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## Late Silurian-Middle Devonian Miospores

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### 1. Introduction

Recent palynological researches on late Silurian to Middle Devonian terrestrial palynomorph have culminate on cryptospores and miospores zonation system (e.g., Richardson and McGregor 1986; Streel *et al.* 1987; Massa and Moreau-Benoît 1976; Melo and Loboziak 2003; Hassan Kermadjji *et al.* 2008). Although stratigraphic, ecologic and geographic importance of these fossils grasp great effort, but much more work is required on their biostratigraphy and taxonomy before their complete potential can be understand. Nevertheless, palynological research is creating a major contribution to enable an overview of most important characteristics of cryptospores and miospores (Devonian miospore from Algeria, Tunisia and Libya, e.g., Magloire 1967; Moreau-Benoît *et al.* 1993; Loboziak *et al.* 1992; Spina and Vecoli 2009) also Silurian and Devonian miospore from Bolivia, Spain United Kingdom and Saudi Arabia (e.g., McGregor, 1984; Richardson *et al.* 2001; Wellman and Richardson 1993, 1996; Wellman *et al.* 1998; Steemans *et al.* 2007). Sporomorphs are more abundant and wide spread than cryptospores where decreasing in number and variety from older to the younger sediments (e.g., Rubinstein and Steemans 2002). Miospores by their structural complexity and augmentation they may provide more reliable evidence for formal zonal schemes to be proposed. However, uncertainty also exist the precise definition of the binomial species regarding their lateral distribution on local and regional scale, some may have restricted distribution pattern (e.g., Hassan Kermadjji 2007), this is also may be due to the timing of their appearance and development and place of their parent plant evolutionary events (e.g., Edwards and Richardson 1996) and ecological niches.

Local or regional variations in plant distribution during late Silurian-Lower Devonian are due to: close contact of the Rheic Ocean during the early Lochkovian, or moderate distance separating Gondwana and Laurussia, or close proximity of the Avalonia Maguma and Aquitaine areas to the northern border of Gondwana during Přídolí times and or a possible land plant migration route between Laurussia and Gondwana (Rubinstein and Steemans 2002; Steemans and Lakova 2004; Hassan Kermadjji 2007; Richardson *et al.* 2001; Spina and Vecoli 2009). Since the land invaded by plants, palaeoenvironment constrictions are possible. It is, however, significant in demonstrating the influence of Gondwanan parent flora on the miospore populations of the southern regions of Laurussia. This is may serve for providing a link between Laurussian and Gondwanan palynofloras.

Late Silurian-Lower Devonian stratigraphy is rather complicated where different miospore biozones are recognized. Correlations of North Africa Gondwanan miospore biozones

remain hard to be compared precisely with Euramerica well established spore zonation but may be resolved by studies based on phytoplankton, chitinozoa, conodonts and graptolites. Primary biostratigraphic subdivision within the late Silurian-Lower Devonian has been done by recognition of progressive change in terrestrial miospores. Subdivision is based on new incoming of well established miospores. Euramerican stages containing six Spore Zones and two Opplé Zones where they provide bases for local and regional correlations. Although, some miospore assemblage similarities exist between Gondwana and Euramerica, there are significant differences as well. For instance species characteristics of Lochkovian (e.g., *Streelisporea newportensis* s.s., *Emphanisporites zavallatus*, *E. microrhatus* s.s) are absent or rare in most parts of Gondwana (Melo and Loboziak 2003; Steemans *et al.* 2008), in Euramerica appear to be geographically well established which may suggest that they are apparently regionally confined. On the other hand, other biozonal species characteristics of late Silurian-Lower Devonian are found in Europe, North America and Gondwana (e.g., *Chelinospora cassicula*, *C. hemisferica*, *Leonispora argovejae*, *Perotrilites microbaculatus*, *Dictyotrilites emsiensis*, *Verrucosporites polygonalis*, *D. subgranifer*, *E. annulatus*, *D. echinaceus*, *Calyptosporites velatus*, *Rhabdosporites langii*). These palynological similarities might point out possible common constituents of their parent plants producing these miospores.

Late Silurian and Lower Devonian times are thus a key period for the developing of miospore zonation with confident suggestion in biostratigraphic, phytogeographic and palaeoenvironmental studies.

This chapter therefore will concentrate on late Silurian and early Devonian miospores biozones and systematic issues also will deal with early Middle Devonian miospores regarding their biozonation consequence and evolutionary significance.

## 2. Sporomorphs evolution

Richardson (1996) reviewed in brief development record of terrestrial sporomorphs. Stated that the problematic organic-walled microfossils occur in Vendian rocks and named by Volkova (1976) and 'are associated with leiosphaerid acritarchs' probably derived from brown alga. Also he believes that the first occurrence of cryptospores and miospores is approximate. The earliest terrestrial sporomorphs resembling miospores record is outside the scope of this chapter. However, it is extremely interesting to record the development of sporomorphs concerning the study.

The sporomorph events described below are based on data from type sequences. These will provide minimum age range for the events stated by, (Hassan Kermadji 2007; Hassan Kermadji *et al.* 2008) which agrees with (Richardson and McGregor 1986; Streel *et al.* 1987; Richardson *et al.* 2001) detection. Detailed review of the many palynological studies of Silurian and Devonian deposits of Euramerica and western Gondwana, reveals obvious coincidence of many of significant palynological events.

In both Euramerica and western Gondwana, possibly Llanvirn-Caradoc cryptospore population are characterised by distinctive elements (permanent tetrads, pseudodyads and monads), they possess nearly identical structure and sculptural ornaments. Many studies (Gray 1992; Richardson 1988; Wellman *et al.* 1998; Steemans 1999a, b) reported possible cryptospores from Middle and late Ordovician. The recorded possible cryptospore assemblages from deposits older than Caradoc are either naked or enclosed within a thin, smooth or variously ornamented envelopes. Consequently, Richardson (1988) considers that pseudotetrads,

pseudodyads and monads envelop possibly developed prior to Caradoc. Cryptospore bearing plants were becoming more widespread and numerous during late Ordovician and early Silurian (Gray 1985, 1988; Burgess 1991; Burgess and Richardson 1991). They were reported from terrestrial and near shore environments. Many studies (e.g.; Vaverdova 1988) believe that high abundance of cryptospores may be facies controlled. Others (e.g.; Richardson 1992) relate high abundance to the upper Ashgill glacial period which played a major role in the extinction of faunas and floras and not affected the cryptospores of the high latitude. This is based on Burgess's study (1991) on Llandovery deposits, south Wales that there is only minor differences between Ashgill and Llandovery cryptospore assemblages.

Although, there is no specific record for the earliest cryptospore creator, it is very hard to analyse that the cryptospores reflects true diversity. Because, different cryptospore morphotypes have similar envelope (taking in consideration that many envelopes may be lost or changed during preparation). Furthermore, many of these forms, morphologically and structurally, are simple. Such simple forms could have been produced by a number of plant types or by the same parent plant (Richardson 1988, 1992; Gray 1991; Strother 1991). Similarly, Fanning *et al.* (1988) refer to morphologically identical plant may produce different spore forms; they reflect it to the rapid evolution of the spore morphology. Wellman *et al.* (1998) came to the comparable conclusion that superficially morphologically similar miospores were produced by different plant types. This is all because the unavailability of studies denotes the *in situ* relationship between the parent plants and dispersal cryptospores and miospores.

Studies of (Gray *et al.* 1982; Gray 1985; Vaverdova 1984; Burgess and Edwards 1991; Gensel *et al.* 1991; Wellman 1995; Edwards and Wellman 1996; Hassan 1982; Hassan Kermendji and Khelifi Touhami 2008) show that the enigmatic dispersal phytodebris and land plants of the late Lower and Middle Palaeozoic sediments probably, are the core stone of the plants produced dispersal cryptospores and miospores. They show that the dispersal fragments consist of ornamented and laevigate types of cuticles, tubular structures, tissues and filamentous, occurs isolated or commonly in complex form mainly in continental deposits. The oldest known record of permanent tetrad and dyads is from the early Llanvirn of Bohemia by Vaverdova (1984) and Vaverdova's (1990) record for Prague basin. Although, cryptospore spreading declined upward, it exists in its diversity until to the early Devonian. Early cryptospores, permanent tetrads, dyads and monads, though it is not well documented, believed that they are of terrestrial origin (non marine sediments) and near shore environment (Strother and Traverse 1979; Wellman and Richardson 1993; Richardson 1996) and that 'cryptospores are more abundant than miospores in inshore sediments' Richardson and Rasul (1990). Many of these cryptospores (dyads and tetrads) were derived from plants with bifurcating axes and sporangia Wellman *et al.* (1998). It appears that monads, dyads and tetrads frequently have similar envelopes, this tend to suggest that they closely related, probably derived from the same species (Richardson 1988, 1992; Johnson 1984). Whereas trilete miospores dissociated from immature tetrads which are match forms among existing embryophytes.

The cryptospore assemblages decline in its taxonomic diversity in Homeric and younger sediments perhaps is environmental effect (probably facies controlled) Richardson (1988) and or an evolutionary indication (Hassan Kermendji *et al.* in preparation).

The earliest recorded embryophyte miospores was by Vaverdova (1984) from early Llanvirn of Bohemia; also identical miospore assemblages were reported from mid Ordovician to early Silurian by: Richardson (1988) Gray (1985, 1991), Burgess (1991) Strother (1991),

Strother *et al.* (1996), Wellman (1996), Steemans (1999a). However, (Wellman and Richardson 1993; Strother and Traverse 1979; Richardson 1992; Gray *et al.* 1992; Wellman and Gray 2000; Steemans 1999b) believe that the structure and morphology of these early miospores are atypical comparing with existing miospores of younger ages, therefore some times, embryophyte miospores been used as cryptospores. This is due to that the widely spread vegetation was of restricted diversity and diminutive evolutionary change.

Most studies reveal that major changes occur to the miospore nature during late Lower Silurian. The mature miospores of existing embryophytes become dominant and more abundant than cryptospores by Ludlow Wellman and Gray (2000, fig. 1). Their diversity and abundance increased throughout the late Silurian. Steemans *et al.* (1996), Wellman, Higgs and Steemans (2000) studies show that trilete miospores and hilate monads of northeast Gondwana appear during late Ordovician and early Silurian. Sculptured forms of both trilete miospore and hilate monads flourished throughout late Silurian and early Devonian Burgess and Richardson (1995); Steemans (1999b). The hilate monads number decline in latest Silurian and earliest Devonian, and cryptospores exist as a minor constituents in miospore assemblages through Lower Devonian and extinct at the end of Emsian Hassan Kermadji *et al.* (In the press).

Considerable variations in dispersed miospore record exist through late Silurian and early Devonian, (mainly Přídolí and Lochkovian). This creates problems when trying to recognize phytogeographic variations (Rubinstein and Steemans 2002; Richardson *et al.* 2001; Hassan Kermadji 2007). Sequences of spore assemblages from Western Europe are similar in composition except some minor differences, this is indicate that it contain a flora representing a single palaeophytogeographic province. Although miospore assemblages sequences of northern Gondwana sharing some elements but display striking differences, signifying that they belong to a different palaeophytogeographic province. Comparison between Lochkovian miospore assemblages of the two provinces is difficult; probably they belong to different parent plants. The differences become less obvious during late Emsian and Eifelian.

Although, the *in situ* miospore records for early land plant megafossils are rare, it is more common in higher sediments. This is due to nature of land plant preservation, where they preserved as coalified compressions. Though, suitable preservations (uncompressed coalifications with splendid cellular detail) have been recorded in Lochkovian localities of south Wales (Edwards and Richardson 1996; Edwards 1996). The record of early land plants show that many miospores (*Ambitisporites*, *Synorisporites*, and *Streelispora*) have been recovered from the sporangia of rhyniophyte *Cooksonia* (Funning *et al.* 1988; Richardson 1996) which is a factual tracheophyte Edwards *et al.* (1992) and most trilete miospores appear to have consisted of plants with bifurcating axes/sporangia and more frequently stomata (Edwards 1995; Wellman *et al.* 1998). On the other hand, some dispersed miospore assemblages such as patinate species and *Emphanisporites* are abundant, but there *in situ* forms are extremely rare. This is probably facies and/or preservational effect.

The main evolutionary performance divided into events based on dispersed palynomorphs (text fig. 1), nearly all events described below are based on information from type sequences.

## 2.1 Crassitate, distally laevigate miospore event

The Aeronian and early Telychian miospores are distally laevigate and equatorially crassitate and belong to the genus *Ambitisporites avitus*, *Amitisporits dilutes*. Also appear some tetrads and

System	Stage/ Series	Palynological events	Main Characters
D E V O N I A N	Eifelian	Zonate-pseudosaccate and coarse bifurcate spinose miospore	Incoming of considrable significant finely sculptured pseudosaccate miospores ( <i>C.velatus</i> and <i>R. langii</i> ). Waning of <i>Acinosporites</i> and patinate taxa.
		Monopseudosacciti and Bifurcate-tipped appendages miospore	Incoming of bifurcate appendages ( <i>Hystricosporites</i> species).Persistent of <i>Grandispora</i> , <i>Acinosporites</i> , <i>Geminospora</i> and <i>Grandispora</i> species. Disappearance of <i>Scylaspora</i> and cryptospores.
	Emsian	Bizonate, proximally cristate and distally annulate miospore	Proliferation of zonate and pseudosaccate ( <i>C. Sextantii</i> ), <i>Geminospora</i> forms Appearance of proximally radially ribbed with distinct distal annulae ( <i>E. annulatus</i> ) and distally convoluted murornate species ( <i>Acinosporites</i> ).
		Diversification of proximal prominent stout radial muri miospore	Incoming of retusoid miospores with verrucate or murornate sculpture ( <i>D. subgranifer</i> , <i>V. polygonalis</i> ) . Waning of cryptospores.
	Pragian	Coarse biform apiculae with cingulicavati and foveolae miospore	Incoming of <i>Dibolisporites</i> , distally with spines, and biform elements and retusoid <i>Apiculiretusispora</i> . Diversification of cingulate species of <i>Camptozonotriletes</i> and <i>Clivosispora</i> .. Waning of <i>Scylaspora</i> species
		Distally murornate, proximally radially ribbed miospore	Incoming of <i>E. spinaeformis</i> and <i>D. emsiensis</i> ; persistent of hilate cryptospore monads and dyads. Diversification of apiculate monad cryptospores and laevigate, apiculate tetrads.
	Lochkovian	Diversification of distally cingulate,patinate miospore	Incoming of annulate, cingulate rugulate and patinate spores. Persistent of perinate and crassitate species. Appearance of <i>A. miserabilis</i> and <i>C.proteus</i>
		Proximally slightly ribbed, distally apiculate crassitate, perinate miospore	Persistent of apiculate, microrugulate, crassitae miospores, incoming of perinate and patinate species. Proliferation of laevigate dyads, monads and tetrads. Appearance of <i>S. tidikeltense</i> and <i>P. microbaculatus</i> .
			Diversification and proliferation of murornate equatorially crassitate miospores, incoming of apiculate curvaturate forms and hilate dydes. Appearance of <i>S. radiata</i> and <i>A. synoria</i> .
	Přídolí	Diversification of crassitae, disto-equatorially multi sculptured miospore	
S I L U R I A N	Ludfordian	Murornate, apiculate patinate miospore	Diversifications of distally reticulate patinate and foveolate sculptured miospores. Incoming of tripapillate and equatorially crassitate murornate forms and hilate dyads. Appearance of <i>C. hemiesferica</i>
		Patinate, proximally hilate with distal faint muri miospore	Diversification of variably sculptured patinate, crassitate and cingulate and radially ribbed sporomorphs. Appearance of <i>C. sanpetrensis</i> and <i>C. triangulatus</i> .
	Grosstian	Apiculate, patinate with faint radial muri miospore	Incoming of distally murornate miospores with radially ribed patinate miospores. Consistent of hilate cryptospores and tetrads.
	Homerian	Granulate,apiculate, crassitate miospore	Incoming of sporomorphs with proximal radial muri and equatorial radial thickening and distal granules and verrucae. Appearance of <i>Cheilotetras caledonica</i>
		Murinate,verrucate crassitate,patinate miospore	Proliferation of verrucate, murornate emphanoid forms and patinates miospores with distal radial muri. Also, include verrucate cryprospores. Appearance of <i>S. vetusta</i> and <i>S. kozlica</i> .
		Murornate,verrucate miospore	Domination of distally apiculate and verrucate crassitate and cingulate miospores. Persistent of hilate cryptospores. Appearance of <i>Hispanaediscus verrucatus</i> .
		Hilate monad miospore	Incoming of patinate miospores, also including dyads and tetrads, persistent of cryptospores.
	Shtenwoodian	Patinate, proximally hilate laevigate miospore	Incoming of hilate miospores, <i>A. chulus/nanus</i> complex, equatorially crassitate miospores and tetrads and dyads
	Telychian	Crassitate,distally laevigate miospore	Incoming of laevigate crassitate miospores and some tetrads and dyads and persistent of cryptospores.

Fig. 1. Summery of principle Silurian-Devonian sporomorphs evolution.

some dyads and cryptospores are present (Hassan Kermadjji *et al.* in preparation). The age is based on acritarchs and chitinozoans in the type Llandovery area Burgess and Richardson (1991).

## 2.2 Patinate, proximally hilate laevigate miospore event

The exact stratigraphic range where equatorially crassitate, patinate miospores, tetrads and dyads occur is uncertain, possibly they appear in rocks older than Homerician probably Upper Aeronian (Richardson 1988, 1996), they include *Archaeozonotriletes chulus/nanus* complex where associated with graptolite zone (*turriculatus* or *cripus*) (Richardson 1996). The *A. chulus/nanus* compound occurs in Libyan sediments of Middle and Upper Telychian (Al-Ameri 1980 in Richardson 1996). The assemblages are probably of Middle and Upper Telychian, they may extend to late Homerician.

## 2.3 Hilate monad miospore event

These palynomorphs include *Laevolancis divellomedia*, recorded in marine sediments as *Tasmanites avelinoi* by Al-Ameri (1980), ranging from Llandovery to Lower Devonian. This is also including pseudodyads, dyads, tetrads and hilate cryptospore monad. They occur possibly in Telychian to become predominant in much younger sediments.

## 2.4 Murornate, verrucate miospore event

Appearance of sporomorphs with varied distal sculpture including verrucate, murornate *Synorisporites* and emphanoid forms. Both cryptospores and miospores were appeared with distal verrucae and proximal radial muri. Cryptospores were first appeared with verrucate-murinate distal sculpture and proximal radial muri in south Wales by Burgess and Richardson (1991). This event is also, include patinate miospore with distal radial muri. Telychian to Sheinwoodian.

## 2.5 Murinate, verrucate crassitate miospore event

Appearance of murinate, verrucate, crassitate, confined proximal radial muri radiating from curvaturae perfectae trilete Upper Homerician miospores including *Emphanisporites protophanus*. In addition, it is including, distally verrucate, murinate hilate alele monads and some cryptospores with radial proximal muri (Richardson and McGregor 1986; Richardson *et al.* 2001; Hassan Kermadjji 2007).

## 2.6 Granulate, apiculate, crassitate miospore event

It is characterized by miospores with equatorial radial thickening "curvatural crassitude" becoming indistinct towards the proximal pole, proximally with radial anastomosing muri and/or regulae, distally apiculate granulate and minutely verrucate of *Scylaspora* and *Synorisporites* species. In addition it is including cryptospores Burgess and Richardson (1995). Early and late Homerician.

## 2.7 Apiculate, patinate with faint radial muri miospore event

Appearance of granulate, micro rugulate curvatural proximal sculpture, distally with low narrow murornate, verrucate patinae and narrow hilum *Chelinospora*, *Scylaspora* species.

This is also including cryptospores (Burgess and Richardson 1995; Richardson *et al.* 2001; Hassan Kermadjji *et al.* in preparation). Grostian to Lower Ludfordian.

### **2.8 Patinate, proximally hilate with distal faint muri miospore event**

Characterised by the diversification of verrucate, apiculate patinate, domination of crassitate and cingulate and proximally radially ribbed forms of *Chelinospora*, *Cymbosporites*, *Concentricosporites* and *Emphanisporites* miospores (Richardson and Ioannides 1973; Richardson *et al.* 2001; Hassan Kermadjji 2007) and cryptospores. Early and late Ludfordian

### **2.9 Murornate, apiculate patinate miospore event**

In coming of distally reticulate, patinate miospores with thin contact areas (*Chelinospora*) Richardson *et al.* (2001). Appearance of species with foveolate sculpture (*Brochotriletes*) Richardson and McGregor (1986). Persistent of murornate, apiculate species of the previous zones Hassan Kermadjji (2007).

### **2.10 Diversification of crassitae, disto-equatorially multi sculptured miospore event**

Characterized by diversification of equatorially crassitate and proximally tripapillate, distally murornate, apiculate patinate miospores of *Scylaspora*, *Synorisporites*, *Cymbosporites* and *Chelinospora* (Richardson and Lister 1969; Burgess and Richardson 1995). Proliferation of verrucate, retusoid, apiculate and radially ribbed, foveolate and murornate miospores of *Apiculiretusispora* and *Dictyotriletes*. Permanent tetrads and cryptospores also occur, Hassan Kermadjji (2007).

### **2.11 Proximally slightly ribbed, distally apiculate, crassitate, perinate miospore event**

Proliferation of apiculate and proximally radially ribbed miospores (*Apiculiretusispora* and *Emphanisporites*). Persistence of apiculate, proximo-equatorial microgranulate crassitate, patinate and perinate miospores of (*Scylaspora*, *Perotilites* and *Cymbosporites*) Hassan Kermadjji *et al.* (2008). Early (but not earliest) to early late Lochkovian.

### **2.12 Diversification of distally cingulate, patinate miospore event**

Appearance of cingulate, annulate and patinate miospores of *Amocosporites* and *Cybosporites*. Persistent of perinate and crassitate species of the older strata. Late early and early late Lochkovian.

### **2.13 Distally murornate, proximally radially ribbed miospore event**

Proliferation and diversification of proximally retusoid, distally apiculate, reticulate *Dictyotriletes*. Increasing of the variety of distally granulate-apiculate-spinose, proximally radially ribbed *Emphanisporites* and incoming of bizonate, proximally with highly irregular 'scalloped' folds and distally with distinct annular thickening *Breconsporites* Richardson *et al.* (1982). Latest Lochkovian and earliest Pragian.

### 2.14 Coarse biform apiculae with cingulicavati and foveolae miospore event

In coming of *Dibolisporites* species with prominent spines, tubercles and biform elements. Diversification of *Camptozonotriletes* and *Clivosispora* and *Apiculiretusispora* species. Late early to early late Pragian.

### 2.15 Diversification of proximal prominent stout radial muri miospore event

Appearance of retusoid reticulate, non reticulate and foveolate species of *Dictyotriletes* and *Brochotriletes*. Proliferation of regularly verrucate taxa of *Verrucosisporites*. Persistent of tuberculornati and cingulicavati species from the previous zone. Latest Pragian and earliest Emsian.

### 2.16 Bizonate, proximally cristate and distally annulate miospore event

First appearance and diversification of proximally radially ribbed and distinct delimited distally annulate species of *Emphanisporites* and distally convoluted murornate species of *Acinosporites*. Abundance of biform sculptured forms of *Dibolisporites*. First appearance of stout, prominent-spined species of *Acanthotriletes*. Proliferation of distally patinate species of *Tholisporites* and *Chelinospora*. Diversification of zonate and pseudosaccates forms of *Camarozonotriletes* and *Geminosporea* species. Disappearance of most reticulate and tripapillate miospores (Richardson and McGregor 1986; Streel *et al.* 1987; Hassan Kermadji *et al.* 2008). Early and early late Emsian.

### 2.17 Bifurcate-tipped appendages and monopseudosacciti miospore event

First appearance of prominent bifurcate appendages forms of *Hystricosporites* species. Proliferation and diversification of *Grandispora* forms. Propagation and persistence of *Dibolisporites*, *Acinosporites* and *Geminosporea* species. Persistence of many species from the previous zone Hassan Kermadji *et al.* (2008). Latest Emsian and earliest Eifelian.

### 2.18 Zonate-pseudosaccate and coarse bifurcate spinose miospore event

Characterized by incoming of finely-sculptured zonate-pseudosaccate miospores of *Calyptosporites* and *Rhabdosporites* species. Proliferation of *Samarisporites*, *Corystisporites* and *Ancyrospora* species. Gradually waning of *Acinosporites* and patinate taxa (Richardson and McGregor 1986; Streel *et al.* 1987; Hassan Kermadji *et al.* 2008). Early Eifelian.

The correlation between the Algerian miospore assemblage biozones and the standard Euramerican North Gondwanan miospore biozones is shown in Figure 2. All these data originated from the Tidikelt Plateau, Triassic Province, Oued Saoura and Illizi regions, west and east Sahara Algerian Desert synclines, North Africa, Old Red Sandstone continent and adjacent regions, but other regions may contribute for improvement of the results. For instance, I have used in the legend of the figure additional correlation data from south Wales.

## 3. Stratigraphic miospore distribution

Significant progress has been made in areas regarding morphologic events of the sporomorphs stratigraphic distribution Richardson (1996) and Zonal concepts were used by many workers;

some described it as local events (Loboziak *et al.* 1992; Rubinstein and Steemans 2002; Richardson and Edwards 1989; Wellman and Richardson 1996; Jardiné and Yapaudjian 1968; Melo and Loboziak 2003; Moreau-Benoît *et al.* 1993; Hassan Kermadjji *et al.* 2008; Richardson and Ioannides 1973, Massa and Moreau-Benoît, 1976), others are used the concept in more wider sense “on global scale” (e.g. Richardson and McGregor 1986; Streel *et al.* 1987). Richardson and McGregor (1986) concept for Devonian miospore zonation, based on spore assemblage biozones to describe miospore distributions of the Old Red Sandstone Continent and adjacent regions, whereas Streel *et al.* (1987) employed the scheme based on spore Oppel zones and Interval zones recognized in the progressive changes from shallow to more deeper marine sediments of the Ardenne-Rhenish region. Both schemes have been utilized beyond their regions where they established (e.g. McGregor and Playford 1992, Loboziak and Streel 1995). Fundamentally both schemes based on the appearance of well recognized, laterally extensively distributed spore taxa. Although the Richardson and McGregor’s magnificent zonation concept is loose (Streel and Loboziak, 1996), it is practical, based on assemblages of characteristic taxa allow correlations on great scale. The branded Interval zone concept of Streel *et al.* (1987) is build up within a single great phytogeographic province and on distinctive miospore taxa, to some extent, many of their typical taxa hard to occur in another region (Wellman 2006; Breuer *et al.* 2007; Steemans *et al.* 2008; Hassan Kermadjji *et al.* 2008). Nevertheless, Streel and Loboziak (1996) are employed Western Gondwana and southern Euramerica as a single major phytogeographic province.

There are significant difficulties concerned correlations between Upper Silurian-early Lower Devonian miospore assemblage sequences of north Africa (Sahara Algeria, Libya and Tunisia) and those of Old Red Sandstone and adjacent regions by Richardson and McGregor (1986) and the Ardenne-Rhenish regions by Streel *et al.* (1987). The major differences between miospores sequences of Moreau-Benoît *et al.* (1993), Melo and Loboziak (2003), Steelmans *et al.* (2008), Rubinstein and Steemans (2002), Steemans *et al.* (2007), Hassan Kermadjji (2007), Hassan Kermadjji *et al.* (2008), Spina and Vecoli (2009) and many others are that: they contain groups of palynomorphs of different stratigraphic significance. They are different particularly, in terms of the characteristic taxa and the absence of common index species from the zones. The degree of similarities in terms of the general characteristics and composition between Euramerican and Gondwana miospores were overestimated by many workers: Loboziak and Streel 1989; Loboziak *et al.* 1992, and many others. However, some similarities exist between Euramerica and Western Gondwana but many regions of northern Gondwana contain limited numbers of Euramerican characteristics zonal miopores within assemblages of different composition Wellman (2006). Therefore, Upper Silurian-early Lower Devonian Euramerican miospore biozones are hard to be in use in the Western Gondwana province.

Comparable zonation schemes for the Upper Silurian and Lower Devonian of North Africa are unexpectedly few despite a long history of investigations that have concentrated on phytoplankton and land plant miospore assemblages of deep drillings. No Proposal exists for a formal zonation. Nevertheless, the Silurian and Devonian biostratigraphic studies neither for the Western Libyan deep drilling deposits by: Massa and Moreau Benoit 1976; Richardson *et al.* 1981; Rubinstein and Steemans 2002; Le Hérissé 2002; Spina and Vecoli 2009; nor those of Mid Palaeozoic Algerian Sahara petroleum sediments by Magloire 1967; Jardiné and Yapaudjian 1968; Moreau-Benoît *et al.* 1993; Abdesselam-Rouighi, 1986, 1996,

2003. They are preliminary and do not permit exact correlation with standard zonations of Euramerican palynozones by Richardson and McGregor (1986), Streel *et al.* (1987) and Richardson *et al.* (2001). However, detail proposal do exist for the Tidikelt and Oued Myia deposits in the central and south western Algerian Sahara synclines (Hassan Kermadjji 2007, Hassan Kermadjji *et al.* 2008) which are equivalent to the Přídolí, Lochkovian, Pragian, Emsian and Eifelian deposits of Euramerica. They establish well-defined ten miospore assemblage biozones and one interval zone extending from the Homerian to early Eifelian. Zonal index taxa were recognized and the general pattern of changes in miospore distribution through Homerian and early (but not earliest) Emsian to Lower Eifelian, more or less, comparable to those changes reported in Euramerica region. While the pattern of changes in miospore distribution through Ludfordian, Přídolí, Lochkovian, Pragian and Lower Emsian does not reflect changes comparable to those stated in Euramerican province. They are differing in the selection of zonal index taxa, zonal miospore composition and vertical stratigraphic occurrence.

The most diverse and distinctive, moderately well preserved Silurian and Devonian sporomorphs assemblages occur in shallow marine and terrestrial strata of the Triassic Province and Tidikelt plateau were studied biostratigraphically. This is well coincide with Richardson (1984) finding that 'sporomorph assemblages occur in rocks deposited either on land or in marine environments'.

#### 4. Sporomorphs distribution development

Detailed studies of many local and regional palynological zonations of the middle to late Silurian and early to early Middle Devonian deposits in the Euramerica and Western Gondwana reveal many difficulties, probably due to the time of closure (Lochkovian or Pragian-Emsian) of the Rheic Ocean which may cause climate and palaeophytogeographic isolation. On the other hand, this may lead to widespread dispersal ability and climatic tolerance of late Silurian and early Devonian land plants Raymond *et al.* (2006). This palaeophytogeographic differentiation of macroflora does not imitate spore distributional pattern. On the basis of dispersal miospores distribution patterns Wellman and Gray (2000) and Edwards and Wellman (2001) distinguished a Euramerican miospore biogeographic unit from a Gondwanan unit for late Silurian times. Though palaeophytogeographic differentiation does not well reflect miospores distribution patterns for this period Richardson *et al.* (2001).

On the basis of sporomorphs classification which is based on morphology, appears that earliest cryptospores with apparent thick curvatural crassitude may have close relation with initial *Ambitisporites*. This may indicate that plants producing cryptospores may be predecessors of those producing *Ambitisporites* miospores Richardson (1996). Morphological features show that there are close relation between some cryptospore tetrads with retusoid miospores bearing distinct contact areas, curvaturae perfectae not confined to the equator and distally patinate with thin proximal wall (*Ambitisporites* and *Archaeozonotriletes* which occur a little latter). The progressive advantages in complexity of morphological structure occur in sequence of parallel changes in both closely related cryptospores and miospores. The appearance of some types of ornaments was not always synchronous in both groups, for instance proximal papillae first occur on miospores in early Přídolí, whereas it appears on cryptospores in early Lochkovian. This is probably related to the environmental responses with two closely related groups of plants responding to the same motivation.

With reference to the main spomorphs evolution events, their distribution patterns are discussed. However, the appearance or the disappearance of structural group or a single genus and/or whole complex of forms provides helpful indicators in establishing local or regional miospore zonations.

#### 4.1 Cryptospores

Cryptospores are usually more abundant and diversified than miospores in early sediments, mainly occur in inshore environments, and decline in abundance offshore more than miospores. They decrease in abundance number in younger sediments and taxonomically become more varied. This may indicate that their parent plants possibly were living on sediments of ephemeral environment. The high abundance and diversity of cryptospores suggesting that their parent plant flourishing and occurred together with miospores producing plants, probably of vascular type Wellman and Richardson (1996). The earliest geological record of cryptospores was in Caradoc, late Ordovician, but probably they appear much earlier.

The cryptospore diversifications are varied from place to place. The variations are due to the nature of depositional environment. Laevigate taxa are more diverse than sculptured forms. Some granulate; apiculate cryptospore types are found *in situ* (Funning *et al.* 1991).

Cryptospores 'generally' are represented by long ranging taxa such as, *Tetrahedraletes medienensis* (Pl.1, Fig.2, Pl.2, Fig.6), *Laevolancis divellomedia* (Pl.1, Figs. 8, 13), *Cheilotetras caledonica* (Pl.1, Fig.1), *Cymbohilates horidus*, (Pl.1 Figs. 3, 5, 6, 11) and *Cymbohilates allenii* var. *allenii* (Pl.1, Fig.14), *Cymbohilates allenii* var. *magnus* (Pl.1, Fig.4), *Hispanaediscus verrucatus* (Pl.1, Figs.7, 12), *Artemopyra? scalariformis* (Pl. 1, Fig. 9) and *Acontotetras inconspicuis* (Pl.1, Fig.10). All these taxa have been recorded in many late early Silurian to Lochkovian sedimentary sequence, from many Euramerican and Gondwanan areas.

On the basis of proliferation and diversification of cryptospores from the Type Wenlock and Towy Anticline, Burgess and Richardson (1991, 1995) confirmed the first occurrence of seven zonally significant species in Sheinwoodian to Ludfordian and graptolite bearing strata of Euramerican province. Most of these sub-zones are regionally confined and have not been observed in North Africa. Out of two spore assemblage biozones, two spore biozones, two sub-biozones and one spore interval biozone of Ludfordian-Lochkovian from the Cantabrian Mountains, NW Spain by Richardson *et al.* (2001), only *Scylaspora vetusta*-*Scylaspora kozlica* (Dufka) Spore Assemblage Biozone and the spore interval biozone correspond to just two Přídolí spore interval biozone (*hemiesferica*) and the *Scylaspora radiate-Apiculiretusispora synoria* Miospore Assemblage Biozone of western and central Algeria by Hassan Kermadji (2007, Fig.3). The endemism of some miospore species caused many terrestrial plants to appear earlier in Gondwana, also infrequency of plants producing these palynomorphs, palynologically unfavorable types of sediments, incomplete study of available rocks and inappropriate environments may originate these variations.

#### 4.2 Miospores

The earliest recorded laevigate retusoid, equatorially thickened miospores is specimens resemble *Ambitisporites* appear little earlier than true *Ambitisporites* Hoffmeister (1959) Pl. 2,

Figs. 2, 4, of latest Aeronian. Whereas laevigate, distally patinate, proximally generally hilate, *Archaeozonotriletes* (Naumova) Allen (1965), appear in Telychian. Both taxa persist into Lower Devonian. This is indicating that land flora producing these taxa are uniformly distributed over wide regions. Some retusoid forms are found *in situ*, for instance *Retusotriletes coronadus* found in the lower Downton Group, also some sporangia have yielded verrucate crassitate *Synorisporites verrucatus* and some others has yielded, crassitate papillate *Synorisporites tripapillatus*. Whereas, no laevigate patinate *Archaeozonotriletes* has been found *in situ*, this is may indicate that their parent plants lived in ephemeral environment Richardson (1996). Nevertheless, equally crassitate and patinate taxa are remarkably abundant in offshore environment. Richardson and McGregor (1986) in their zonal concept used *A. avitus*-*A. dilutus* for Aeronian and *A. chulus*-*A. nanus* for Sheinwoodian as cosmopolitan assemblage zones. The two assemblage zones are considered by McGregor and Playford (1992) and Streel and Loboziak (1996) as loose biozones.

There are some familiarities in miospore assemblage composition throughout Homerian-Přídolíán sediment reported from Euramerican and Gondwanan phytogeographic provencies. The common zonal species are represented by: *S. kozlica* Pl.2, Fig.3; *S. vetusta* Pl.2, Fig. 11; *C. hemiesferica* Pl.2, Fig. 5; *C. sanpetrensis* Pl.4, Fig.12, Pl.5, Fig. 13; *C. (Lophozonotriletes?) poecilomorpha* Pl.2, Figs. 7, 8). The first two species form nominal taxa of the Middle Homerian sediments, whereas, the rest are nominal taxa for Ludfordian and Přídolíán strata (Burgess and Richardson 1995, Richardson *et al.* 2001, Hassan Kermadji 2007).

Lower Devonian sediments of the Gondwanan province includes many miospore species known elsewhere, though striking assemblages of the same stratigraphic range are difficult to be found in other studied regions. For instance *S. tidikeltense* Pl.2, Fig. 10 of early Lochkovian and *C. triangulates* Pl.2, Fig. 9 of Ludfordian are recorded only in Gondwanan province. Whereas, *S. newportensis* ss, *E. micornatus* ss, *E. zavallatus* ss are recorded in Lockovian sediments of Euramerican phytogeographic province. Some other characteristic species such as *C. cassicula*, *L. argovejae* have different stratigraphic occurrence in the two provinces. This is probably are due to insufficient favorable sediment, nature or rarity of plants producing these miospores, unsuitable environments, the absence of an effective physiographic barrier ( Steemans 1999b; Steemans *et al.* 2007, 2008; Edwards and Richardson 2004; Richardson 2007).

To illustrate these differences between the two phytogeographic provinces, the miospore zonal scheme of text figure (2) demonstrate these differences. A comparison with the Old Red Sandstone Continent zonation shows that only two Western Sahara Algeria syncline (*annulatus-sextantii* and *velatus-langii*) is correspond to just two Emsian to early Middle Eifelian assemblage zones of Richardson and McGregor (1986). Nearly 6 Interval zones (Po-AB) of the Ardenne-Rhine regions zonation of Streel *et al.* (1987) correspond to just two Middle and Upper Pragian miospore assemblage biozones (*arenorugosa-caperatus* and *polygonalis-subgranifer*) of Western Sahara Algeria syncline of Hassan Kermadji *et al.* (2008, Fig.4). Despite this limited matching, they contain many more identical characteristic species of Lochkovian to early Eifelian but of different occurrence and stratigraphic range. The Innovation contrast with miospore assemblages is by their cosmopolitanism culminating in the Emsian *Emnanisporites annulatus*. This species began in early but not earliest Emsian and well expanded during Emsian and early Eifelian and collapsed at latest Devonian, allowing accurate correlations throughout the world.

System	DEVONIAN						SILURIAN				DEVONIAN				
Series	MIDDLE		EIFELIAN	LOWER				PRIDOLI	DOWNTONIAN	LUDLOW		GROS-TIAN	HOME-RIAN	WENLOCK	SHEINWOODIAN
Stage	EMSIAN			PRA GIAN	LOCHKOVIAN	tripapillatus-spicula	libycus-poecilomorphus			cf. protophanus-verrucatus	chulus-nanus				

Fig. 2. Correlation between miospore zonation in the Lower and Middle Silurian and Devonian of Euramerica and Western Gondwana.

## PLATE 1

All figures x 1000 where stated otherwise.

Figure 1. *Cheilotetras caledonica* Wellman and Richardson, 1993. (NL: samp. 1/21, sl. 3/1) Sheinwoodian, ECF-1 borehole, Illizi Basin, Sahara Algeria.

Figure 2. *Tetrahedraletes medinensis* (Strother and Traverse, 1979) Wellman and Richardson, 1996. (NL: samp. 1/14, sl. 2/1), Upper Homerian, NGS-1 borehole, Triassic Province, Sahara Algeria.

Figures 3, 5, 6&11. *Cymbohilates horridus* Richardson, 1996. Figs. 3 & 6 (NL: samp. 21082.5m, sl. 224), figs. 5 & 11 (NL: dep. 2082.5m, sl. 223), Lower Lochkovian, GMD-3 & ISS-1 boreholes respectively, Tedikelt Plateau, Sahara Algeria. Figs. 5, 6 x500.

Figure 4. *Cymbohilates allenii* var. *magnus* Richardson, 1996. (NL: dep. 2082.5m, sl. 223), Lower Lochkovian, ISS-1 boreholes, Tedikelt Plateau, Sahara Algeria.

Figure 7 & 12. *Hispanaediscus verrucatus* (Cramer) Burgess and Richardson, 1991. (NL: samp. 7/20, sl. 15/2), Homerian, ECF -1 borehole, Illizi Basin, Sahara Algeria.

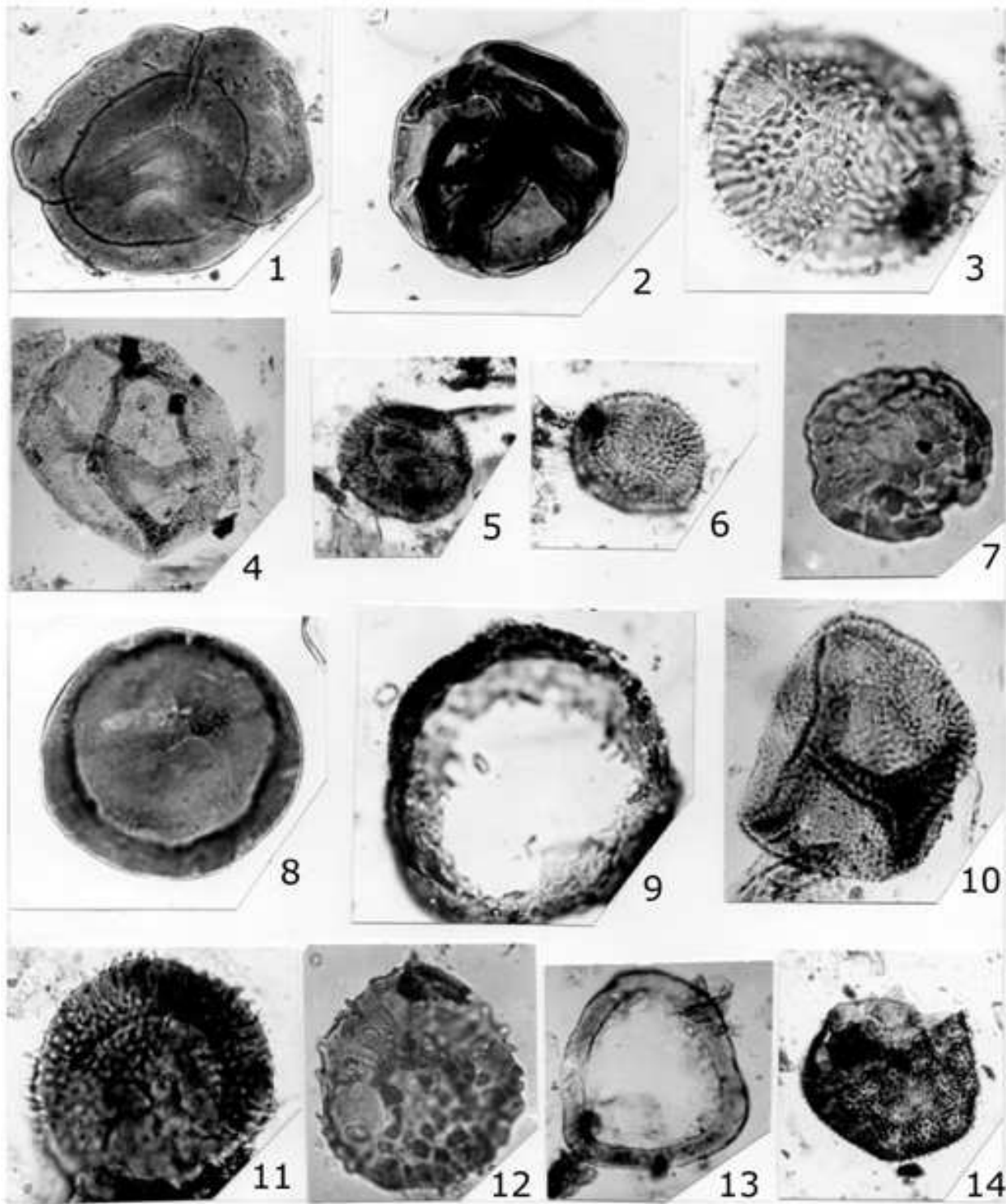
Figures 8&13. *Laevolancis divellomedia* (Chibrikova) Burgess and Richardson, 1991. (NL: samp. 2/20, sl. 2/2), Sheinwoodian, ECF -1 borehole, Illizi Basin, Sahara Algeria.

Figure 9. *Artemopyra? scalariformis* Richardson, 1996. (NL: dep. 2082.5m, sl. 223) Lower Lochkovian, ISS-1 borehole, Tedikelt Plateau, Sahara Algeria.

Figure 10. *Acontotetras inconspicuis* Richardson, 1996. (NL: dep. 2082.5m, sl. 223) Lower Lochkovian, ISS1-borehole, Tedikelt Plateau, Sahara Algeria.

Figure 14. *Cymbohilates allenii* var. *allenii* Richardson, 1996. (NL: samp. 1/14, sl. 2/1), Homerian, NGS-1 borehole, Triassic Province, Sahara algeria.

PLATE 1



## PLATE 2

All figures x 1000 where stated otherwise.

Figure 1. *Apiculiretusispora spicula* Richardson and Lister, 1969. (NL: dep. 2082.5m, sl.222), Přídolí, GMD-3 borehole, Tidikelt Plateau, Sahara Algeria.

Figure 2. *Ambitisporites dilutus* Hoffmeister, 1959. (NL: samp.2/11, sl. 9/2), Homerian, GMD-2 borehole, Tidikelt Plateau, Sahara Algeria.

Figs.3. *Scylaspora kozlica* (Dufka) Richardson, Rodriguez and Sutherland, 2001. (NL: samp. 1/14, sl. 2/1), Homerian, NGS-1 borehole, Triassic Province, Sahara Algeria.

Figure 4. *Ambitisporites avitus* Hoffmeister, 1959. (NL: samp.4/11, sl. 16/4), Sheinwoodian, GMD-2 borehole, Tidikelt Plateau, Sahara Algeria.

Figure 5. *Chelinospora hemiesferica* (Cramer and Diez) Richardson, Rodriguez and Sutherland, 2001. (NL: samp.5/13, sl. 7/5), Lower Přídolí, NGS-1 borehole, Triassic Province, Sahara Algeria.

Figure 6. *Tetrahedraletes mediensis* Strother and Traveres, 1979. (NL: samp.2/21, sl. 5/2) ECF-1 borehole, Sheinwoodian, Illizi Basin, Sahara Algeria..

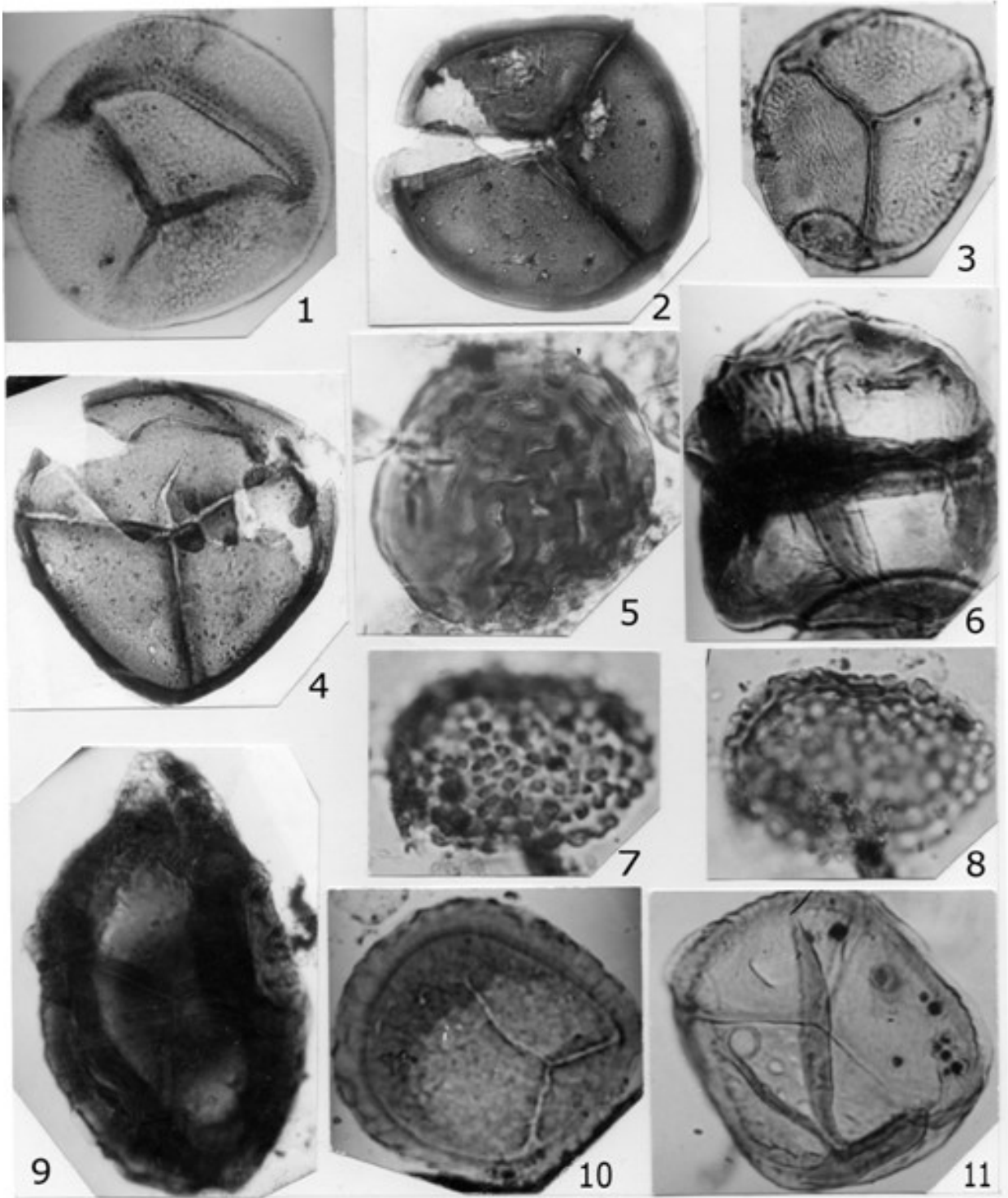
Figures 7&8. *Chelinospora* (*Lophozonotriletes*?) *poecilomorpha* (Richardson and Ioannides) Richardson, Rodriguez and Sutherland, 2001. (NL: samp.2/11, sl.8/2), Ludfordian, NGS-1 borehole, Triassic Province, Sahara Algeria.

Figure 9. *Cymbosporites triangulatus* Hassan Kermendji, 2007. (NL: 3/13, 5/3), Ludfordian, NGS-1 borehole, Triassic Province, Sahara Algeria.

Figure 10. *Scylaspora tidikeltense* Hassan Kermendji 2008. (NL: dep. 2082.5m, sl. 223), Lower (but not lowermost) Lochkovian, GMD-3 borehole, Tidikelt Plateau, Sahara Algeria.

Figure 11. *Scylaspora vetusta* (Rodriguez) Richardson, Rodriguez and Sutherland, 2001. (NL: samp.2/11, sl.5/2), Homerian, NGS-1 borehole, Triassic Province, Sahara Algeria.

PLATE 2



## PLATE 3

All figures x 1000 where stated otherwise.

Figures 1&8. *Verrucosporites polygonalis* (Lanninger) McGregor, 1973. (NL: dep. 1012.7m, sl. 419), late Pragian-earliest Emsian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.

Figure 2. *Emphanisporites neglectus* Vigran, 1964. (NL: samp.2/11, sl.8/2), Ludfordian, NGS-1 borehole, Triassic Province, Sahara Algeria.

Figure 3. *Cymbosporites cyathus* Allen, 1965. (NL: samp. MD42, sl. 42/3), late Pragian-earliest Emsian, Djabel el Kahla, Oued Saoura, Western syncline, Sahara Algeria. x700.

Figures 4, 7&10. *Perotrilites microbaculatus* Richardson and Lister, 1969. (NL: dep.2082.5m, sl. 224), Lower (but not lowermost) Lochkovian, GMD-3 borehole, Tidikelt Plateau, Sahara Algeria.

Figures 5&11. *Amocosporites miserabilis* Cramer, 1966. (NL: dep. 1183.0m, sl. 102), Lower Lochkovian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.

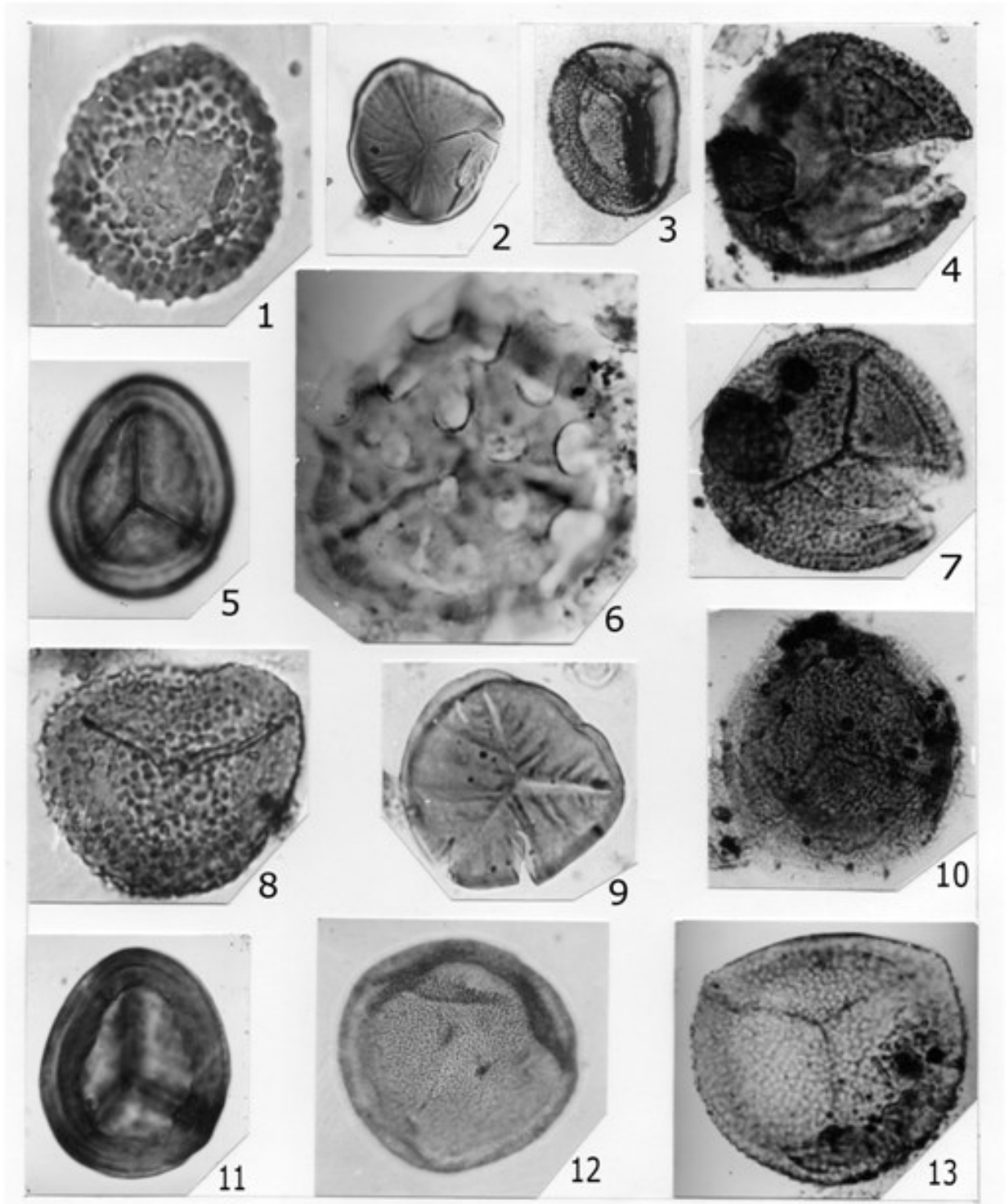
Figure 6. *Brochotiletes libyensis* Moreau-Benoît, 1979. (NL: dep.1012.7m, sl. 419), Pragian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.

Figure 9. *Emphanisporites spinaeformis* Schultz, 1968. (NL: samp. MD21, sl. 21/5), late Lochkovian, Mounzar Debad Km 30, Oued Souara, Western syncline, Sahara Algeria.

Figure 12. *Dibolisporites echinaceus* (Eisenack) Richardson, 1965. (NL: dep. 1911.0m, sl. 511), late Pragian-earliest Emsian, ISS-1 borehole, Tidikelt Plateau, Sahara Algeria.

Figure 13. ?*Cymbosporites* cf. *proteus* McGregor and Camfield, 1976. (NL: dep. 1077.1m, sl. 310), latest Lochkovian-earliest Pragian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.

PLATE 3



## PLATE 4

All figures x 1000 where stated otherwise.

Figures 1 & 4. *Clivosispora verrucata* var. *convoluta* McGregor and Camfield, 1976. (NL: dep. 1012. 7m, sl. 419), Middle Pragian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.

Figure 2. *Corystisporites* cf. *multispinosus* Richardson, 1965. (NL : samp. MD56, sl. 56/5) latest Emsian, Moungar Debad Km 30, Oued Saoura, Western syncline, Sahara Algeria.

Figures 3 & 6. *Samarisporites orcadiensis* Richardson, 1965. (NL: dep. 955.0 m, sl. 405), Eifelian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.

Figures 5 & 9. *Camptozonotriletes caperatus* McGregor, 1973. (NL: dep. 1012. 7m, sl. 419), Middle Pragian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.

Figure 7. *Samarisporites mediconus* (Richardson) Richardson, 1965. (NL: samp. MD62, sl. 62/3), Eifelian, Moungar Debad Km 30, Oued Saoura, Western syncline, Sahara Algeria.

Figure 8. *Geminospora* cf. *treverica* Riegel, 1973. (NL: dep. 955.0 m, sl. 405), Eifelian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.

Figures 10 & 11. *Dictyotriletes emsiensis* (Allen) McGregor 1973. (NL: dep. 1012. 7m, sl. 419), Middle Pragian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.

Figures 12. *Chelinospora sanpetrensis* (Rodriguez) Richardson, Rodriguez, Sutherland, 2001. (NL: samp. OA, sl. 7/2), Ludfordian, Gurziem, Oued Saoura, Western syncline, Sahara Algeria.

Figure 13. *Dictyotriletes subgranifer* McGregor 1973. (NL: dep. 1027.5m, sl. 405), latest Pragian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.

PLATE 4

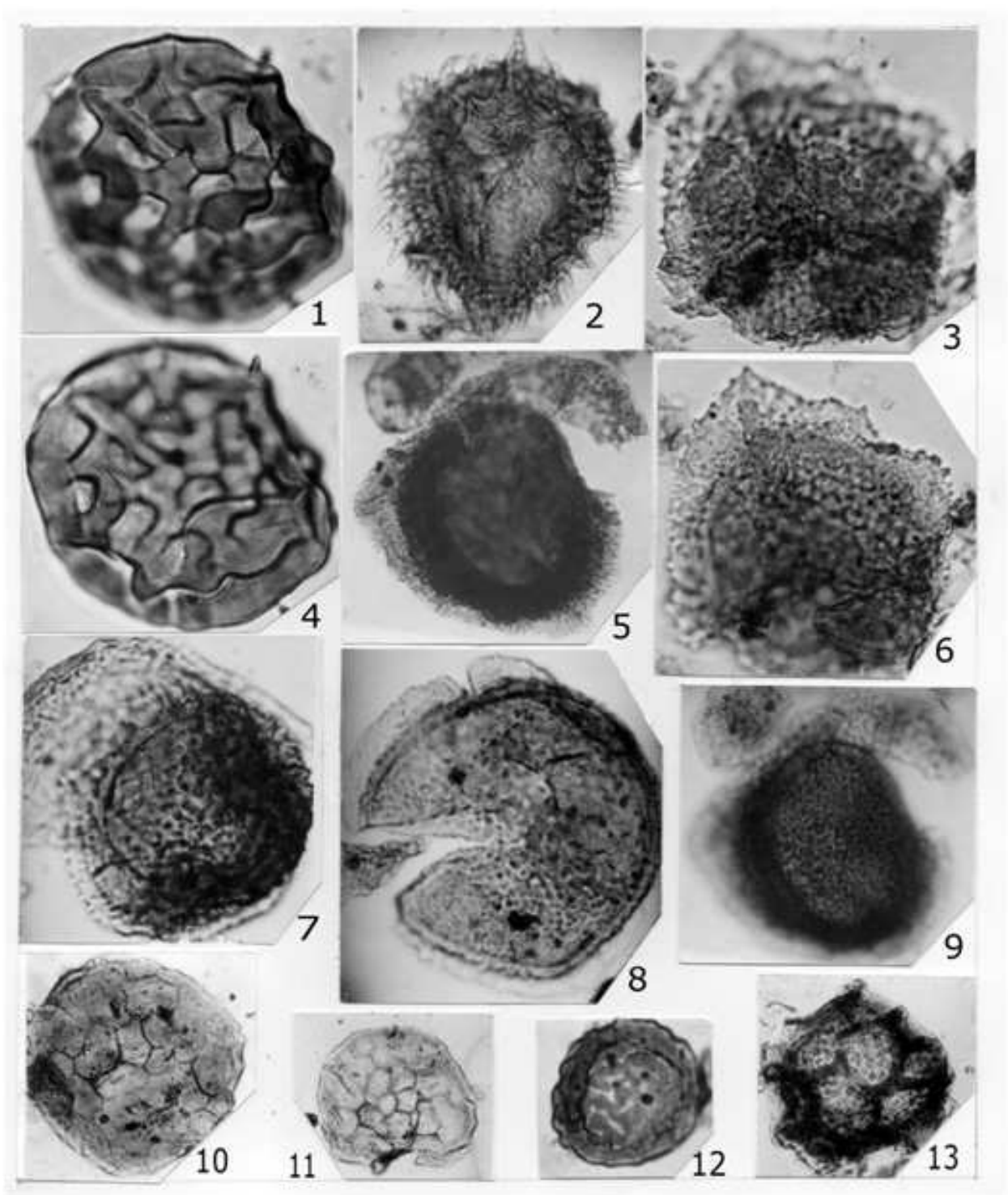
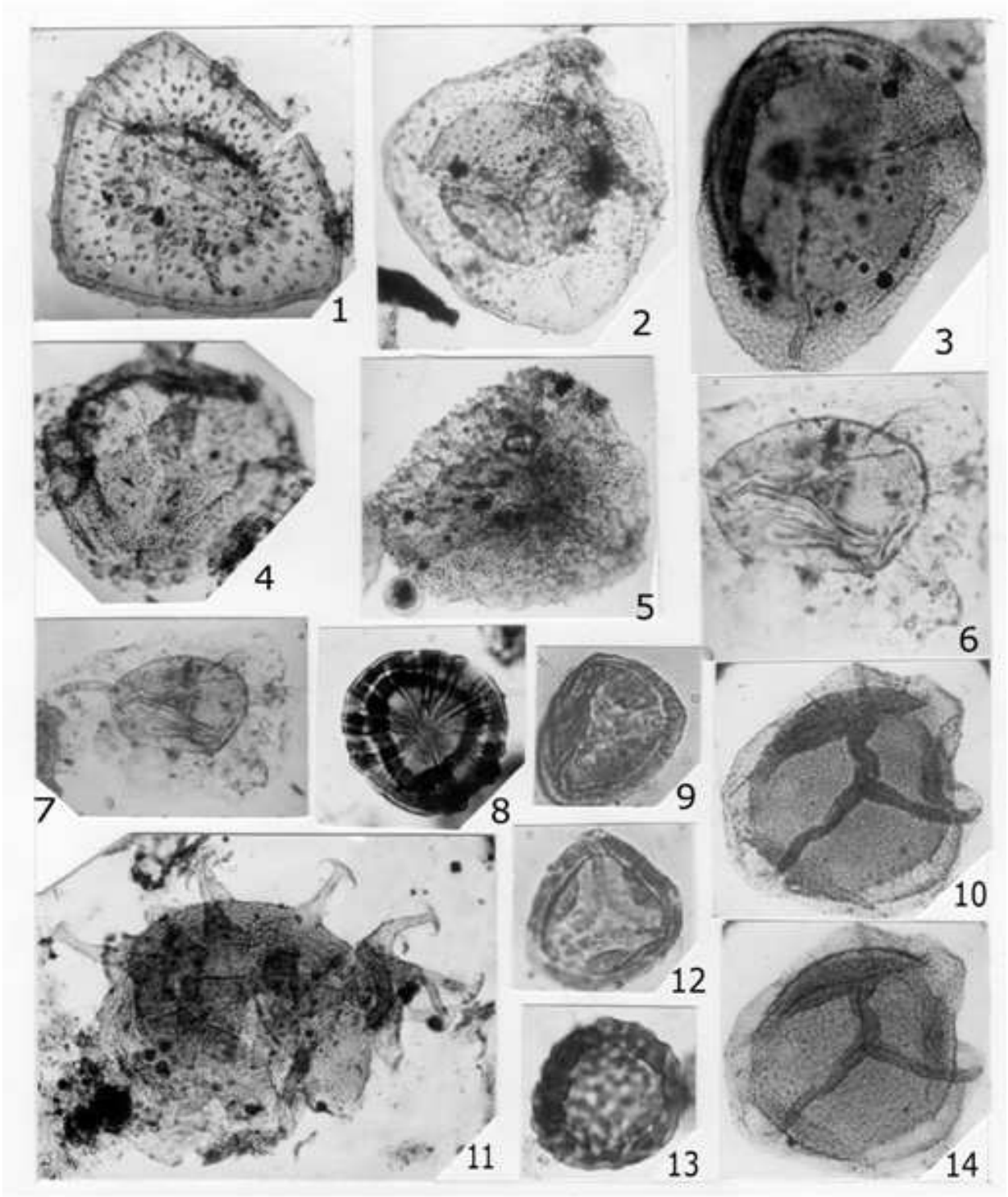


PLATE 5

All figures x 1000 where stated otherwise.
Figure 1. <i>Grandispora libyensis</i> Moreau Benoît, 1980. (NL: DM 62, sl.62/5), latest Eifelian, Moungar Debad Km 30, Oued Saoura, Western syncline, Sahara Algeria..
Figure 2. <i>Grandispora inculta</i> Allen, 1965. (NL: dep. 955.0m, sl. 405), Eifelian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.
Figure 3. <i>Rhabdosporites langii</i> (Eisenack) Richardson 1960. (NL: dep. 955.0m, sl. 312), Eifelian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.
Figure 4. <i>Apiculiretusispora arenorugosa</i> McGregor, 1973. (NL: dep. 1055.7m, sl. 400), Middle Pragian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.
Figures 5. <i>Grandispora protea</i> (Naumova) Allen, 1965. (NL: samp. MD56, sl. 56/9), latest Emsian, Moungar Debad Km 30, Oued Saoura, Western syncline, Sahara Algeria.
Figures 6 & 7. <i>Calyptosporites velatus</i> (Eisenack) Richardson 1962. (NL: dep. 955.0m, sl. 310), Eifelian MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.
Figure 8. <i>Emphanisporites annulatus</i> McGregor, 1961. (NL: dep. 955.0m, sl. 425), Emsian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria.
Figure 9 & 12. <i>Camarozonotriletes filatoffi</i> Breur, Al-Ghazi, Al-Ruwaili, Higgs, Steemans and Wellman, 2007. (NL: dep. 955.0m, sl. 427), Emsian, MSR-1 borehole, Tidikelt Plateau. Algeria.
Figures 10 & 14. <i>Rhabdosporites parvulus</i> Richardson, 1965. (NL: dep. 955.0, sl. 312), Eifelian, MSR-1 borehole, Tidikelt Plateau, Sahara Algeria..
Figure 11. <i>Ancyrospora ancyrea</i> var. <i>brevispinosa</i> Richardson 1962. (NL: dep. 955.0m, sl. 311), Eifelian, MSR-1 borehole, Tidikelt Plateau. Sahara Algeria.
Figures 13. <i>Chelinospora sanpetrensis</i> (Rodriguez) Richardson, Rodriguez, Sutherland, 2001. (NL: samp. OA, sl. 7/2), Ludfordian, NGS-1borehole, Triassic Province, Sahara Algeria.

PLATE 5



## 5. Appendix 1 List of species

- Acanthotriletes raptus* Allen 1965  
*Acinosporites verrucatus* Streel 1967  
*Acinosporites conatus* Hassann Kermadjji 2008  
*Acontotetras inconspicuis* Richardson 1996  
*Ambitisporites avitus* Hoffmeister 1959  
*Ambitisporites dilutus* (Hoffmeister) Richardson & Lister 1969  
*Ambitisporites tripapillatus* Moreau-Benoît, 1976  
*Amocosporites miserabilis* Cramer and Diez 1975  
*Ancyrospora ancyrea* var. *brevispinosa* Richardson 1962  
*Apiculiretusispora arenorugosa* McGregor 1973  
*Apiculiretusispora plicata* (Allen) Streel 1967  
*Apiculiretusispora spicula* Richardson and Lister, 1969  
*Apiculiretusispora synoria* Richardson & Lister 1969  
*Archaeozonotriletes chulus* var. *chulus* Richardson and Lister 1969  
*Archaeozonotriletes chulus* var. *nanus* Richardson and Lister 1969  
*Artemopyra ?scalariformis* Richardson 1996  
*Brochotriletes foveolatus* ? Naumova 1953  
*Brochotriletes libyensis* Moreau-Benoît 1979  
*Calyptosporites velatus* (Eisenack) Richardson 1965  
*Camarozonotriletes filatoffi* Breur, Al-Ghazi, Al-Ruwaili, Higges, Steemans and Wellman 2007  
*Camarozonotriletes sextantii* McGregor and Camfield 1976  
*Camptozonotriletes caperatus* McGregor 1973  
*Camptozonotriletes aliquantus* Allen 1965  
*Cheilotetras caledonica* Wellman and Richardson 1993  
*Chelinospora cassicula* Richardson & Lister 1969  
*Chelinospora hemiesferica* (Cramer & Diez) Richardson, Rodriguez and Sutherland 2001  
*Chelinospora perforata* Allen 1965  
*Chelinospora* (*Lophozonotriletes* ?) *poecilomorpha* (Richardson & Ioannides) Richardson, Rodriguez and Sutherland 2001  
*Chelinospora sanpetrensis* (Rodriguez) Richardson, Rodriguez and Sutherland 2001  
*Clivosispora verrucata* var. *Convoluta* McGregor and Camfield 1976  
*Concentricosisporites sagittarius* (Rodriguez) Rodriguez 1983  
*Corystisporites* cf. *multispinosus* Richardson 1965  
*Cymbohilates horridus* Richardson 1996  
*Cymbohilates allenii* var. *allenii*, Richardson 1996  
*Cymbosporites* cf. *dittonensis* Richardson and Lister 1969  
*Cymbosporites proteus* McGregor and Camfield 1976  
*Cymbosporites* cf. *proteus* McGregor and Camfield 1976  
*Cymbosporites catillus* Allen 1965  
*Cymbosporites cyathus* Allen 1965  
*Cymbosporites triangulatus* Hassan Kermadjji 2007  
*Dibolisporites saharansis* Hassan Kermadjji 2008  
*Dibolisporites echinaceus* (Eisenack) Richardson 1965  
*Dibolisporites* cf. *gibberosus* (Naumova) var. *major* (Kedo) Richardson 1965

- Dictyotriletes emsiensis* (Allen) McGregor 1973  
*Dictyotriletes subgranifer* McGregor 1973  
*Emphanisporites annulatus* McGregor 1973  
*Emphanisporites decoratus* Allen 1965  
*Emphanisporites epicautus* Richardson and Lister 1969  
*Emphanisporites* cf. *micronatus* Richardson and Lister 1969  
*Emphanisporites neglectus* Vigran 1964  
*Emphanisporites protophanus* Richardson and Ioannides 1973  
*Emphanisporites spinaeformis* Schultz 1968  
*Emphanisporites splendens* (Richardson and Ioannides) Richardson and Ioannides 1979  
*Geminospora* cf. *spinosa* Allen 1965  
*Geminospora svalbardiae* (Vigran) Allen 1965  
*Geminospora* cf. *treverica* Reigel 1973  
*Grandispora diamphida* Allen 1965  
*Grandispora inculta* Allen 1965  
*Grandispora libyensis* Moreau-Benoît, 1980  
*Grandispora protea* (Naumova) Allen 1965  
*Hispanaediscus lamontii* Wellman 1993  
? *Hystricosporites* cf. *corystus* Richardson 1962  
*Hystricosporites microancyreus* Reigel 1973  
*Laevolancis divellomedia* (Chibrikova) Burgess and Richardson 1991  
*Leonispora argovejea* Cramer and Diez 1975  
*Lophozonotriletes curvatus* Naumova 1953  
*Perotriletes microbaculatus* Richardson and Lister 1969  
*Retusotriletes abundo* Rodriguez 1978  
*Retusotriletes actinomorphus* Chibrikova 1962  
*Retusotriletes* cf. *frivulus* Chibrikova 1959  
*Retusotriletes triangulatus* (Streel) Streel 1967  
*Rhabdosporites langii* (Eisenack) Richardson 1960  
*Rhabdosporites parvulus*, Richardson 1965  
*Samarisporites mediconus* (Richardson) Richardson 1965  
*Samarisporites orcadiensis* Richardson 1965  
*Scylaspora cymba* Hassan Kermadjji 2007  
*Scylaspora distincta* Hassan Kermadjji 2007  
*Scylaspora kozlica* (Dufka) Richardson, Rodriguez and Sutherland 2001  
*Scylaspora radiata* Hassan Kermadjji 2007  
*Scylaspora undulata* Hassan Kermadjji 2007  
*Scylaspora vetusta* (Rodriguez) Richardson, Rodriguez and Sutherland 2001  
*Scylaspora tidikeltense* Hassan Kermadjji 2008  
*Synorisporites tipapillatus* Richardson and Lister 1969  
*Synorisporites verrucatus* Richardson and Lister 1969  
*Stenozonotriletes furtivus* Allen 1965  
*Tetrahedralets medinensis* (Strother and Traverse) Wellman and Richardson 1993  
*Tholisporites ancylus* Allen 1965  
*Verrucosisporites polygonalis* (Lanninger) McGregor 1973

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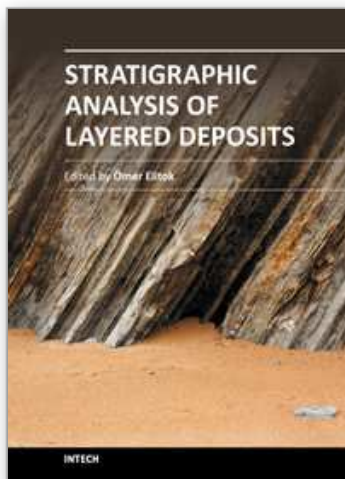
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## **Stratigraphic Analysis of Layered Deposits**

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Stratigraphy, a branch of geology, is the science of describing the vertical and lateral relationships of different rock formations formed through time to understand the earth history. These relationships may be based on lithologic properties (named lithostratigraphy), fossil content (labeled biostratigraphy), magnetic properties (called magnetostratigraphy), chemical features (named chemostratigraphy), reflection seismology (named seismic stratigraphy), age relations (called chronostratigraphy). Also, it refers to archaeological deposits called archaeological stratigraphy. Stratigraphy is built on the concept "the present is the key to the past" which was first outlined by James Hutton in the late 1700s and developed by Charles Lyell in the early 1800s. This book focuses particularly on application of geophysical methods in stratigraphic investigations and stratigraphic analysis of layered basin deposits from different geologic settings and present continental areas extending from Mexico region (north America) through Alpine belt including Italy, Greece, Iraq to Russia (northern Asia).

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