A high resolution palynozonation for the Pennsylvanian to Lower Permian Al Khlata Formation, south Oman

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ABSTRACT

Palynology is the main method of correlating the subsurface glaciogenic Al Khlata Formation of Oman, due to extreme lateral variability of facies, and poor seismic resolution. The chief
operating company in Oman, Petroleum Development Oman, has developed a robust in-house palynozonation through almost 40 years of exploration and production based on thousands of samples and hundreds of well sections. In this paper the formal definitions of the biozones are published, and the biozones are correlated in detail with faunally-calibrated palynological biozones in Western Australia, thereby allowing correlation with the standard Russian stages. Seven biozones are distinguished. The oldest, biozones 2159A and B, of probable late Pennsylvanian age, are characterised by low diversity assemblages of *Punctatisporites* and monosaccate pollen, with Biozone 2159A having a lower proportion of monosaccate pollen than Biozone 2159B. Biozone 2165A, of probable Asselian age, is characterised by common cingulicamerate spores and *Microbaculispora* Group; while Biozone 2165B contains in addition to the above, common *Horriditriletes* Group, and is likely to be Asselian-Sakmarian in age. Biozone 2141A is characterised by common taeniate and non-taeniate bisaccate pollen and *Cycadopites cymbatus*, particularly toward the top; and the succeeding 2141B by common *Microbaculispora* Group and *C. cymbatus*. Biozones 2141A and B are believed to be Sakmarian in age. The youngest, Biozone 2141C, is characterised by *Microbaculispora* and *Horriditriletes* Group with the former being more abundant. The seven-fold subdivision is a considerable improvement on previous palynozonations of the Al Khlata Formation, which only allowed three or four-fold subdivisions; however, there still remain considerable uncertainties in dating the lowest biozones, 2159A and B. Improvements in dating of Al Khlata Formation sediments are most likely to come from palynological correlation with radiometrically- or faunally dated sequences in South America, eastern Australia and southern Africa.

**INTRODUCTION**
Pennsylvanian to Lower Permian rocks crop out over relatively small areas of central Saudi Arabia, the Wajid outcrop area in southwestern Saudi Arabia, and in the Haushi-Huqf outcrop area in Oman (Text-Figure 1), but are present widely in the subsurface, where they form important hydrocarbon reservoirs (McGillivray and Hussein, 1992; Hughes Clarke, 1988). The main formations of the region containing Pennsylvanian to Lower Permian sequences are the Al Khlata and Gharif formations in Oman, and the Unayzah Formation in Saudi Arabia.

The Al Khlata Formation consists of a complex package of clastic lithologies that range from conglomerates through diamictites, gravels, pebbly sandstones, siltstones to silty shales (Braakman et al., 1982; Hughes Clarke, 1988; Levell et al., 1988; Dubreuilh et al., 1992; Roger et al., 1992; Al-Belushi et al., 1996; Angiolini et al., 2003). The glaciogenic nature of the Al Khlata Formation was established from studies of the outcrop area on the western flank of the Haushi-Huqf Uplift where striated pavements of the Precambrian Khufai Formation have been found (Braakman et al., 1982; Al-Belushi et al., 1996). Hughes Clarke (1988) credited Levell et al. (1982) with the definition of the type section of the Al Khlata Formation, which is located at Wadi Al Khlata near the Haushi-Huqf Uplift (57°25’46”E, 19°46’43”N; Text-Figure 1) where it is about 100 m thick. The subsurface reference section of the Al Khlata Formation was defined in Rahab-2 well, south Oman (55°06’32”E, 18°01’09”N) where the formation is more than 246 m thick (Hughes Clarke, 1988; Mohammed et al., 1997). In the subsurface of south Oman, the thickness of the Al Khlata Formation varies from about 100 to 800 m (Levell et al., 1988; Love, 1994; Knight and Hartkamp-Bakker, 1998). The variation of thickness is largely the result of syn-depositional subsidence and erosional palaeorelief on the pre-Al Khlata unconformity (Levell et al., 1988; Knight and Hartkamp-Bakker, 1998). During its deposition, the infra-Cambrian Ara salt in the South Oman Salt Basin moved diapirically to form salt domes, and developed a series of NS-oriented salt pods.
As a result, thick Al Khlata sediments are found in synclines formed by salt withdrawal. On the Eastern Flank, thick Al Khlata Formation deposits are also found where salt was apparently syndepositionally dissolved by groundwater (Heward, 1990; Osterloff et al., 2004).

The Al Khlata Formation is present throughout the central interior of Oman south of the Oman Mountains, and west of the Huqf Axis high (Text-Figure 1). It rests with angular unconformity on Devonian and older rocks (Hughes Clark, 1988). The upper boundary of the subsurface Al Khlata Formation is described by Mohammed et al. (1997) as broadly conformable with the overlying Gharif Formation. This lithological boundary is generally picked at the base of the lowermost Gharif sandstone, overlying the upper Rahab Member of the Al Khlata Formation. On electric logs this boundary is marked by a downhole increase in gamma ray, sonic, and the separation of the density and neutron logs down-hole (Osterloff et al., 2004). In north-central Oman, the Rahab Member is not distinct and the boundary is mainly identified via palynostratigraphical proxy.

Petroleum Development Oman has used palynology extensively for correlating the subsurface Al Khlata Formation, such that at present it is the chief method used due to extreme lateral variability of facies (and therefore of the wireline logs), and poor seismic resolution. Historically PDO have identified important palynomorphs by code numbers rather than Linnaean binomials, for example the colpate pollen taxon *Cycadopites cymbatus* is known by the code 2141. Where a taxon is taken as marker or index for a biozone, its code is used also to denote that biozone. Hence the original 2141 Biozone in its broadest terms was characterised by the common occurrence of *Cycadopites cymbatus*. The system in various forms has been in operation for nearly 40 years in PDO, and has proved to be extremely robust having been developed from a database of thousands of samples and hundreds of well sections. However, although its basic characteristics have been illustrated (Osterloff et al.
2004, fig. 7), formal definitions of the biozones have not been published. The biozones have also not been correlated in detail with other biozones of Gondwana. Thus the main purpose of this paper is to define and correlate the biozones. For continuity and simplicity, the nomenclature for biozones used internally in PDO is retained.

**PALYNOLOGICAL SUCCESSION**

Generally the diversity and yield of palynomorphs increases upsection through the Al Khlata Formation, probably in response to climatic amelioration, related to global post glacial warming and the northward movement of the Arabian Plate between the Pennsylvanian and Early Permian (Stephenson and Filatoff 2000; Stephenson et al., 2005; 2007). The earlier assemblages are characterised by common monosaccate pollen and *Punctatisporites* Group, while later assemblages are of greater diversity including cingulicamerate and cheilocardioid spores, and colpate and bisaccate pollen. The biozones are of the acme type with bases defined by quantitative changes in a palynomorph group or taxon. In this paper we will list the constituents of the groups and then show how the patterns of occurrence of groups define the biozones. The composition of the groups and authors of taxa are given in Table 1. Along with groups, certain taxa are also important, for example *Anapiculatisporites concinnus*, *Cycadopites cymbatus*, and *Kingiocolpites subcircularis*. Key taxa and groups are illustrated in Plates 1 and 2.

**BIOZONATION**

**Methodology.** Percentage proportions of taxon groups and species are central to the method of biozonation, and proportions quoted in this paper are averages gained from many
hundreds of well analyses involving thousands of samples (Table 2). PDO in-house procedures suggest that counts of approximately 150 to 200 specimens per slide are adequate to represent true proportions. Three reliability categories are applied: ‘poor’ (total count 50 - 74 specimens), ‘fair’ (75 – 99 specimens) and ‘good’ (over 100 specimens). Samples with counts of less than 50 are designated non-diagnostic and therefore are not used in biozonation, except in the case of 2159, where a tentative assignment is allowed with counts of between 25 and 50. Samples from cored well sections are the main basis of the biozonation, though sidewall core samples are used in important sections where core is not available.

It should be noted that biostratigraphy of this type, based mainly on quantitative trends is not an exact science, and judgement is sometimes required in the positioning of biozonal boundaries. This is also true in the case of reworking of palynomorphs, which is common in glaciogenic sediments. The Al Khlata Formation contains palynomorphs derived by glacial erosion of consolidated hinterland rocks (‘long-cycle’ reworked palynomorphs, for example from the Devonian) as well those derived from younger unconsolidated glacial sediments (‘short-cycle’ reworked palynomorphs; Stephenson, 2008). The latter, which are difficult to distinguish from in situ palynomorphs, make reliable palynozonation difficult without reference to sedimentary facies and appropriate experience concerning which data to use or reject.

2159A Biozone. The lowest biozone of the Al Khlata Formation has a cored reference section in Marmul-6H1 well between 920.39 to 902.77m (Text-Figure 2). The primary diagnostic criterion is the abundance of the Punctatisporites Group which constitutes up to 100% of assemblages. Taxa of the Monosaccate Group constitute less than 5% of assemblages. Below the base of the biozone, samples contain non-diagnostic assemblages or
are barren with sparse reworking of Devonian to Lower Palaeozoic spores, cryptospores or acritarchs. Rarely *Anapiculatisporites concinnus*, *Aratrisporites saharaensis*, *Brevitriletes* spp., and members of the Cingulicamerate Group such as *Vallatisporites arcuatus* occur as do algal palynomorphs such as *Botryococcus*, *Tetraporina* spp. and *Tasmanites*. Apart from the reference section, this biozone is well represented in the cored interval from Qata-9 (Text-Figure 2). However, in uncored sections it is usually identified from spot sidewall samples such as exemplified in Rima-65 (see also Text-Figure 2).

There is a transition between 2159A and the succeeding Biozone 2159B, with the result that the boundary between the zones is difficult to position precisely. In the transition section, the percentage of monosaccate pollen fluctuate on average between 5% and 10% with the balance of the assemblage consisting mainly of the *Punctatisporites* Group (Qata-9, Text-Figure 2).

**2159B Biozone.** The reference section is the cored Marmul-6H1 interval from 901.8 to 870.5m (Text-Figure 2), and the main feature that distinguishes 2159B from 2159A is the increase in the proportion of the Monosaccate Group to greater than 10% of assemblages with a proportional decrease in *Punctatisporites* Group. 2159B Biozone is also more diverse than 2159A in containing *Anapiculatisporites concinnus* (usually less than 5% of the assemblage), *Aratrisporites saharaensis*, *Apiculiretisporispora* spp., *Brevitriletes* spp., *Cyclogranisporites* spp., *Densosporites* spp. (including *D. rotundidentatus*), *Dibolisporites*, *Wilsonites australiensis*, *Spelaeotriletes* spp. (including *S. triangulus*), *Vallatisporites arcuatus* and *Verrucosisporites andersonii*. Overall there is an increase in the Monosaccate Group upsection through the biozone and this group may be locally very abundant (up to 70% of
assemblages) at the top of the biozone (Rima-65, Text-Figure 2). Apart from the reference section, this biozone is well represented in cored intervals within Al Burj-36 and Rima-65.

### 2165A Biozone

The reference section is the Wadi Al Khlata Borehole-5 between 27.0 and 17.75m. The primary diagnostic criteria are (1) the Cingulicamerate Group constitutes up to approximately 30% of the assemblages (mainly *Vallatisporites arcuatus*, *Lundbladispora braziliensis* and *Cristatisporites* spp.); and (2) the *Microbaculispora* Group constitutes approximately 5% of assemblages, although it can be rare or absent locally (Text-Figure 3). The *Punctatisporites* and Monosaccate groups may also be abundant. *Anapiculatisporites concinnus* is present, usually comprising less than 5% of the assemblage, and the *Horriditriletes* and Bisaccate groups are usually rare or absent. Diversity is relatively high in comparison with 2159A, with *Ahrensisporites cristatus* 1979, *A. saharaensis*, *Apiculiretusispora* spp., *Cyclogranispotites* spp., *Densosporites* spp., *D. disfacies*, *W. australiensis* and *V. andersonii* present (Text-Figure 3). Apart from the cored reference section, this biozone is well represented in sidewall sampled intervals within Dimeet-1 and Al Burj-23 (Text-Figure 3).

### 2165B Biozone

The reference section is Wadi Al Khlata Borehole-5 from 16.73 to 14.45m. The primary diagnostic criteria are (1) *Horriditriletes* Group constitutes between 5 and 10%, or up to 20% of assemblages; and (2) *Microbaculispora* Group constitutes usually around 3 to 5% of assemblages but can be occasionally absent. The Cingulicamerate Group may constitute 20 to 30% or more of assemblages. (mainly *Lundbladispora* spp., *Cristatisporites* spp. and *Vallatisporites arcuatus*). The *Punctatisporites* Group is usually less frequent than in the underlying biozones. *Cycadopites cymbatus*, *Granulatisporites*...
confluens, Converrucosisporites grandegranulatus, Marsupipollenites spp. and the Vittatina and Taeniate Bisaccate groups appear towards the top of this biozone (Text-Figure 3, 5). Apart from the reference section, this biozone is well represented in the cored interval within Amal-9 and sidewall sampled sections from Dimeet-1 and Al Burj-23 (see also Text-Figure 3).

**2141A Biozone.** The reference section is Nimr-46 cored interval between 934.59 to 897.1m. The primary diagnostic criteria are: (1) non-taeniate and taeniate bisaccate groups together represent more than 10% of the assemblages; and (2) Cycadopites cymbatus is rare towards the base but increases to 5 to 10% of assemblages towards the top. The proportions of the Cingulicamerate Group vary considerably but are usually lower than those of 2165A or B biozones. The proportion of Punctatisporites Group continues to decrease so that percentages are lower than in 2165B. Horriditriletes Group usually represents 10% but can be up to 20% of assemblages, and the Microbaculispora Group is approximately 3 to 5% of assemblages but can be occasionally absent. Taxa or groups that occur rarely include Kingiacolpites subcircularis and the Vittatina Group, Brevitriletes cornutus, Dibolisporites disfacies, Densosporites spp. (including Densosporites rotundidentatus), Verrucosisporites spp., Botryococcus, Deusilites tentus, Tetraporina spp. and Tasmanites (Text-Figure 4). Apart from the reference section, this biozone is well represented in the cored intervals of Rahab-2 and Wadi Al Khlata Borehole-2 (Text-Figure 4).

**2141B Biozone.** The reference section is Rahab-2 between 1008.32 and 992.14 m. The primary diagnostic criteria are (1) The Microbaculispora Group represents greater than 10% and can constitute up to 60% of assemblages, in addition the Microbaculispora Group is
more abundant than the *Horriditriletes* Group; (2) *Cycadopites cymbatus* makes up 5 to 10% of assemblages; and (3) the Cingulicamerate Group are extremely rare or absent. The Non-Taeniate Bisaccate Group exceeds the Taeniate Bisaccate Group. Taxa that occur rarely include *Kingiacolpites subcircularis, Deusilites tentus, Tetraropina* spp. and *Tasmanites*. Apart from the reference section, this biozone is also well represented in the cored interval of Rahab-28 (Text-Figure 4).

**2141C Biozone.** The reference section is Rahab-2 between 982.38 and 964.7m. The primary diagnostic criterion is that the *Microbaculispora* Group represents more than 10% of assemblages, but the *Horriditriletes* Group exceeds it in proportion, reaching 30% or more. *Cycadopites cymbatus* and the Non-Taeniate Bisaccate Group are variable but usually common to abundant, reaching abundances of 60% or more of assemblages. The Taeniate Bisaccate Group represents 5 to 20% of assemblages but is always less abundant than the non-taeniate taxa. The accessory taxa are broadly the same as those in 2141B. Working downhole, however, the first appearances of *Vittatina cf. scutata* and *Converrucosisporites grandegranulatus* are characteristic of this biozone. Apart from the reference section, this biozone is also well represented in the cored interval of Rahab-28 (Text-Figure 4).

**CORRELATION WITH ARABIA AND WESTERN AUSTRALIA**

Besems and Schuurman (1987) and Love (1994) produced palynostratigraphical schemes for Oman (Text-Figure 6). The former authors, working on outcrops of the Al Khlata Formation in east-Central Oman, recognised two distinct palynological assemblages. Assemblage Group A is dominated by zonate, trilete spores and Assemblage Group B is characterised by taeniate
and non-taeniate bisaccate pollen. The quantitative data of Besems and Schuurman (1987; text-figures 3-7), which comes from a very small number of sample horizons suggests that Assemblage Group A correlates with 2165A and B, and Assemblage Group B with 2141A. The boundary between Assemblage Groups A and B coincides with that between 2165B and 2141A, because both are defined on the increase of bisaccate pollen to approximately 10%.

Love (1994) described four palynological assemblages from the entire subsurface Haushi Group. The Potonieisporites Assemblage is reportedly low in diversity containing simple trilete spores and monosaccate pollen such as Potonieisporites. His succeeding Microbaculispora Assemblage was correlated to Besems and Schuurman’s Assemblage Group A (Text-Figure 6) and his third assemblage, the Cycadopites cymbatus Assemblage to Besems and Schuurman’s Assemblage Group B. Based on the data of Besems and Schuurman (1987) which show percentages of approximately 10% Cingulicamerate Group in Assemblage Group B, we correlate that biozone with the 2141A Biozone proposed here. Thus only the lower part of the Cycadopites cymbatus Assemblage of Love (1994) correlates with Assemblage Group B. As a whole the Cycadopites cymbatus Assemblage correlates with 2141A to C because the eponymous taxon and the Bisaccate Group are common throughout those biozones. Love’s Kingiacolpites subcircularis Assemblage, which is not dealt with here, is equivalent to zones immediately overlying 2141C.

The field scale biozonation of Stephenson and Osterloff (2002) was primarily aimed at high resolution correlation of the Lower Gharif Member and Rahab Shale. The lowest Microbaculispora tentula Biozone correlates with 2141B because it is primarily characterised by high numbers of that taxon (>10% of assemblages). The succeeding Converrucosisporites sp. A - Microbaculispora grandegeanulata Biozone correlates to the 2141C Biozone because
it is based on the presence of common coarsely ornamented cheilocardioid spores reaching approximately 5% (Text-Figure 6).

OSPZ1 the lowest of the Arabian regional biozones (Stephenson et al. 2003) is characterised by assemblages dominated by *Punctatisporites, Retusotriletes* and bilaterally and radially symmetrical monosaccate pollen, which also contain *Anapiculatisporites concinnus*, thus it correlates with 2159A and B biozones. The base of OSPZ2 is defined on the first occurrence of *Microbaculispora tentula* and *Horriditriletes* spp. thus this horizon correlates approximately with the base of 2165A. The upper parts of OSPZ2 are characterised by rising numbers of *C. cymbatus, M. tentula* and coarsely ornamented cheilocardioid spores and thus correlate with the interval 2165B to 2141C.

In this paper we correlate with Western Australia primarily because these sequences have been documented in detail including quantitative data, allowing correlation with the present biozones which are defined with quantitative criteria. Also Western Australia has the most comprehensive marine faunal record which has allowed the palynological succession to be correlated with the standard Russian sequence (Archbold 1999; Stephenson 2008).

The palynostratigraphy of Australasian pre-glacial and periglacial sediments is known in less detail than that of later Australasian sequences (Kemp et al. 1977). Amongst published studies, Kemp et al. (1977) and Powis (1984) give generalised details on Australian Stage 1 and 2 biozones (Text-Figure 6). Data from single sequences or small groups of sequences within this interval were supplied by Truswell (1978), Backhouse (1991, 1993) and Jones and Truswell (1992). The unpublished doctoral thesis of Powis (1979) concerning the pre-glacial and periglacial sediments of the Canning Basin, Western Australia provides perhaps the most comprehensive survey of the palynostratigraphy of such sediments. Powis (1984) defined the
base of Stage 2 as the level of the collective first appearance of *Microbaculispora tentula*, *Horriditriletes ramosus* and *Horriditriletes tereteangulatus*, and Jones and Truswell (1992) correlated their *Microbaculispora tentula* Biozone with Stage 2 of Powis (1984). Thus, the base of 2165A correlates with the bases of Stage 2 of Powis (1984) and the *Microbaculispora tentula* Biozone of Jones and Truswell (1992).

Backhouse (1991, 1993) reported that *C. confluens* occurs first toward the top of eastern Australian Stage 2, and this order of first occurrence is also evident in Oman, where *C. confluens* occurs stratigraphically well above the first occurrences of *M. tentula* and *H. ramosus*. Hence, 2165A and B correlate in part with ‘Stage 2’ sensu Backhouse. *Converrucosisporites confluens* occurs first between 2165B and 2141B thus the *C. confluens* Biozone of Backhouse (1991) correlates with those south Oman biozones. The presence of large, heavily-ornamented cheilocardiod spores such as *Converrucosisporites* sp. A and *Verrucosisporites* cf. *naumovae* in 2141C may suggest that this biozone correlates with the *Pseudoreticulatispora pseudoreticulata* Biozone of Backhouse (1991).

An advantage of correlation between south Oman biozones and Western Australia is that the calibration by marine fauna available in the latter area can be applied in south Oman.

Backhouse (1991) considered his Stage 2 to be ?Asselian in age, while the *Pseudoreticulatispora pseudoreticulata* biozone was considered Sakmanian. The *Converrucosisporites confluens* Biozone appears to straddle the boundary between Asselian and Sakmanian (see Backhouse, 1991, fig. 10). By correlation therefore, 2165A and B are likely to be Asselian in age, while 2141A to C are likely Sakmanian. A single faunal calibration is available in Oman, since the Haushi limestone (of the Lower Gharif Member) which overlies the Al Khlata formation, contains definite Sakmanian fusulinids (Angiolini et al. 2006; Text-Figure 6). Age assessments for biozones 2159A and B are less certain since
Western Australian faunal calibration does not reach below Stage 2 of Powis (1984) or Backhouse (1991). However, Jones and Truswell (1992) considered their *Asperispora reticulatispinosus* Biozone to be uppermost Westphalian D (Late Moscovian based upon the assessment of Davydov et al., 2004) to Autunian or Early Asselian in age, and a similar age is therefore adopted for 2159A and B for the present.

**CONCLUSIONS**

Palynology is the main method of correlating the subsurface glaciogenic Al Khlata Formation of Oman, due to extreme lateral variability of facies, and poor seismic resolution. Over many years a robust seven-fold in-house PDO palynozonation has been developed and in this paper the formal definitions of the biozones are published, and the biozones are correlated. Ages applied to the upper five biozones are the most precise that can presently be offered, through correlation with recently faunally-dated palynological biozones in Western Australia. The dates thereby gained are consistent with the single faunal tie-point given by fusulinids in the Haushi limestone of the Lower Gharif Member, which shows that the entire Al Khlata Formation is Sakmarian or older. Age assessments for biozones 2159A and B are less certain since Western Australian faunal calibration does not reach below Stage 2 of Western Australia. Further improvements in dating of Al Khlata Formation sediments are most likely to come from palynological correlation with radiometrically- or faunally dated sequences in South America, eastern Australia and southern Africa (see Stephenson, 2008).

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**FIGURE CAPTIONS**

Fig. 1. South Oman study area indicating locations of 2159, 2165 and 2141 palynozonal correlation lines.

Fig. 2. South Oman 2159 palynozonal correlation example; (left to right) Marmul-6 well reference section and Qata-9, Al Burj-36 and Rima-65 well sections.

Fig. 3. South Oman 2165 palynozonal correlation example; (left to right) Dimeet-1, Al Burj-23, Amal-9 well sections and Wadi Al Khlata (short) Borehole-5 reference section.

Fig. 4. South Oman 2141 palynozonal correlation example; (left to right) Rahab-28 well section, Rahab-2 reference section, Nimr-46 and Wadi Al Khlata Borehole-2 well sections.
Fig. 5. Haushi Palynozonation scheme displaying palynomorphs groups, key and main accessory taxa.

Fig. 6. Correlation chart with Arabia and Australia.

Table 1. Composition of taxon groups used in palynozonation.

Table 2. Summary of main biozone characteristics.

Plate 1. Representative palynomorphs from the Cingulicamerate, *Horriditriletes*, *Microbaculispora*, *Punctatisporites* groups and other 2159 biozonal taxa from the Al Khlata Formation, South Oman. Magnification X600. All slides are held in the collection of Petroleum Development Oman, Muscat.

1 - 4. *Microbaculispora* Group. 1,2 *Microbaculispora tentula* Habhab-2 1200.41m core, M39/4and X31/3 ; 3 *Converrucosisporites grandegranulatus* Habhab-2 1205.42m core, P28/4; 4 *Converrucosisporites confluens* Habhab-2 1205.42m core, C24/3.

5, 8 and 9 Other 2159 Zonal Taxa. 5 *Anapiculatisporites concinnus* Habhab-2 1207.50m core, K21/4; 8 *Wilsonites australiensis* 1202.70m core, N39/4; 9 *Dibolisporites* sp. 1202.70m core, H25.

6, 7 *Horriditriletes* Group; 6 Habhab-2 1197.60m core, P32 and 7 Nimr-38H1 914.48m core, N30.

10 – 15 Cingulicamerate Group. 10 *Lundbladispora* sp. Wadi Al Khlata Borehole #5 17.70m; 11, 13 and 15 *Cristatisporites* spp. Habhab-2 1207.50m core, B37/4 and 1202.70m core, O17/3, Nimr-38 914.48m core, D29/3 ; 12 *Lundbladispora* sp. Habhab-2 1200.41m core, W34/1 ; 14 *Vallatisporites arcuatus* Nimr-38 914.48m core, P32.
Punctatisporites Group. 16, 17 Calamospora spp. Habhab-2 1213.52m core, T26/0; 1197.60m core, C44/1. 18 Punctatisporites gretensis Habhab-2 1216.50m core, K31/1.

Plate 2. Representative palynomorphs from the Non-Taeniate Bisaccate, Taeniate Bisaccate and Monosaccate Groups, colpate pollen and algal taxa. Magnification X600,

Slide repository as for plate 1.

1 – 6 Colpate pollen taxa: 1 and 2 Cycadopites cymbatus Habhab-2 1200.41m, R35/4 and 1200.41m, K46/0; 3 Striasulcites sp.; Habhab-2, 4 and 5 Marsupipollenites spp. Habhab-2H1 1213.52m, Q26 and Saih Rawl-8 2961.38m, V44/4; 6 Kingiacolpites subcircularis Amal South-5 1450.05m, C25/3.

8, 9 Algae: ?Tetraporina spp., 8 Habhab-2 1207.50m, E21/3; 9 Wadi Al Khlata Borehole #2, 14.40m M39/4.

7, 10 Non-Taeniate Bisaccate Group: 7 Alisporites sp. Habhab-2 1200.41m, X38; 10 Alisporites indarraensis Amal-9 1298.45m, K39/1.

11 – 14 Taeniate Bisaccate Group: 11 Striatoabieites multistratiatus Rima-69 975m, O38/4; 12 Vittatina saccata Habhab-2 1207.50m, Q35/2; 13 Protohaploxypinus amplus Habhab-2 1205.42m, B23/3; 14 Strotersporites sp. cf. indicus Habhab-2 1200.41m, F29/4.

15, 16 Monosaccate Group: 15 Caheniasaccites cf. ovatus Nimr-38 901.03m, S36/4; 16 Potonieisporites sp. Nimr-38 901.03m, D28.

17, 20, 21 Taeniate Bisaccate Group: 17 Strotersporites indicus Nimr-39, 914.48m, M24; 20 Protohaploxypinus cf. goraiensis Nimr-38, 913.68m, O34/2; 21 Complexisporites polymorphus Habhab-2 1205.42m, M22/3.
18, 19, 22, 23 Monosaccate Group: 18 *?Divarisaccus* sp. Habhab-2 1216.50m, C19/2; 19

*Florinites flaccidus* Habhab-2 1205.42m, R24/2; 22 *Plicatipollenites malabarensis* Habhab-2 1197.60m, D39/4; 23 *Barakarites cf. rotatus* Habhab-2 1218.82, W26/3.
### Palynomorph Groups & Key Taxa

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<tr>
<th>Palynomorph Zone (Spore/Pollen)</th>
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<tr>
<td>Punctatisporites Group</td>
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<td>Monosaccate Group</td>
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<td>Anapliculatisporites concinnus</td>
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<td>Microbaculispora Group</td>
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<td>Bisaccates (taeniate)</td>
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<td>Horriditriletes Group</td>
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<td>Cycadopites cymatus</td>
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<td>Vitata Group</td>
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### Main Accessory Taxa

- Wilsonites australiensis
- Apiculareispora spp.
- Ahrensisporites cristatus
- Arctisporites saharainsis
- Cyclogranisporites spp.
- Verrucosisporites andersonii
- Densosporites spp.
- Marsupipollenites spp.
- Converrucosisporites spp.
- Converrucosisporites spp.
- Converrucosisporites spp.
- Deusilites tentus
- Vitata cf. scutata

### Palynomorph Zone

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### Non-Diagnostic

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<tr>
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### Main Accessory Taxa

- Wilsonites australiensis
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- Cyclogranisporites spp.
- Verrucosisporites andersonii
- Densosporites spp.
- Marsupipollenites spp.
- Converrucosisporites spp.
- Deusilites tentus
- Vitata cf. scutata
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<td>Microbaculispora</td>
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<td>? Asselian</td>
<td>Sakmarian</td>
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<td>Arabian faunal content</td>
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<td>Oman, Love, 1994</td>
<td>This study</td>
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<tr>
<td>? Late Moscovian - Gzhelian</td>
<td>? Asperispora reticulatispinosus Biozone</td>
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<tr>
<td>Potoniopsis</td>
<td>Microbaculispora tentula Biozone = eastern Australian Stage 2</td>
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<td>Stage 1</td>
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<td>Group</td>
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<td>'Punctatisporites' Group</td>
<td>Punctatisporites, Calamospora, Cyclogranisporites, Retusotriletes</td>
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<tr>
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<td>Vallatisporites, Densoisporites, Lundbladispora, Cristatisporites, Indotriradites</td>
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<tr>
<td>Microbaculispora’ Group</td>
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<td>'Horriditriletes' Group</td>
<td>Horriditriletes, Lophotritiletes</td>
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<td>'Monosaccate' Group</td>
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<td>Bisaccate (Non taeniate) Group</td>
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<td>'Vittatina’ Group</td>
<td>Circumstriatites, Marsupipollenites, Pakhapites, Vittatina, Striasulcites</td>
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<td>Biozone</td>
<td>Main characteristics</td>
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<tr>
<td>2159A</td>
<td>Abundance of <em>Punctatisporites</em> Group which constitutes up to 100% of assemblages. Taxa of the Monosaccate Group constitute less than 5% of assemblages.</td>
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<tr>
<td>2159B</td>
<td>Increase in the proportion of the Monosaccate Group to greater 10% of assemblages such that <em>Punctatisporites</em> spp. does not exceed 90% of assemblages.</td>
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<tr>
<td>2165A</td>
<td>(1) the Cingulicamerate Group constitutes up to approximately 30% of the assemblages; and (2) the <em>Microbaculispora</em> Group constitutes approximately 5% of assemblages.</td>
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<td>2165B</td>
<td>(1) <em>Horriditriletes</em> Group constitutes between 5 and 10%, or up to 20% of assemblages; and (2) <em>Microbaculispora</em> Group constitutes usually around 3 to 5% of assemblages.</td>
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<tr>
<td>2141A</td>
<td>(1) non-taeniate and taeniate bisaccate groups together represent more than 10% of the assemblages; and (2) <em>Cycadopites cymbatus</em> is rare towards the base but increases to 5 to 10% of assemblages towards the top of the biozone.</td>
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<tr>
<td>2141B</td>
<td>(1) The <em>Microbaculispora</em> Group represents greater than 10% and can constitute up to 60% of assemblages, in addition the <em>Microbaculispora</em> Group is more abundant than the <em>Horriditriletes</em> Group; (2) <em>Cycadopites cymbatus</em> makes up 5 to 10% of assemblages; and (3) the Cingulicamerate Group are extremely rare or absent.</td>
</tr>
<tr>
<td>2141C</td>
<td>The <em>Microbaculispora</em> Group represents more than 10% of assemblages, but the <em>Horriditriletes</em> Group exceeds it in numbers, reaching 30% or more.</td>
</tr>
</tbody>
</table>
APPENDIX

The following is a complete listing of all taxa mentioned in the text of this paper including their full author citations.

_Ahrensispores cristatus_ Playford & Powis 1979
_Alisporites indarraensis_ Segroves 1970
_Anapiculattisporites concinnus_ Playford 1962
_Apiculiretusispora_ spp.
_Aratrisporites saharaensis_ Loboziak et al., 1986
_Barakarites rotatus_ (Balme & Henelly) Bharadwaj & Tiwari 1964
_Brevitriletes cornutus_ (Balme & Henelly) Backhouse 1991
_Caheniasaccites ovatus_ Bose & Kar 1966
_Circumstriatites talchirensis_ Lele & Makada 1972
_Converrucosisporites confluentis_ (Archangelsky & Gamero) Playford & Dino 2002
_Converrucosisporites grandegranulatus_ (Anderson) Lindström 1995
_Cristatisporites crassilabrates_ Archangelsky & Gamero 1979.
_Cycadopites cymbatus_ (Balme & Henelly) Segroves 1970
_Densoisporites rotundidentatus_ Segroves 1970
_Densoisporites solidus_ Segroves 1970
_Densoisporites_ sp. Jones & Truswell 1992
_Deusilites tentus_ Hemer & Nygreen 1967
_Dibolisporites disfacies_ Jones & Truswell 1992
_Florinates flacciudes_ Menéndez & Azcuy 1973
_Horriditriletes ramosus_ (Balme & Henelly) Bharadwaj & Salujah 1964
_Horriditriletes tereteangulatus_ (Balme & Henelly) Backhouse 1991
_Horriditriletes uruguayensis_ (Marques-Toigo) Archangelsky & Gamero 1979
_Kingiocolpites subcircularis_ Tiwari & Moiz 1971
_Lophotrilites sparsus_ Singh 1964
_Lundbladispora_ spp.
_Lundbladispora braziliensis_ (Pant & Srivastava) Marques Toigo & Pons 1976
_Marsupipollenites striatus_ (Balme & Henelly) Foster 1975
_Microbaculispora tentula_ Tiwari 1965
_Pakhapites fusus_ (Bose & Kar) Menéndez 1971
_Piccatipollenites malabarenensis_ (Potonie & Sah) Foster 1975
_Potoniesporites brasiliensis_ (Nahuys et al.) Archangelsky & Gamero 1979
_Potoniesporites novicus_ Bharadwaj 1954.
_Protohaploxypinus amplus_ (Balme & Henelly) Hart 1964
_Protohaploxypinus_ cf. goraiensis (Potonie & Lele) Hart 1964
_Punctatisporites gretenisis_ Balme & Henelly 1956
_Punctatisporites gretenisis_ forma minor, (Balme & Henelly) Hart 1965
_Punctatisporites lucidulus_ Playford & Helby 1966
_Sahnites gondwanensis_ (Mehta) Pant 1955
_Spelaeotrilites triangulus_ Neves & Owens 1966
_Striatoabietites multistriatus_ (Balme & Henelly) Hart 1964
_Striasulcites tectus_ Venkatachala & Kar 1968
_Strotersporites_ cf. indicus_ Tiwari 1965
_Vallatisporites arcuatus_ (Marques-Toigo) Archangelsky & Gamero 1979
_Vallatisporites_ cf. vallatus_ Hacquebard 1957
_Verruocosispores andersonii_ Backhouse 1988
Verrucosisporites cf. naumovae Hart 1963
Vittatina cf. scutata (Balme & Hennelly) Bharadwaj 1962
Vittatina subsaccata Samoilovich 1953
Wilsonites australiensis Playford & Helby 1968