STRATIGRAPHIC NOTE: UPDATE ON THE PALYNOLOGY OF THE AKBARAH AND KUHLAN FORMATIONS, NORTHWEST YEMEN

Mike H. Stephenson and Sa'ad Zeki A. Kader Al-Mashaikie

SUMMARY

Following a preliminary palynological report of two samples from the lower part of the Kuhlan Formation (Unit A) near Kuhlan village, northwest Yemen (Stephenson and Al-Mashaikie, 2010), a further seven samples from Unit A, and an additional 22 samples from the underlying Akbarah Formation in the same locality are reported. The seven new samples from the Kuhlan Formation support the 2165A to 2141A Biozone age originally suggested by Stephenson & Al-Mashaikie (2010), and the new Akbarah Formation samples suggest an age not markedly different since *Anapiculatisporites concinnus* and *Spelaeotriletes triangulus* are also present in the Akbarah Formation (e.g. samples AK-11 and AK-12). This correlation confirms that the lower Kuhlan Formation and the Akbarah Formation, are likely to be late Carboniferous in age and equivalent to the lower parts of the Al Khlata Formation of Oman.

INTRODUCTION

The type section of the Kuhlan Formation is close to the village of Kuhlan, northwest Yemen, about 70 km northwest of Sana'a city (see Stephenson and Al-Mashaikie, 2010 for details of location), and is underlain by the Akbarah Formation. The Kuhlan

Formation consists of yellowish brown, pinkish and red, massive, cross-bedded, medium to fine-grained sandstone units, which are interbedded with thick, fissile and stratified siltstone/shale beds of grey to red colour (Figure 1; Kruck and Thiele, 1983; Diggens et al., 1988; Beydoun et al., 1998). Al-Mashaikie (2005) described ten lithofacies types within the Kuhlan Formation. The lower part (Unit A of Al-Mashaikie, 2005), from which the palynological samples of this and our previous study (Stephenson and Al-Mashaikie, 2010) came, consists of a series of alternating sandstones and fissile mudstones, with occasional coarser-grained beds (Figure 1).

At the Kuhlan Village section, the Akbarah Formation is in two parts (Figure 1). The lower part is composed of thick sandstone beds fining upwards to siltstone and thick fissile shale. These units are interbedded with massive and stratified diamictite beds. Dropstones are embedded within the sandstone and the shale beds, and their size decreases upward illustrating increasingly distal conditions. This part is interpreted broadly as of glacial origin. The upper part is composed of several cycles beginning with beds of thin, fine-grained sandstone fining upwards to thick fissile shale beds, interpreted to be of marine origin.

Al-Wosabi (2011) criticised the findings of Stephenson & Al-Mashaikie (2010) suggesting that two samples were not sufficient to date the lower 60m of Unit A of the Kuhlan Formation. We stand by our argument that two well-preserved assemblages containing a large number of palynomorphs allow a robust date; however in the interests of reinforcing the dating of the Kuhlan Formation we revisited the outcrop to provide further samples. The visit also allowed samples from the Akbarah Formation to be collected.

The Akbarah Formation has only been dated very imprecisely in the past. Kruck et al. (1983) collected samples of grey claystone lithologies from unspecified exposures along the Kuhlan – Hajjah road (see Stephenson and Al-Mashaikie, 2010 for details; Neves *in* Kruck and Thiele, 1983). The organic residues recovered by Neves were interpreted as being of '...Permian, possibly Early Permian age...' (see details in Stephenson and Al-Mashaikie, 2010). El-Nakhal et al. (2002) reported six samples collected from the Akbarah Formation at the Beit Al-Kooli section (2 km southwest of Kuhlan village; see details in Stephenson and Al-Mashaikie, 2010). Two samples from the lower part of the Khalaqah Shale Member (in the upper part of the Akbarah Formation) yielded palynomorphs suggesting only a tentative Late Carboniferous to Early Permian age (El-Nakhal et al., 2002). Here we report on 22 samples from throughout the Akbarah Formation at Kuhlan, allowing a much more detailed analysis than has been previously possible.

All the samples were prepared by crushing, followed by hydrochloric and hydrofluoric acid treatments (Wood et al., 1996). The post-hydrofluoric acid organic residues were oxidized using Schulze's solution and dilute nitric acid. The slides are held in the Collection of the British Geological Survey, Keyworth, Nottingham, UK, NG12 5GG.

CHARACTER AND AGE OF THE PALYNOLOGICAL ASSEMBLAGES

Stephenson and Al-Mashaikie (2010) described the character of assemblages from samples AF-5 and AF-8 from Unit A of the Kuhlan Formation (Figure 1). The assemblages from the additional seven samples of this study, which are distributed evenly through Unit A, are entirely consistent with those of AF-5 and AF-8, being represented by brown, moderately- to well-preserved palynomorphs (Figure 1; Plates 1 and 2). The most common taxa are indeterminate monosaccate pollen (mainly radially- symmetrical forms, probably poorly preserved specimens of *Cannanoropollis*, *Potonieisporites* and *Plicatipollenites*), *Cristatisporites* spp., *Cannanoropollis janakii*, *Deusilites tentus*, *Leiosphaeridia* sp. and *Punctatisporites* spp. Other common taxa include *Brevitriletes cornutus*, *B. parmatus*, *Dibolisporites disfacies*, *Horriditriletes uruguaiensis*, *H. ramosus*, *Lundbladispora braziliensis*, *Microbaculispora tentula*, *Spelaeotriletes triangulus*, *Vallatisporites arcuatus* and *Verrucosisporites andersonii*. Rarer taxa include *Ahrensisporites cristatus*, *Anapiculatisporites concinnus* and *Wilsonites australiensis.*

Assemblages from the Akbarah Formation are broadly similar in being dominated by indeterminate monosaccate pollen, *Cristatisporites* spp., *Cannanoropollis janakii*, *Deusilites tentus*, *Leiosphaeridia* sp. and *Punctatisporites* spp. The main palynological differences appear to be:

1. Monosaccate pollen, *Microbaculispora tentula*, and *Critstatisporites* spp. are more common in the Kuhlan Formation;
2. *Botryococcus* spp., a freshwater green alga, occurs almost exclusively in the Kuhlan Formation.
3. *Deusilites tentus*, a probable alga, is more common in the Akbarah Formation.

A number of taxa make their first appearance close to the base of the Kuhlan Formation, including *Horriditriletes* spp., *Lophotriletes sparsus* and *Vallatisporites arcuatus*.

The differences between the assemblages are relatively minor with the result that the Akbarah and Kuhlan formations cannot be assigned to different biozones. The presence of common cingulicamerate spores (e.g. *Cristatisporites* spp.) and monosaccate pollen, and the presence of *B. cornutus*, *B. parmatus, D. tentus*, *D. disfacies*, *M. tentula* and *V. andersonii*, as well as the presence of *A. concinnus* and *S. triangulus* suggests correlation to the 2165A to 2141A biozones of south Oman (Penney et al., 2008). It is interesting that a single specimen each of *Ahrensisporites cristatus* and *Wilsonites australiensis* was recorded in the new set of samples from the Kuhlan Formation (Figure 1), which were not recorded by Stephenson and Al-Mashaikie (2010). These taxa are rare in Oman but are thought to be confined to the 2159 and 2165A biozones (Penney et al., 2008). Their presence might indicate that the section under study is more likely to be of 2165A age than of 2165B or 2141A biozone age.

As discussed by Stephenson and Al-Mashaikie (2010, 2011), the 2165A to 2141A biozones, and biozones C and B of the Mukhaizna Field, Oman (Stephenson et al., 2008) were originally considered Early Permian (Asselian to early Sakmarian) based on correlations with faunally-calibrated palynological biozones in Western Australia, but recent work on radiometrically-dated sequences in Namibia and South America (Stephenson, 2009; Césari, 2007, 2011) has shown that Early Permian biozones are probably older than previously thought. Thus Unit A of the Kuhlan Formation and the Akbarah Formation are likely to be late Carboniferous in age.

Though there is no clear biostratigraphic age separation between the two formations, the difference in autochthonous algal palynomorph content in the sequences (*Botyrococcus* is almost absent from the Akbarah Formation while *D. tentus* is more common in the latter) might indicate that there was a fundamental change in the palaeoenvironment at the end of the deposition of the Akbarah Formation.

CONCLUSIONS

Seven samples from Unit A of the Kuhlan Formation, and 22 samples from the Akbarah Formation at the Kuhlan village section suggest that both the formations in that locality correlate with the PDO 2165A to 2141A biozones, and are likely late Carboniferous in age and equivalent to the lower parts of the Al Khlata Formation of Oman.

ACKNOWLEDGMENTS

Mike Stephenson publishes with the permission of the Executive Director of the British Geological Survey (NERC). Jane Flint (BGS) processed the palynology samples.

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APPENDIX – AUTHOR CITATIONS OF TAXA RECORDED

Ahrensisporites cristatus Playford and Powis, 1979

Anapiculatisporites concinnus Playford, 1962

Brevitriletes cornutus (Balme and Hennelly) Backhouse, 1991

Brevitriletes leptoacaina Jones and Truswell, 1992

Brevitriletes parmatus (Balme and Hennelly) Backhouse, 1991

Cannanoropollis janakii Potonié and Sah, 1960

Deusilites tentus Hemer and Nygreen, 1967

Dibolisporites disfacies Jones and Truswell, 1992

Horriditriletes ramosus (Balme and Hennelly) Bharadwaj and Salujah, 1964

Horriditriletes uruguaiensis (Marques-Toigo) Archangelsky and Gamerro, 1979

Lophotriletes sparsus Singh, 1964

Lundbladispora braziliensis (Pant and Srivastava) Marques-Toigo and Pons, 1976

Microbaculispora tentula Tiwari, 1965

Spelaeotriletes triangulus Neves and Owens, 1966

Vallatisporites arcuatus (Marques-Toigo) Archangelsky and Gamerro, 1979

Verrucosisporites andersonii Backhouse, 1988

Wilsonites australiensis Playford and Helby, 1968

FIGURE CAPTIONS

Fig. 1. Sketch of lithology and palynology of the lower part of the Kuhlan Formation (Unit A) and the Akbarah Formation.

PLATE 1

The specimen locations are given using the England Finder coordinate, then the slide number. The final code is the BGS collection number. Scale bars indicate size in microns (µm). (a) *Dibolisporites disfacies* D56/2, 60514, 14190; (b) *Verrucosisporites andersonii*, S51, 60514, 14191; (c) *Cannanoropollis janakii*, D40/2, 60513, 14192; (d) *Potonieisporites brasiliensis*, H44/4, 60512, 14193; (e) *Horriditriletes tereteangulatus*, C43, 60511, 14194; (f) *Vallatisporites arcuatus*, R44/2, 60511, 14195; (h) *Cannanoropollis janakii*, G66, 60511, 14196; (g) *Anapiculatisporites concinnus*, J63/3, 60508, 14197.

PLATE 2

(a) *Microbaculispora tentula*, D62/4, 60507, 14198; (b) *Microbaculispora tentula*, D62/4, 60507, 14198 (nomarski); (c) *Spelaeotriletes triangulus*, K61, 60507, 14199; (d) *Vallatisporites arcuatus*, Q50/1, 60507, 14200; (e) *Cristatisporites* sp., L68/1, 60505, 14201; (f) *Deusilites tentus* , M62/4, 60505, 14202; (g) *Deusilites tentus* , U51/1, 60505, 14203; (h) *Brevitriletes leptoacaina*, E44/1, 58569, 14204; (i) *Anapiculatisporites concinnus*, D40/1, 58568, 14205; (j) *Punctatisporites* sp., S43/1, 60393, 14206; (k) *Verrucosisporites andersonii*, H50/4, 60393, 14207.

ABOUT THE AUTHORS

Mike H. Stephenson, British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK, email: mhste@bgs.ac.uk

Prof. Mike Stephenson is Head of Science (Energy) at the British Geological Survey (BGS), Nottingham, United Kingdom. His education has included a BSc, MSc and PhD from Imperial College and University of Sheffield, and various postgraduate teaching qualifications. Mike is an expert on the stratigraphy of the Middle East, and he has published around 30 papers on this region as well as working extensively as a consultant for oil companies in the area. He is a Fellow of the Geological Society, sits on the Petroleum Group Committee of the Geological Society and is a member of the Petroleum Exploration Society of Great Britain (PESGB). He was Secretary-General of the Commission Internationale de Microflore du Paléozoique (CIMP) between 2002 and 2008, and is presently Editor-in-Chief of the Elsevier science journal *Review of Palaeobotany and Palynology*. Mike Stephenson is an Honorary Professor at the universities of Nottingham and Leicester.

Sa'ad Zeki A. Kader Al-Mashaikie, Consultant, Geological Survey and Mineral Resources Board, Sana'a, Yemen. E-mail: geozakee@yahoo.com

Sa'ad Zeki A. Kader Al-Mashaikie was awarded an MSc in 1979 from Baghdad University for a study of the Paleocene Kolosh Formation of North and North East Iraq. He first worked as Assistant teacher in the Dept. of Geology, College of Sciences, Baghdad University. He was also awarded a PhD in 2003 from Sana'a University in Yemen for a study of the stratigraphy, geochemistry and basin analysis of the glacio-turbidite Akbra Formation of Carboniferous-Permian. He worked as an Assistant Professor from 2003 to 2005 in the Dept. of Marine Geology in the Faculty of Marine and Environmental Sciences, Al-Hodiedah University, and from 2005 in the Dept of Geology and Environmental Sciences, Faculty of Applied Sciences, Dhamar University. Since 2005 Dr Al-Mashaikie has been a Consultant in the Ministry of Oil and Minerals, Geological Survey and Mineral Resources Board, Yemen. He is interested in oil and gas prospectivity in the Palaeozoic rocks of the Rub'Alkhali Basin, as well as palynology and facies in Palaeozoic successions in Yemen and adjacent countries.

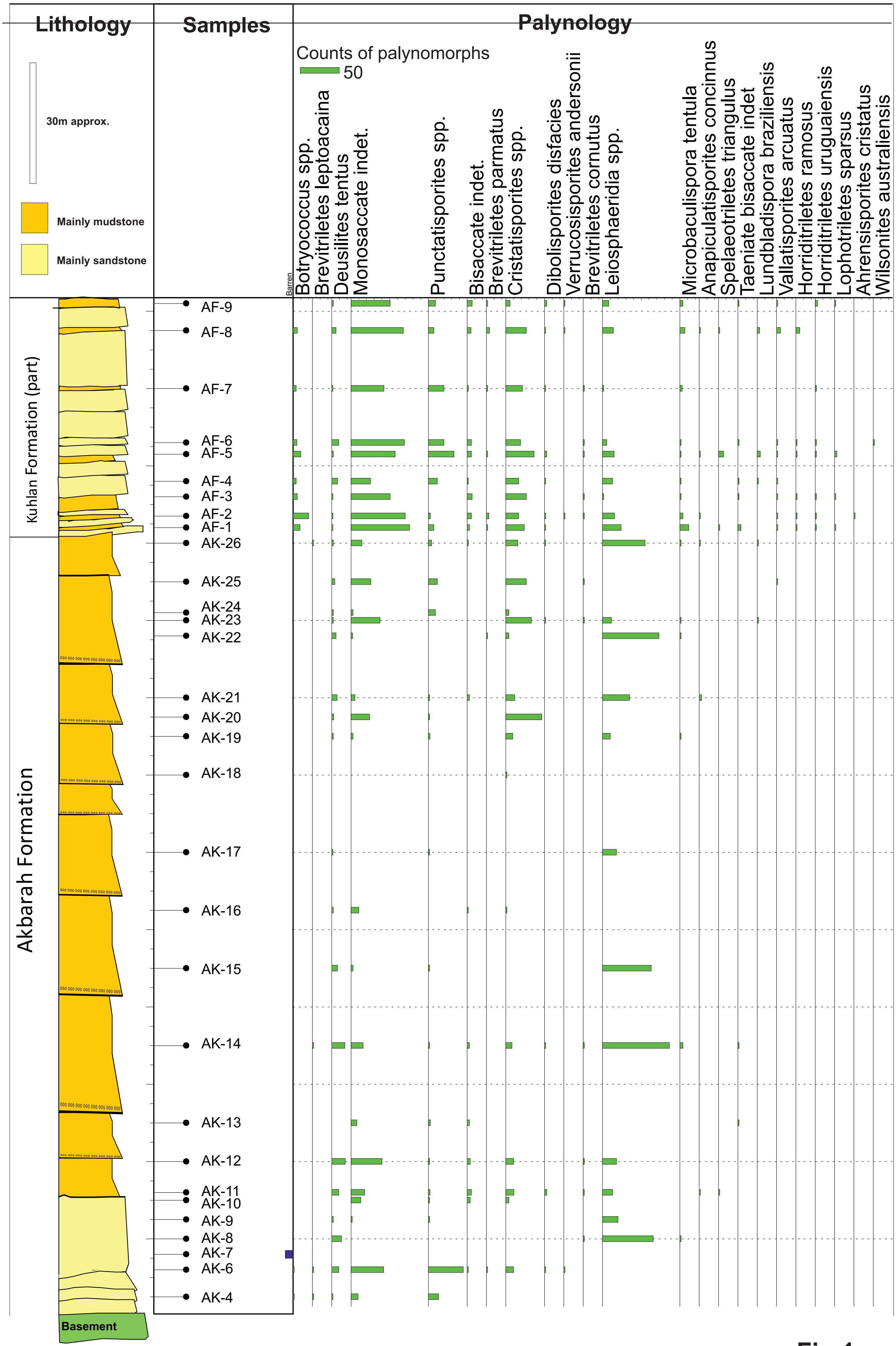
Lithology
Samples
Palynology
30m approx.
Mainly mudstone
Mainly sandstone
Counts of palynomorphs
50
Barren
Botryococcus spp.
Brevitriletes leptoacaina
Deusilites tentus
Monosaccate indet.
Punctatisporites spp.
Bisaccate indet.
Brevitriletes parmatus
Cristatisporites spp.
Dibolisporites disfacies
Verrucosisporites andersonii
Brevitriletes cornutus
Leiosphaeridia spp.
Microbaculispora tentula
Anapiculatisporites concinnus
Spelaeotriletes triangulus
Taeniate bisaccate indet
Lundbladispora braziliensis
Vallatisporites arcuatus
Horriditriletes ramosus
Horriditriletes uruguaiensis
Lophotriletes sparsus
Ahrensisporites cristatus
Wilsonites australiensis
Kuhlan Formation (part)
Akbarah Formation
AF-9
AF-8
AF-7
AF-6
AF-5
AF-4
AF-3
AF-2
AF-1
AK-26
AK-25
AK-24
AK-23
AK-22
AK-21
AK-20
AK-19
AK-18
AK-17
AK-16
AK-15
AK-14
AK-13
AK-12
AK-11
AK-10
AK-9
AK-8
AK-7
AK-6
AK-4
Basement

Fig 1

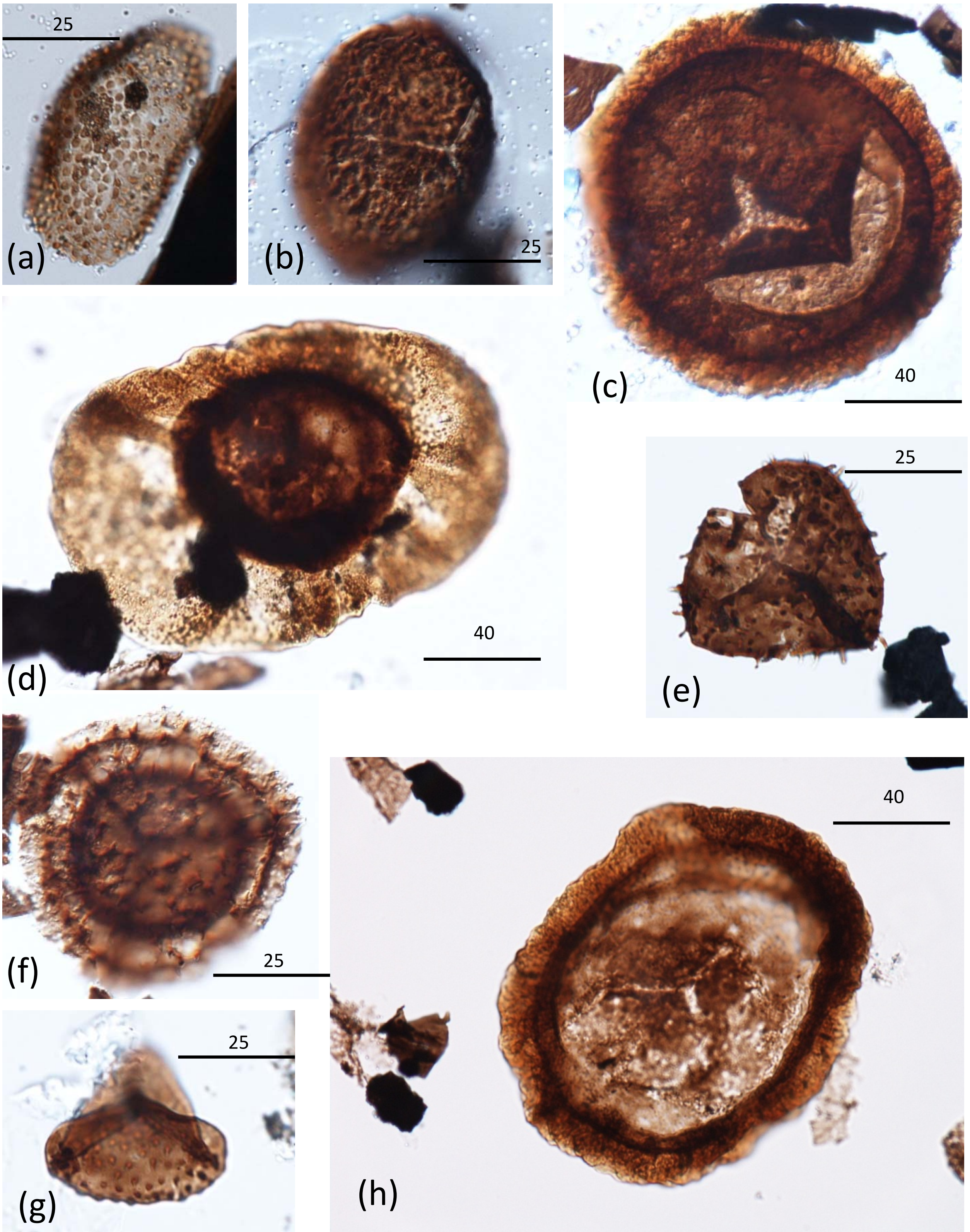

Plate 1

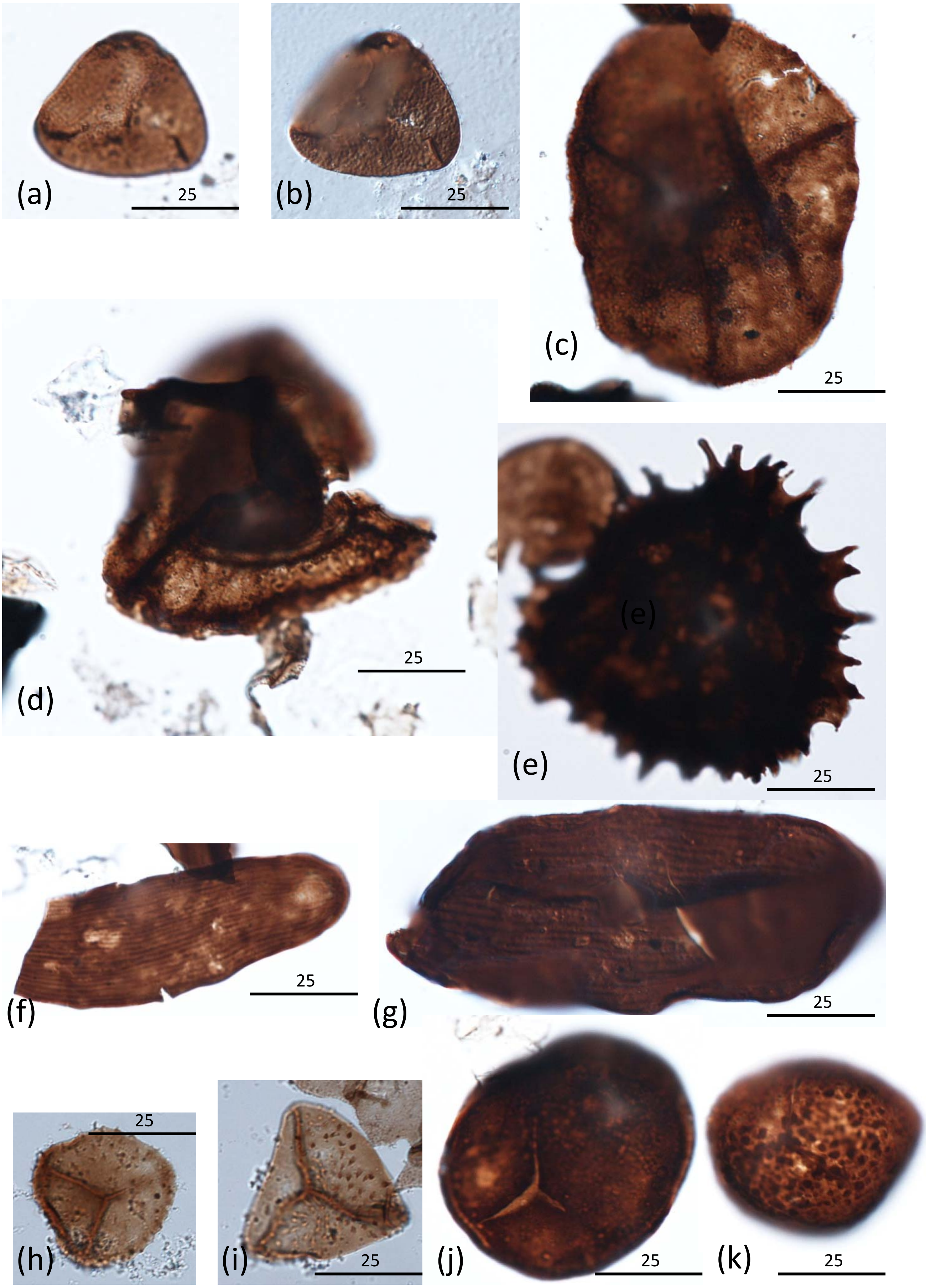

Plate 2