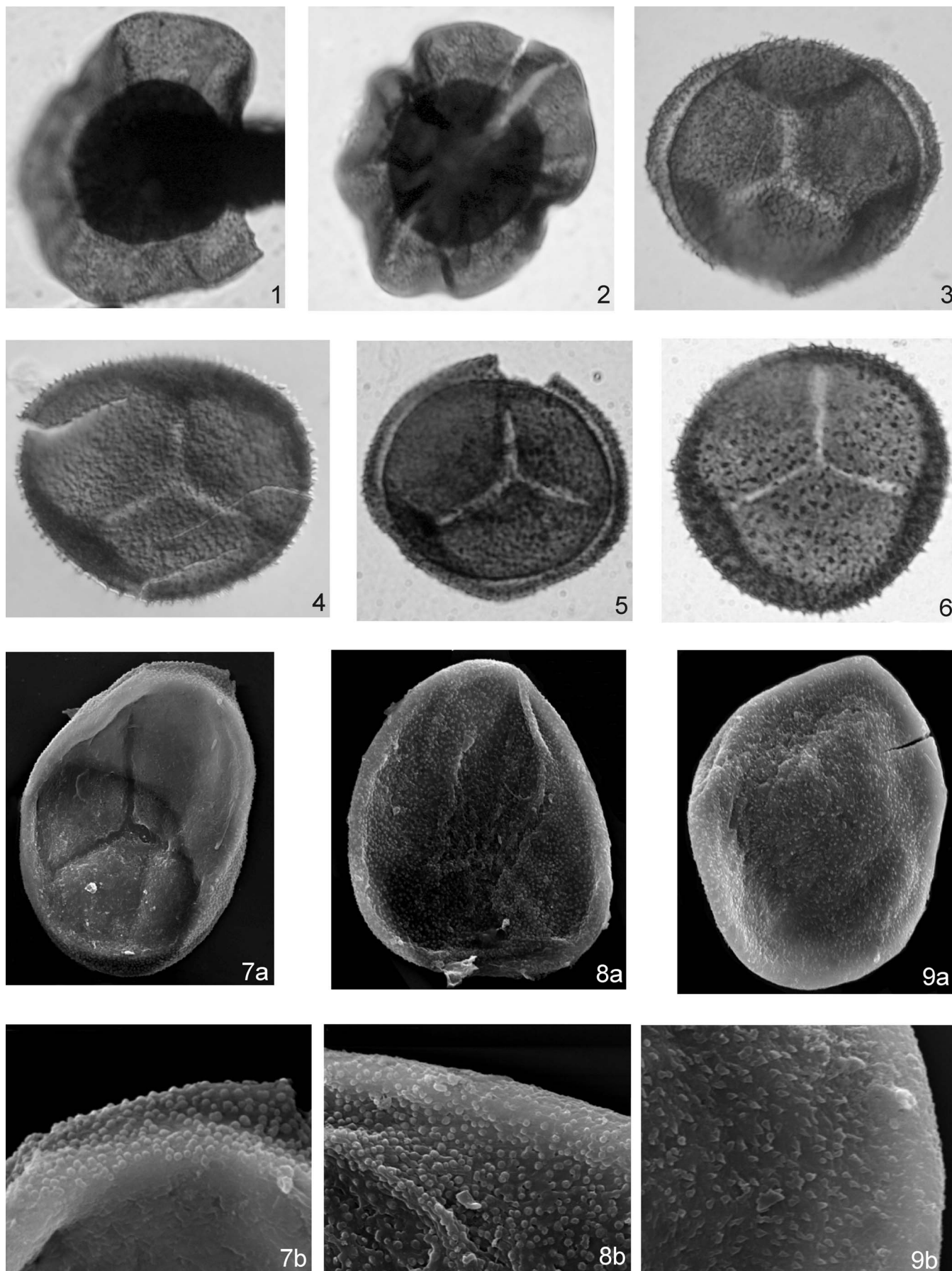
Dimensions (18 specimens): Overall equatorial diameter 43 (64) 75µm; diameter of intexine (polar aspect) 30 (39) 50µm.

Previous records: *Spelaeotriletes arenaceus* Neves and Owens 1966 has been reported worldwide from Mississippian through

PLATE 6

- 1,2 *Auroraspora solisorta* Hoffmeister, Staplin and Malloy 1955; median foci. 1, ×900. 2, ×1200.
- 3-9 *Endoculeospora marrakechensis* n. sp. 3 (holotype), 4, 5, 6, median foci, ×1200. 7a, proximal surface,

×1100. 7b, sculptural detail, ×4500. 8a, distal surface, ×1200. 8b, sculptural detail, ×3500. 9a, distal surface, ×1200. 9b, sculptural detail, ×4000.



Lower Permian strata, but mainly within the Viséan-Bashkirian interval (Playford and Dino 2000).

Spelaeotriletes?* sp. cf. *S. owensii Loboziak and Alpern 1978
Plate 7, figures 10-12; Plate 8, figures 1-5

cf. *Spelaeotriletes owensii* LOBOZIAK and ALPERN 1978, pp. 60-61, pl. 2, figs. 15-17.

Description: Spores radial, trilete, cavate, with two- or three-layered exine. Amb rounded subtriangular. Laesurae distinct, straight to somewhat sinuous, extending to, or almost to equator, accompanied by narrow lips, 1.5-3µm high, generally tapering towards equatorial margin. Exoexine 1-1.5µm thick, with equatorial crassitude 3-6µm thick. Contact areas laevigate, with or without sparse, minute spinae up to 0.5µm high. Equatorial and distal exoexine sculptured with minute rugulae up to 0.5µm in overall width, and discrete, ± regularly distributed verrucae, spinae and coni, 0.5-1.5µm wide and high, that may project equatorially. Intexine one- or two-layered. In former case, intexine distinct, thin, + conformable with amb, length one-half to three-quarters of overall spore diameter. Where two-layered, intexine consisting of a laevigate inner layer, 0.3-0.5µm thick, generally more rounded than amb, occupying one- to two-thirds of spore diameter; and an outer laevigate layer, slightly thinner than the inner one, more triangular in polar view, occupying two-thirds to three-quarters of overall spore diameter. Intexine layers may display equatorial compression folds.

Dimensions (36 specimens): Overall equatorial diameter 46 (52) 66µm; diameter, in polar aspect, of inner intexine, 19 (27) 34µm, and of outer intexine 29 (34) 39µm.

Remarks and comparison: These spores, abundant in all the samples, closely resemble *Spelaeotriletes owensii* Loboziak and Alpern 1978. However, positive assignment to the latter is not deemed advisable because of the slightly smaller size and the two-layered intexine characteristic of many (though not all) of the Moroccan specimens. The assignment of *owensii* to *Spelaeotriletes* Neves and Owens 1966 (pp. 342-344) should perhaps be revised, because the crassitudinous exoexine displayed by the type material, diagnosed by Loboziak and Alpern 1978 (p. 60) as "... une bordure compacte plus ou moins large ..." is not specified in Neves and Owens's (1966) generic diagnosis. As noted above, the crassitude is clearly displayed by the Moroccan specimens.

Previous records. *Spelaeotriletes owensii* has been identified per se in Northern Gondwanan palynofloras as follows:

Viséan-Serpukhovian of Libya (Massa et al. 1980; Clayton and Loboziak 1985; Coquel et al. 1988; Loboziak and Clayton 1988) and Niger (Loboziak and Alpern 1978; Coquel et al. 1995); and upper Viséan-Serpukhovian of Algeria (Lanzoni and Magloire 1969; Attar et al. 1980; Abdesselam-Rouighi et al. 1998; Coquel and Abdesselam-Rouighi 2000), Egypt (Kora 1993) and Saudi Arabia (Clayton 1995; Owens et al. 2000).

Turma MONOLETES Ibrahim 1933
Suprasubturma ACAVATOMONOLETES Dettmann 1963
Subturma AZONOMONOLETES Lubert 1935
Infraturma LAEVIGATOMONOLETI Dybová and Jachowicz 1957

Genus ***Laevigatosporites*** Ibrahim 1933
Type species: *Laevigatosporites vulgaris* (Ibrahim 1932) Ibrahim 1933, by original designation.

Laevigatosporites vulgaris (Ibrahim 1932) Ibrahim 1933
Plate 8, figures 7, 10

Selected synonymy:
Sporonites vulgaris Ibrahim in POTONIÉ, IBRAHIM and LOOSE 1932, p. 448, pl. 15, fig. 16.
Laevigatosporites vulgaris (Ibrahim in R. Potonié, Ibrahim and Loose 1932) IBRAHIM 1933, p. 39, pl. 2, fig. 16.
Phaseolites desmoinesensis WILSON and COE 1940, pp. 182-183, pl. 1, fig. 4.
Laevigatosporites desmoinesensis (Wilson and Coe 1940) SCHOPF, WILSON and BENTALL 1944, p. 37.

Description: Spores bilateral, monolete; amb oval. Laesura distinct, simple, straight, length one-half to three-quarters of spore length. Exine 1-2µm thick, laevigate to finely punctate on distal surface. Contact areas laevigate.

Dimensions (5 specimens): In polar view, length 52-70µm; width 41-52µm.

Previous records: *Laevigatosporites vulgaris* (Ibrahim 1932) Ibrahim 1933 has been recorded worldwide in Pennsylvanian-Lower Permian deposits. In Northern Gondwana, this species is known from the upper Viséan of Niger (Loboziak and Alpern 1978) and lower Serpukhovian of Saudi Arabia (Owens et al. 2000).

***Laevigatosporites* sp. A**
Plate 8, figures 6, 8, 9

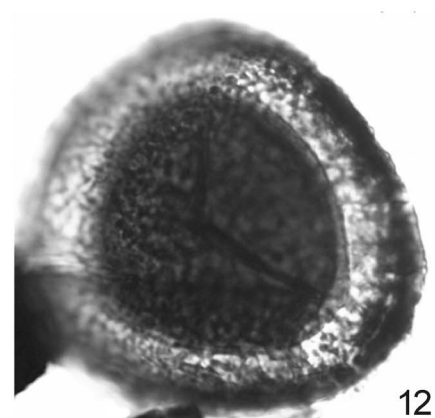
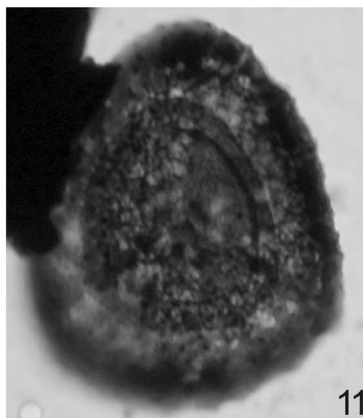
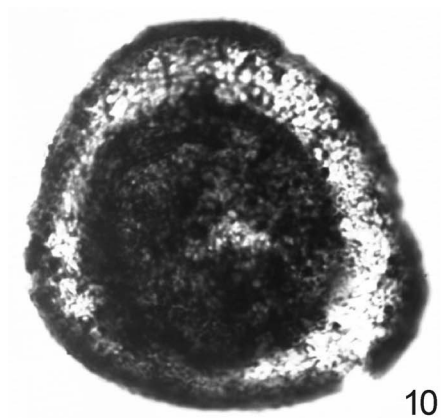
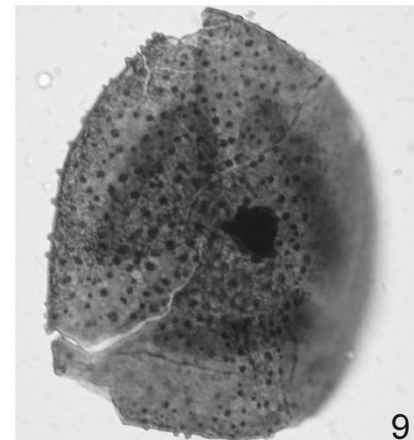
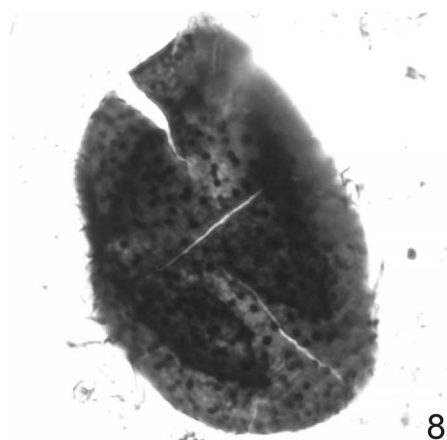
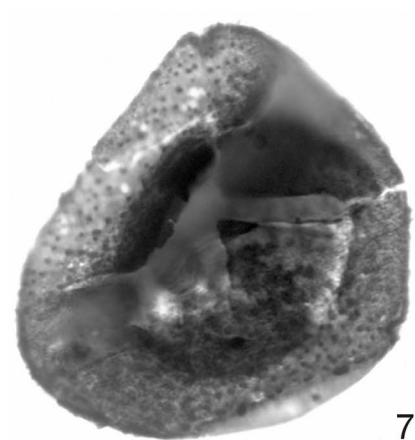
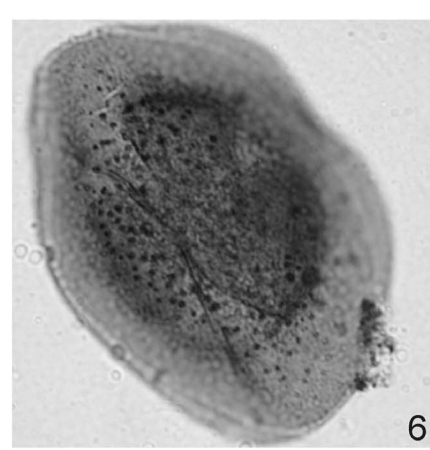
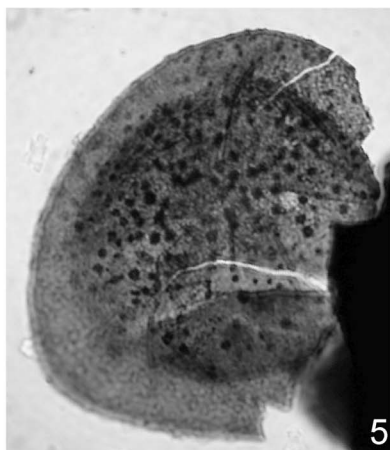
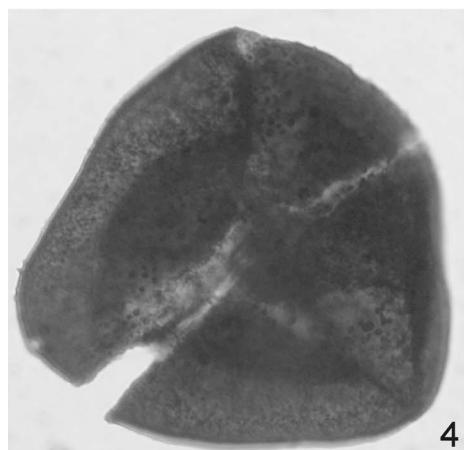
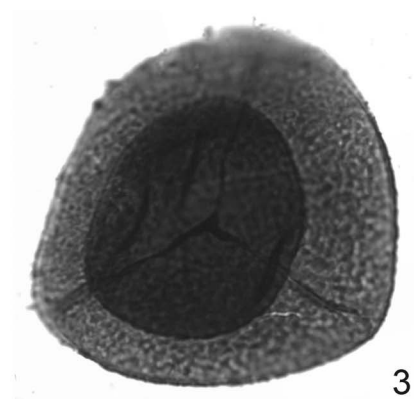
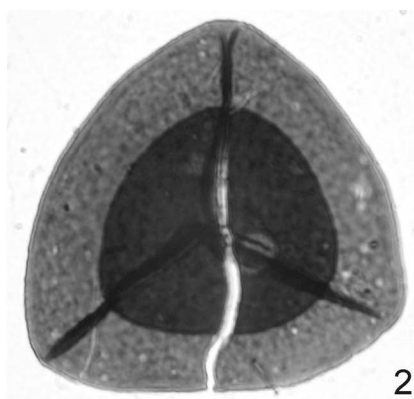
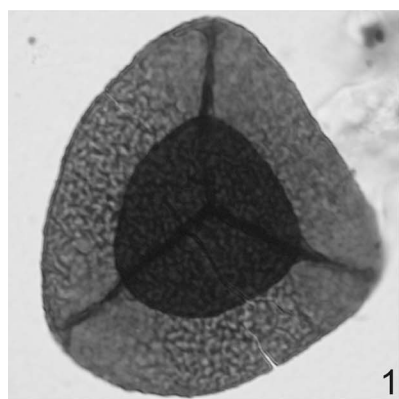
Description: Spores bilateral, monolete. Amb rhomboidal with rounded corners. Laesura distinct, straight to slightly curved, length ca. one-half of spore length, accompanied by narrow lips

PLATE 7

- 1-3 *Endosporites micromanifestus* Hacquebard 1957; median foci, 1, 2, ×800. 3, ×900.
4-9 *Spelaeotriletes arenaceus* Neves and Owens 1966. 4, median focus, ×700. 5, distal focus, ×1000. 6, proximal

focus, ×900. 7, distal focus, ×800. 8, 9, median foci, ×800.

- 10-12 *Spelaeotriletes?* sp. cf. *S. owensii* Loboziak and Alpern 1978; median foci. 10, ×1100. 11, 12, ×800.



up to 3.5µm high. Curvaturae perfectae distinct to barely perceptible. Exine 1-1.5µm thick. Contact areas laevigate; equatorial and distal exine scabrate.

Dimensions (3 specimens): In polar view, length 43-58µm; width 42-48µm.

Comparison: The characteristic rhomboidal shape of these specimens appears unmatched by previously described representatives of *Laevigatosporites* Ibrahim 1933.

Genus ***Monoletes*** Ibrahim 1933 emend. Schopf, Wilson and Bentall 1944

Type species: *Monoletes ovatus* Schopf 1935, by subsequent designation of Schopf, Wilson and Bentall (1944, pp. 38-39).

Discussion: The allegedly unsatisfactory validation of *Monoletes* Ibrahim 1933 (see Potonié 1960, p. 67), which led to the establishment of *Schopfipollenites* by Potonié and Kremp (1954, p. 180), was rejected by Balme (1995, p. 189). Accordingly, the latter author regarded *Schopfipollenites* R. Potonié and Kremp 1954 as a junior subjective synonym of *Monoletes* Ibrahim 1933 emend. Schopf, Wilson and Bentall 1944. Balme's (1995) viewpoint is accepted here.

Monoletes ellipsoides (Ibrahim 1933) Schopf 1938
Plate 8, figures 11, 12

Sporonites ellipsoides Ibrahim in R. POTONIÉ, IBRAHIM and LOOSE 1932, p. 449, pl. 17, fig. 29.

Monoletes ellipsoides (Ibrahim 1932) SCHOPF 1938, p. 45, pl. 1, fig. 14, pl. 6, figs. 5, 6.

Schopfipollenites ellipsoides (Ibrahim 1932) R. POTONIÉ and KREMP 1954, p. 180.

For additional synonymy see Smith and Butterworth (1967, p. 310).

Description: Spores bilateral, monolete, with elliptical to rounded subquadrangular amb. Laesura distinct, straight, simple, length approximately three-quarters of maximum spore length. Exine laevigate to infrapunctate, 3-4.5µm thick, with one or two distal longitudinal folds up to 5µm in overall width.

Dimensions (2 specimens): In polar view, length 89-100µm, width 59-70µm.

Previous records: Globally distributed in Upper Mississippian through Pennsylvanian strata. In Northern Gondwana, this species has been recorded, as *Schopfipollenites ellipsoides* (Ibrahim 1932) R. Potonié and Kremp 1954, from the upper Viséan-Serpukhovian of Libya, Algeria and Saudi Arabia (Attar et al. 1980; Massa et al. 1980; Coquel et al. 1988; Abdesselam-Rouighi et al. 1998; Clayton 1995; Coquel and Abdesselam-Rouighi 2000; Owens et al. 2000).

COMPOSITION OF THE PALYNOFLORA

The 27 palynologically productive samples collected from the Sarhlef Series in the Draa Sfar Mine yielded a moderately well preserved assemblage of land-derived miospores, together with some subordinate marine palynomorphs (acritarchs, prasino-phyte phycmata) and scolecodonts. The biostratigraphic significance of the miospores is discussed below. Taxonomic determination of the organic-walled microphytoplankton and scolecodonts has not been attempted because of their generally unfavorable state of preservation.

The miospore assemblage comprises 29 species assigned to 19 genera. Eighteen of the species are identifiable with previously instituted forms; five are newly established (*Cristatisporites mixtus*, *Densosporites dissonus*, *Indotriradites immutabilis*, *Vallatisporites extensivus* and *Endoculeospora marrakechensis*); two are compared, although not confidently assigned, to previously named species; and four are placed in open nomenclature.

Text-figure 6 depicts the qualitative and quantitative palynofloral composition of the samples collected from the DS125 borehole. Most samples are dominated by simple laevigate forms belonging to *Punctatisporites* and *Retusotriletes*. Also represented appreciably are *Spelaeotriletes*? sp. cf. *S. owensii*, *Vallatisporites agadesensis* and *Endoculeospora marrakechensis*. Less abundant forms include *Verrucosisporites* sp. cf. *V. aspratilis*, *Cristatisporites mixtus*, *Densosporites dissonus*, *Vallatisporites extensivus*, *V. galearis* and *Spelaeotriletes arenaceus*. Other species are rare and intermittently distributed through the sampled sequence.

Punctatisporites spp. and *Retusotriletes incohatus* are predominant in the productive samples, but decline slightly within the 70m interval above the massive sulfides. The reason or reasons for this trend are conjectural and investigation of adjacent boreholes is clearly needed to assess its significance.

CORRELATION AND AGE OF THE PALYNOFLORA

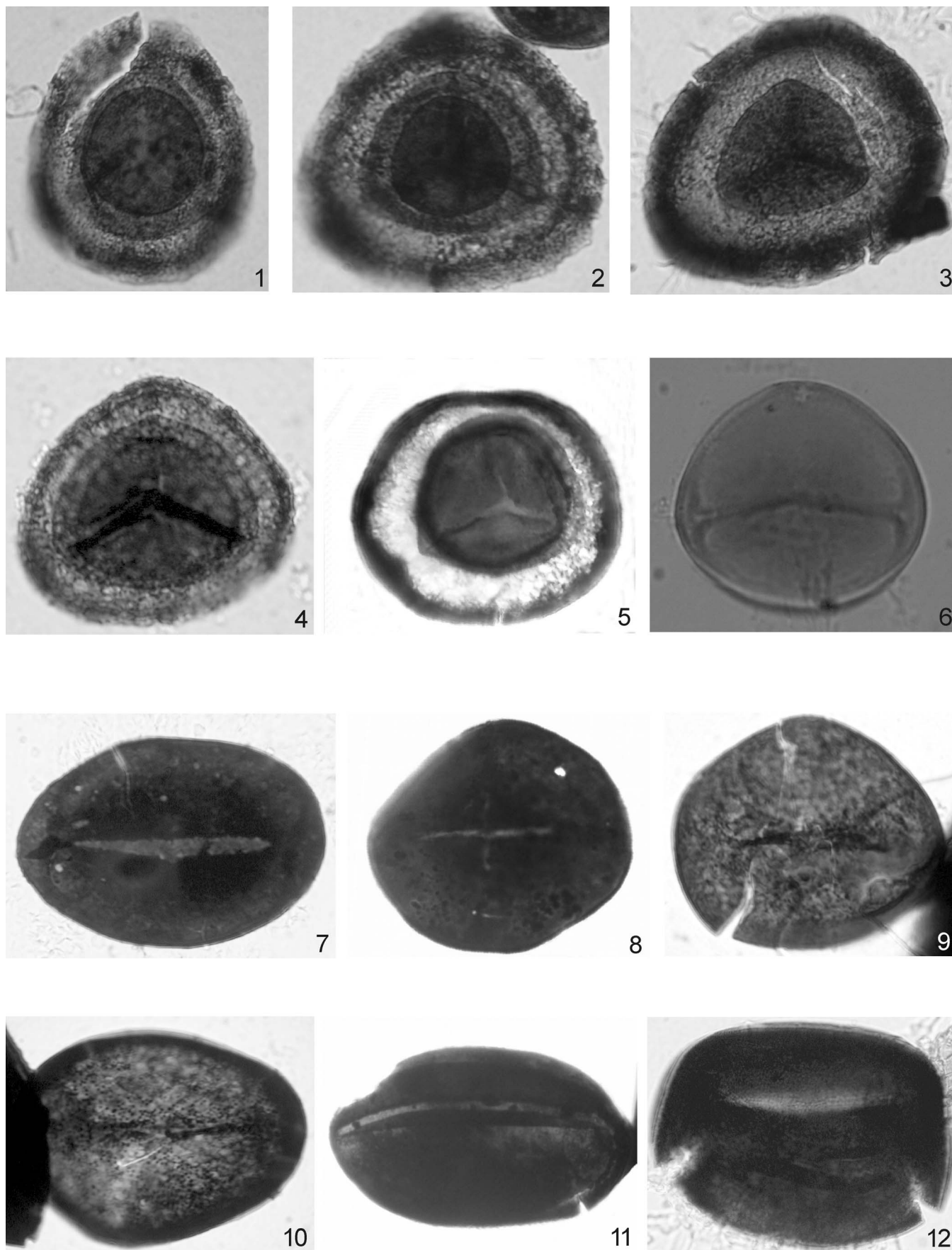
The conspicuous uniformity of the miospore content from sample-to-sample (text-fig. 6) results in the interpretation of the Draa Sfar palynoflora as a single entity. Minor compositional variations are considered to reflect differences in spore preservation among samples, or as a simple consequence of the erratic distribution of uncommon and rare species through the sequence.

Aside from some long-ranging forms that are inapplicable to precise dating and correlation, the Draa Sfar assemblage includes species with more restricted vertical distributions and

PLATE 8

- 1-5 *Spelaeotriletes*? sp. cf. *S. owensii* Loboziak and Alpern 1978; median foci. 1, ×800. 2, 3, ×1000. 4, ×1100. 5, ×900.
6,8,9 *Laevigatosporites* sp. A; proximal foci. 6, 9, ×1000. 8, ×650.

- 7,10 *Laevigatosporites vulgaris* (Ibrahim 1932) Ibrahim 1933; proximal foci. 7, ×800. 10, ×850.
11,12 *Monoletes ellipsoides* (Ibrahim 1933) Schopf 1938; proximal foci. 11, ×500. 12, ×550.



consequently enhanced biostratigraphic potential. Particularly notable in the Draa Sfar palynoflora is the co-occurrence of miospore species of virtually global distribution and others, such as *S. owensii* and *V. agadesensis*, that have been reported exclusively or predominantly from the Upper Mississippian of North Africa and adjacent regions. This circumstance is fairly constant along the Northern Gondwanan margin, and prompted Clayton (1985) to define for this region the *Spelaeotriletes balteatus* Microflora (renamed the *Aratrisporites saharaensis* Microflora by Clayton et al. 1991).

The Draa Sfar palynoflora contains a group of miospore species characteristic of the North African Upper Mississippian (i.e., of the *Aratrisporites saharaensis* Microflora or Province). These include *S. owensii*, *S. arenaceus*, *V. agadesensis* and *L. pusilla* (text-fig. 7). Of these species, only *L. pusilla* has previously been recorded from Morocco; viz., by Loboziak et al. (1990) and Ouarhache et al. (1991) in the upper Viséan of Western Meseta; and *V. agadesensis* by Rahmani-Antari and Lachkar (2001) in the lower Viséan of the Erfoud area. In Algeria, Lanzoni and Magloire (1969) identified *S. arenaceus* (as *Pustulatisporites* cf. *pretiosus* Playford n° 2902), *S. owensii* (as *?Hymenozonotriletes* sp. n° 2900) and *V. agadesensis* (as *Vallatisporites* sp. n° 3324) in the upper Viséan of the Grand Erg Occidental (biozones M6 and M7). Coquel and Abdesselam-Rouighi (2000) subsequently reported *L. pusilla* in assemblages assigned to the M7 Biozone. *Spelaeotriletes owensii*, *S. arenaceus*, *V. agadesensis* and *L. pusilla* were also identified in the Illizi Basin by Attar et al. (1980) and Abdesselam-Rouighi and Coquel (1997). These species exhibit disparate vertical ranges through the Illizi Basin succession, but as an association they conform to the miospore complex of the upper Viséan-Serpukhovian Biozone V of Attar et al. (1980).

In the Libyan Rhadamès Basin, the first appearance of *L. pusilla* defines the base of the upper Viséan-lower Serpukhovian Biozone XV of Massa et al. (1980). *Spelaeotriletes arenaceus*, *S. owensii* and *V. agadesensis*, whose local stratigraphic ranges extend down into the upper Tournaisian and lower Viséan, also persist into Biozone XV. Clayton and Loboziak (1985) and Loboziak and Clayton (1988), working on samples from northeastern Libya, assembled a four-fold palynozonal scheme extending from the Viséan to Gzhelian/lower Asselian. They confirmed the co-occurrence of *S. owensii*, *S. arenaceus*, *V. agadesensis* and *L. pusilla* in the upper part of their upper Viséan-lower Serpukhovian *Prolycospora rugulosa-Spelaeotriletes triangulus* (RT) Biozone.

In Saudi Arabia, the base of a Mississippian stratal sequence containing *S. owensii* and *V. agadesensis* has been correlated by Clayton (1995) with the RT Biozone; whereas the top of the sequence, including representatives of the monosaccate pollen genera *Potonieisporites* Bhardwaj 1954 and *Plicatipollenites* Lele 1964, was assigned to the lower Serpukhovian *Plicatipollenites malabarensis-Cannanoropollis janakii* (MJ) Biozone of Loboziak and Clayton (1988). *Spelaeotriletes arenaceus* was later reported from the Arabian Gulf by Clayton et al. (2000) in strata assigned to the RT Biozone, and *L. pusilla* was recorded by Owens et al. (2000) in a palynoflora compared to that of the MJ Biozone.

The four diagnostic species discussed herein were identified in northern Niger by Coquel et al. (1995) in an interval dated as

Serpukhovian-Bashkirian, although their local stratigraphic ranges, with the exception of *L. pusilla*, extended down into the upper Viséan. Previously, Loboziak and Alpern (1978) had reported *L. pusilla*, *S. owensii* and *V. agadesensis* in an upper Viséan sequence of the Agadès Basin in central Niger. *Spelaeotriletes owensii* and *V. agadesensis* were identified by Ravn et al. (1994) in Syrian strata broadly dated as Viséan. In northeastern Iran, the co-occurrence of the four species was reported by Coquel et al. (1977) from close to the Viséan-Serpukhovian boundary. In Sinai, Egypt, Kora (1993) retrieved three of the species (i.e., excluding *V. agadesensis*) from rocks attributed to the upper Viséan.

Another biostratigraphically relevant species identified in the Draa Sfar material is *Monoletes ellipsoides*. It has been reported widely, including from Northern Gondwana, in sequences not older than late Viséan. In the Illizi Basin, its first occurrence (as *Schopfipollenites ellipsoides*) was used by Attar et al. (1980) to define the base of their Biozone VI, dated as Serpukhovian (base excluded)-Bashkirian. Subsequently, Abdesselam-Rouighi and Coquel (1997) extended its local stratigraphic range in the Illizi Basin down into the upper Viséan, by observing forms attributable to *M. ellipsoides* from just below the base of Biozone V of Attar et al. (1980). From the Grand Erg Occidental (Algeria), Coquel and Abdesselam-Rouighi (2000) recovered representatives of this species from the top of Biozone M7 of Lanzoni and Magloire (1969). In Libya, the species was observed initially by Massa et al. (1980) within their Serpukhovian Biozone XVI, and subsequently by Coquel et al. (1988) in the preceding Biozone XV. Clayton (1995) identified *M. ellipsoides* in a Saudi Arabian miospore assemblage assigned to the RT Biozone of Loboziak and Clayton (1988); and Owens et al. (2000) reported its presence in an assemblage attributed to the succeeding MJ Biozone.

Waltzisporea polita, which occurs intermittently through the sampled sequence, has been recorded in Northern Gondwanan strata not older than late Viséan (Clayton and Loboziak 1985; Clayton 1995; Loboziak and Clayton 1988; Loboziak et al. 1990; Ouarhache et al. 1991). This is in essential agreement with the stratigraphic range of this species as documented widely in other Gondwanan and Laurasian regions (see Playford 1991; Dino and Playford 2002).

The present palynoflora is also noteworthy for its content of species that have been reported extensively, near-globally, from upper Famennian and Tournaisian miospore assemblages. However, in North Africa, most of these species, including *Retusotriletes crassus*, *Vallatisporites verrucosus* and *V. vallatus*, have already been identified in assemblages considered coeval or near-coeval with that of the Draa Sfar mine. *Retusotriletes crassus* is known from the Viséan of Libya (Clayton and Loboziak 1985) and Syria (Ravn et al. 1994), and from the upper Viséan-lower Serpukhovian of Saudi Arabia (Clayton 1995). Moreover, *V. vallatus* and *V. verrucosus* occur in Viséan and lower Serpukhovian palynofloras of Morocco, Libya, Saudi Arabia and Syria (Clayton and Loboziak 1985; Loboziak and Clayton 1988; Ravn et al. 1994; Clayton et al. 2000; Owens et al. 2000 and Rahmani-Antari and Lachkar 2001).

From the above, the Draa Sfar miospore assemblage is clearly compatible palynofloristically with the Northern Gondwanan realm. Nonetheless, particularly noteworthy is the absence of certain species that are reputedly fairly consistent components of North African palynofloras; e.g., *Densosporites claytonii*

(generally recorded as *D. variomarginatus*), *Radiizonates arcuatus* (*R. genuinus*) and, particularly, *Aratrisporites saharaensis* (the eponymous species of the so-called North African "Microflora"). These forms are seemingly no more vulnerable to preservational degradation or laboratory maceration procedures than are those identified in the present samples. Therefore, it seems reasonable to discount post-depositional factors as a cause of apparent absenteeism of these species. The latter circumstance could simply be consequential on the decline or local disappearance of the species towards the close of the Viséan, as has been documented by various authors including Massa et al. (1980), Attar et al. (1980), Marhouni et al. (1984), Coquel et al. (1988), Loboziak and Clayton (1988) and Coquel and Abdesselam-Rouighi (2000).

Palynofloras closely comparable to that identified in the present study have also been reported from Western Gondwana. The northern Brazilian basins of Parnaíba, Solimões and Amazonas include nearly all the species cited above, and their local stratigraphic ranges coincide for the most part with those recorded in Northern Gondwana. The initial palynological investigations in those basins (Daemon and Contreiras 1971; Daemon 1974, 1976; Andrade and Daemon 1974) highlighted the upper Viséan occurrence of *S. owensii* (as *Esporo zonado* sp. 2507) in the upper subinterval of Biozone XII of Daemon and Contreiras (1971). Loboziak et al. (1991), working on samples from the Amazonas Basin, reported that species, together with *V. agadesensis*, *S. arenaceus*, *M. ellipsoides*, *L. pusilla* and *W. polita*, in an interval they correlated with the Tournaisian-lower Viséan PC, CM and Pu biozones of Western Europe. That biozonal attribution was sustained by Loboziak et al. (1992, 1993) in palynological studies conducted subsequently in the Amazonas and Parnaíba basins. However, Loboziak et al. (1998) proposed that their investigated strata should be correlated with the upper Viséan TC, NM and VF biozones of Western Europe. An assemblage resembling those described by Loboziak et al. (1998) from the Amazonas Basin was reported by Melo and Loboziak (2000) from another locality in the Parnaíba Basin. The persistent occurrence of the stratigraphically significant species *Alatisporites tessellatus* Staplin 1960 prompted these authors to correlate their assemblage with the upper Holkerian-Asbian TC and NM biozones of Western Europe. This zonal interval was subsequently equated to the *Reticulatisporites magnidictyus* (Mag) Biozone within the Devonian-Mississippian miospore scheme proposed by Melo and Loboziak (2003) in the Amazonas Basin. Accordingly, the Draa Sfar palynoflora of the present study can be likened to the West Gondwanan Mag Zone.

Text-fig. 8 summarizes the biostratigraphic analysis developed above, charting the currently known vertical distributions of critical species reported herein and elsewhere within North African/Middle Eastern Carboniferous successions. From these palynostratigraphic data, it is evident that the analyzed shaly sequence of the Sarhlef Series can be dated within the late Viséan/earliest Serpukhovian interval.

As previously noted, faunal evidence is indicative of a Viséan-Namurian age for the Sarhlef Series, and an Asbian (=V3b in terms of the Belgian succession) age for the overlying Teksin Formation. Accordingly, a combination of the palynological and faunal data makes it possible to constrain the age of the strata containing the Draa Sfar ore to the late Viséan (Asbian). In addition, the geochronological findings of Mrini et al. (1992), Essaifi et al. (2003) and Marcoux et al. (2008) also

concur with this dating. Their study yielded dates of 327 ± 4 Ma, $330.5^{+0.68}_{-0.83}$ Ma, and 331.7 ± 7.9 Ma, respectively.

CONCLUSIONS

This detailed palynological analysis of black shales of the Sarhlef Series yields the following conclusions:

1. The 27 productive samples representative of the shaly sequence contain fairly uniform assemblages consisting principally of miospores and subordinately of microphytoplankton (acritarchs and prasinophyte phycomata) and scolecodonts. The spore component, systematically documented herein, comprises 29 species (five new) allocated among 19 genera.
2. The miospore assemblage is characterized by the co-occurrence of species having virtually global distribution with other species typically reported in Northern Gondwanan assemblages attributed to the *Aratrisporites saharaensis* palynofloristic province.
3. The Draa Sfar palynoflora is, as a single entity, closely compatible with late Viséan-early Serpukhovian palynofloras reported from North Africa and adjacent regions. In conjunction with available faunal evidence, the Sarhlef Series hosting the Draa Sfar sulfide deposit is considered late Viséan (Asbian).
4. Palynostratigraphic correlations established between the Draa Sfar palynoflora and those reported in other areas of Northern Gondwana can be extended to Western Gondwana (i.e., Parnaíba, Solimões and Amazonas basins of northern Brazil).
5. This study corroborates prior studies conducted by the present authors in the Iberian Pyrite Belt, by reaffirming the unique contribution of palynology in the precise dating of black shales series hosting ore sulphide deposits.

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APPENDIX 1

Register of illustrated specimens from the Sarhlef Series at Draa Sfar Mine (see text-fig. 2). Abbreviations are as follows: H, holotype; P, paratype; UHU, University of Huelva. Asterisk signifies SEM specimen not recovered. The entire collection of specimens illustrated herein will be housed permanently in the Museo Geominero del Instituto Geológico y Minero de España, Madrid.

Species/type	Plate/ figure	Sample number	Prep./ slide no.	England Finder	Type no.	Species/type	Plate/ figure	Sample number	Prep./ slide no.	England Finder	Type no.
<i>Leiotriletes inermis</i>	1/1	455.80	k694/b	L42/2	UHU.255	<i>Vallatisporites agadesensis</i>	4/7	471.30	k662/b	Q53/2	UHU.293
	1/2	170.30	k665/a	J51/0	UHU.256		4/8	447.40	k693/b	Q65/3	UHU.294
<i>Punctatisporites glaber</i>							4/9	360.20	k656/c	V42/3	UHU.295
	1/3	455.80	k494/b	R40/2	UHU.257		4/10	447.40	k693/SEM2	*	*
<i>Punctatisporites irrasus</i>						<i>Vallatisporites extensivus</i>					
	1/4	447.40	k693/b	M59/0	UHU.258	P	4/11a, b	352.10	k667/b	H57/0	UHU.296
	1/5	447.40	k693/b	U45/0	UHU.259	P	5/1	399.40	k689/b	K36/4	UHU.297
<i>Punctatisporites minutus</i>						H	5/2a, b	447.40	k693/5	Q33/0	UHU.298
	1/6	447.40	k693/c	M60/4	UHU.260	P	5/3	455.80	k694/a	D35/0	UHU.299
	1/7	447.40	k693/c	G40/3	UHU.261	P	5/4	447.40	k693/SEM4	L52/1	UHU.300
	1/8	455.80	k694/a	O31/4	UHU.262	P	5/5	447.40	k693/SEM4	Q51/0	UHU.301
<i>Punctatisporites planus</i>						<i>Vallatisporites galearis</i>					
	1/9	508.30	k695/a	G55/3	UHU.263		5/6	447.40	k693/d	K33/0	UHU.302
	1/10	447.40	k693/a	T42/3	UHU.264		5/7	392.00	k688/b	W59/0	UHU.303
							5/8	407.50	k690/b	Q58/0	UHU.304
<i>Retusotriletes crassus</i>						<i>Vallatisporites vallatus</i>					
	2/1	447.40	k693/21	O35/2	UHU.265		5/9	392.00	k688/b	T40/0	UHU.305
	2/2	455.80	k694/b	T55/1	UHU.266		5/10	170.30	k665/c	M32/1	UHU.306
	2/3	447.40	k693/d	E42/0	UHU.267	<i>Vallatisporites verrucosus</i>					
<i>Retusotriletes incohatus</i>							5/11	447.40	k693/b	O32/2	UHU.307
	1/11	352.10	k667/b	J38/1	UHU.268	<i>Auroraspora solisorta</i>					
	1/12	447.40	k693/SEM1	*	*		6/1	407.50	k690/b	E55/3	UHU.308
<i>Waltispora polita</i>							6/2	392.00	k688/a	J37/3	UHU.309
	2/4	170.30	k665/b	B42/2	UHU.269	<i>Endoculeospora marrakechensis</i>					
<i>Verrucosporites</i> sp. cf. <i>V. aspratilis</i>						H	6/3	360.20	k656/c	S50/4	UHU.310
	2/5	170.30	k665/b	T40/0	UHU.270	P	6/4	504.90	k663/b	B65/0	UHU.311
	2/6	447.40	k693/SEM4	P51/2	UHU.271	P	6/5	170.30	k665/c	T61/0	UHU.312
<i>Anapiculatisporites</i> sp. A						P	6/6	447.40	k693/19	O41/0	UHU.313
	2/7	390.50	k673/a	Q52/4	UHU.272	P	6/7a, b	447.40	k693/SEM4	N51/4	UHU.314
	2/8	385.40	k672/a	V50/2	UHU.273		6/8a, b	447.40	k693/SEM4	*	*
<i>Diatomozonotriletes</i> sp. A						P	6/9a, b	447.40	k693/SEM5	M50/1	UHU.315
	2/9	385.40	k672/b	T43/0	UHU.274	<i>Endosporites micromanifestus</i>					
	2/10	392.00	k688/b	S66/2	UHU.275		7/1	425.80	k691/b	S49/2	UHU.316
<i>Reticulatisporites?</i> sp. A							7/2	447.40	k693/1	S31/2	UHU.317
	2/11	368.60	k670/a	T65/1	UHU.276		7/3	352.10	k667/b	X44/2	UHU.318
	2/12	447.40	k693/b	G60/0	UHU.277	<i>Spelaeotriletes arenaceus</i>					
	3/1a, b	447.40	k693/SEM5	N51/0	UHU.278		7/4	447.40	k693/31	O36/2	UHU.319
<i>Cristatisporites mixtus</i>							7/5	54.80	k654/b	S57/1	UHU.320
P	3/2	54.80	k654/b	Q36/0	UHU.279		7/6	392.50	k661/c	R57/1	UHU.321
P	3/3a, b	455.80	k694/b	L50/0	UHU.280		7/7	143.60	k655/b	P52/0	UHU.322
P	3/4	352.10	k667/b	K37/2	UHU.281		7/8	369.10	k660/c	S47/3	UHU.323
H	3/5a, b	447.40	k693/a	L52/0	UHU.282		7/9	425.80	k691/b	S49/3	UHU.324
P	3/6	447.40	k693/SEM5	M51/4	UHU.283	<i>Spelaeotriletes?</i> sp. cf. <i>S. owensii</i>					
<i>Densosporites dissomus</i>							7/10	407.50	k690/c	P63/0	UHU.325
H	3/7	392.00	k688/a	J59/4	UHU.284		7/11	447.40	k693/c	Q74/3	UHU.326
P	3/8	455.80	k694/b	H32/1	UHU.285		7/12	447.40	k693/a	U37/3	UHU.327
P	3/9	432.60	k692/b	Q32/1	UHU.286		8/1	455.80	k694/b	M43/0	UHU.328
P	4/1	447.40	k693/SEM5	M52/1	UHU.287		8/2	455.80	k694/b	V62/4	UHU.329
<i>Lycospora pusilla</i>							8/3	455.80	k694/b	S60/1	UHU.330
	4/2	385.40	k672/b	H34/1	UHU.288		8/4	392.00	k688/a	N40/3	UHU.331
	4/3	385.40	k672/b	M53/0	UHU.289		8/5	447.40	k693/c	D43/3	UHU.332
<i>Indotriradites immutabilis</i>						<i>Laevigatosporites vulgaris</i>					
H	4/4	399.40	k689/b	L52/1	UHU.290		8/7	558.70	k698/a	D69/4	UHU.333
P	4/5	407.50	k690/b	C66/3	UHU.291		8/10	549.10	k697/b	Q43/0	UHU.334
P	4/6	549.10	k697/b	N64/3	UHU.292	<i>Laevigatosporites</i> sp. A					
							8/6	523.40	k696/c	K41/4	UHU.335
							8/8	170.30	k665/8	N36/0	UHU.336
							8/9	425.80	k691/b	S58/2	UHU.337
						<i>Monoletes ellipsoides</i>					
							8/11	143.60	k655/a	O50/0	UHU.338
							8/12	455.80	k694/b	K36/0	UHU.339