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TWO NEW NON-HAPTOTYPIC PALYNOMORPH TAXA FROM THE MIDDLE PERMIAN UPPER GHARIF MEMBER, OMAN

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Abstract. Two non-haptotypic palynomorph taxa, *Schizosporis*? *pennyi* n. sp. and *Tetraporina forbesii* n. sp., are described and illustrated from Subunit B of the Upper Gharif Member immediately underlying the base of the Khuff Formation at the northern Huqf outcrop, Oman. *Tetraporina forbesii* also occurs in heterolithic beds within the lowest part of the Khuff Formation in the Barik-36 oil well. The forms are assigned to the Wordian-Capitanian Oman and Saudi Arabia Palynological Biozone 6 (OSPZ6) on the basis of their occurrence with *Florinites*? *balmei*, and other taxa characteristic of OSPZ6. They were previously assigned to informal taxa and are likely freshwater zygospores, and their prevalence in the Subunit B section of the Upper Gharif Member may indicate impermanent stagnant ponds in a coastal plain or estuarine palaeoenvironment.

Riassunto. Vengono descritti e illustrati due taxa di palinomorfi non-haptotypici, *Schizosporis*? *pennyi* n. sp. e *Tetraporina forbesii* n. sp. Essi provengono dalla Subunit B del membro superiore della Formazione Gharif, immediatamente sottostanti la base della Formazione Khuff, nell'affioramento settentrionale di Huqf, Oman. *Tetraporina forbesii* si rinviene anche negli strati eterolitici entro la parte basale della Formazione Khuff nel pozzo Barik-36. Queste forme vengono riferite alla Biozona Palinologica 6 (OSPZ6) del Wordiano-Capitaniano in Oman e Arabia Saudita, in base alla co-presenza di *Florinites*? *balmei* e altri taxa caratteristici della OSPZ6. Essi venivano assegnati in precedenza a taxa informali, probabilmente quali zygospore di acqua dolce. La loro prevalenza nella Subunit B nel membro superiore della Gharif potrebbe indicare l'esistenza di pozze stagnanti non permanenti, in ambiente di piana costiera o di estuario.

Introduction

The value of spores and pollen from vascular land plants is well established in biostratigraphic studies, but their value as direct indicators of the immediate environment of deposition of the containing sediment is limited because they are mainly dispersed, and hence represent the ecologies of variably distant terrestrial hinterlands. However, Permian palynological assemblages also commonly contain palynomorphs without haptotypic features, which are unlikely to have been produced by vascular land plants (e.g. Stephenson et al. 2004). Many of these are similar to zygospores, spore-like propagules or other structures produced by modern aquatic green algae, which probably grew in water close to the site of deposition. Some of the forms, for example, the organic remains of supporting structures of cells, are identical to those of modern *Botryococcus*, a colonial green alga (Batten & Grenfell 1996); hence the name of the extant taxon is used for fossil examples. Other fossil forms recognised as identical to those found in modern lakes and ponds, for example zygospores of the filamentous algal genera *Spyrogyra*, *Mougeotia* and *Zygnema*, are recognised throughout the Phanerozoic. However fossil examples have different names; for example the fossil genera *Peltacystia* and *Lecaniella* are identical to the modern algal zygospore *Debarya* (van Geel 1979; van Geel & Grenfell 1996). Modern zygospores are almost exclusively freshwater aquatic in origin, and their fossil counterparts have been used by authors (e.g. van Geel 1976) to suggest freshwater, the assumption being that the taxa presently occupy the same habitat that they occupied in the geological past. As part of recent biostratigraphical appraisal of the Upper Gharif Member and its transition to the overlying Khuff Formation in Oman at the Huqf outcrop area and the Barik-36 oil well, large numbers of well-preserved non-haptotypic palynomorphs were recovered and within this population two distinct forms were present. These are described here for the first time.

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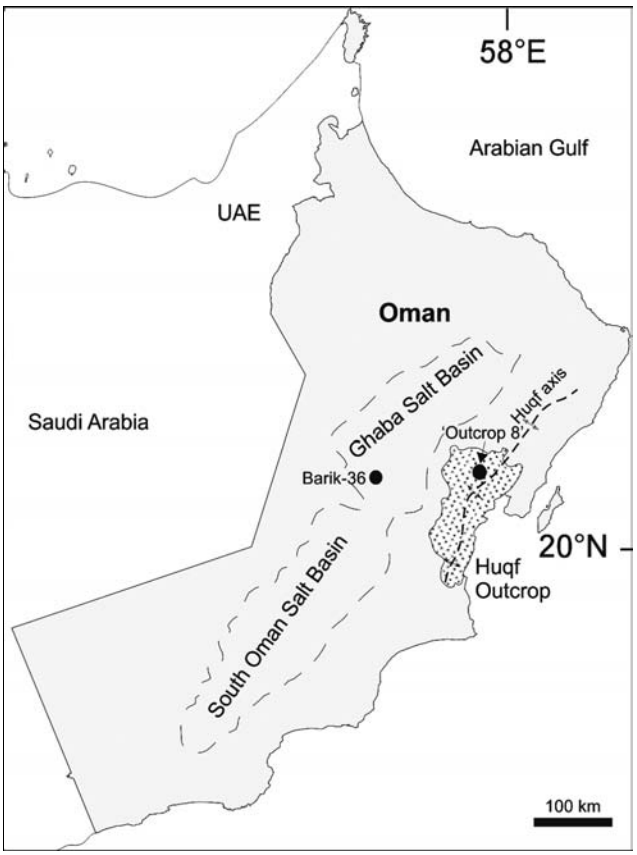

Fig. 1 - Location of the Barik-36 well, the Huqf outcrop area and 'Outcrop 8' of BRGM/TOTAL (1998).

Barik-36 well section

The Barik-36 oil well is cored through the Middle and Upper Gharif members and part of the Khuff Formation in the north-central Oman Barik Field (Fig. 1). Previous papers have documented the spore and pollen biostratigraphy of the section (Stephenson 2006, 2008). In this and other Barik Field wells, the Middle Gharif Member consists, toward the base, of palyniferous fluvial and lacustrine sandstone and mudstones succeeded by a thick stack of red palaeosols known as the 'Middle Gharif shale', which is palynologically barren. The Upper Gharif Member consists of similar fluvial facies interbedded with stacked palynologically-barren palaeosols that have a blocky gamma signature (Fig. 2).

Between 2698.6 and 2619.73 m are poorly- to moderately-preserved, low diversity assemblages that are dominated by bisaccate pollen including distally-taeniate bisaccate pollen (mainly *Distriatites* and *Hamiapollenites*). Spores such as *Indotriradites* spp. and *Playfordiaspora cancellosa* also occur, as well as distinctive monolete spores.

Between 2619.73 m and 2614.84 m in the borehole is a section consisting of heterolithic beds (directly overlain by the Khuff Formation carbonates) whose rich palynomorph assemblages are dominated by bisaccate pollen and cingulizonate spores (Fig. 2). Most assemblages also contain rare non-haptotypic palynomorphs. *Florinites*? *balmei* Stephenson & Filatoff, 2000 is common in this section, which allows it to be assigned to OSPZ6, of Wordian-Capitanian age (Stephenson 2006).

Huqf Outcrop area

A similar pre-Khuff Formation section is also present in the Huqf outcrop area (GPS coordinates E569999 N2324404; Fig. 1), approximately 100 km to the east of Barik-36. Seventeen samples from a short vertical section (1.6 m) of dark mudstones at 'Outcrop 8' (of BRGM/TOTAL 1998; Fig. 3 and 4), a few metres the below heterolithic beds overlain by the Khuff Formation carbonates yielded abundant non-haptotypic palynomorphs, but relatively fewer allochthonous hinterland spores and pollen. However *Florinites*? *balmei*, is common at two levels and *Indotriradites mundus* Stephenson, 2008 is present indicating similarity with the immediate pre-Khuff Formation section in Barik-36. The mudstones are within the 'floodplain facies' of Subunit B of BRGM/TOTAL (1998; see also Angiolini et al. 2004) considered to represent 'swamp claystone' and crevasse splay deposits within an extensive estuarine and floodplain system (Broutin et al. 1995; Berthelin et al. 2003). These mudstones also yielded the 'Gharif Palaeoflora' of Broutin et al. (1995).

Materials and methods

The preparation of strew mounts for palynological analysis involved well-established procedures of crushing followed by hydrochloric and hydrofluoric acid treatments (Wood et al. 1996). Post-hydrofluoric acid organic residues were oxidized with Schulze's Solution (70% HNO3 supersaturated with KClO3). All specimens, except where otherwise noted, are held in the collection of the British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK.

Systematic palaeontology

Genus *Schizosporis* Cookson and Dettmann, 1959

Schizosporis? pennyi n. sp.

Pl. 1, figs 1-25

2006 *Micrhystridium* sp. A Stephenson, pl. 1, fig. 5, 6 [no description]

Holotype: Pl. 1, figs. 10-11.
Paratype: Pl. 1, figs. 3-4.
Type locality: Huqf outcrop area 'Outcrop 8' of BRGM/TOTAL (1998) GPS coordinates E569999 N2324404.

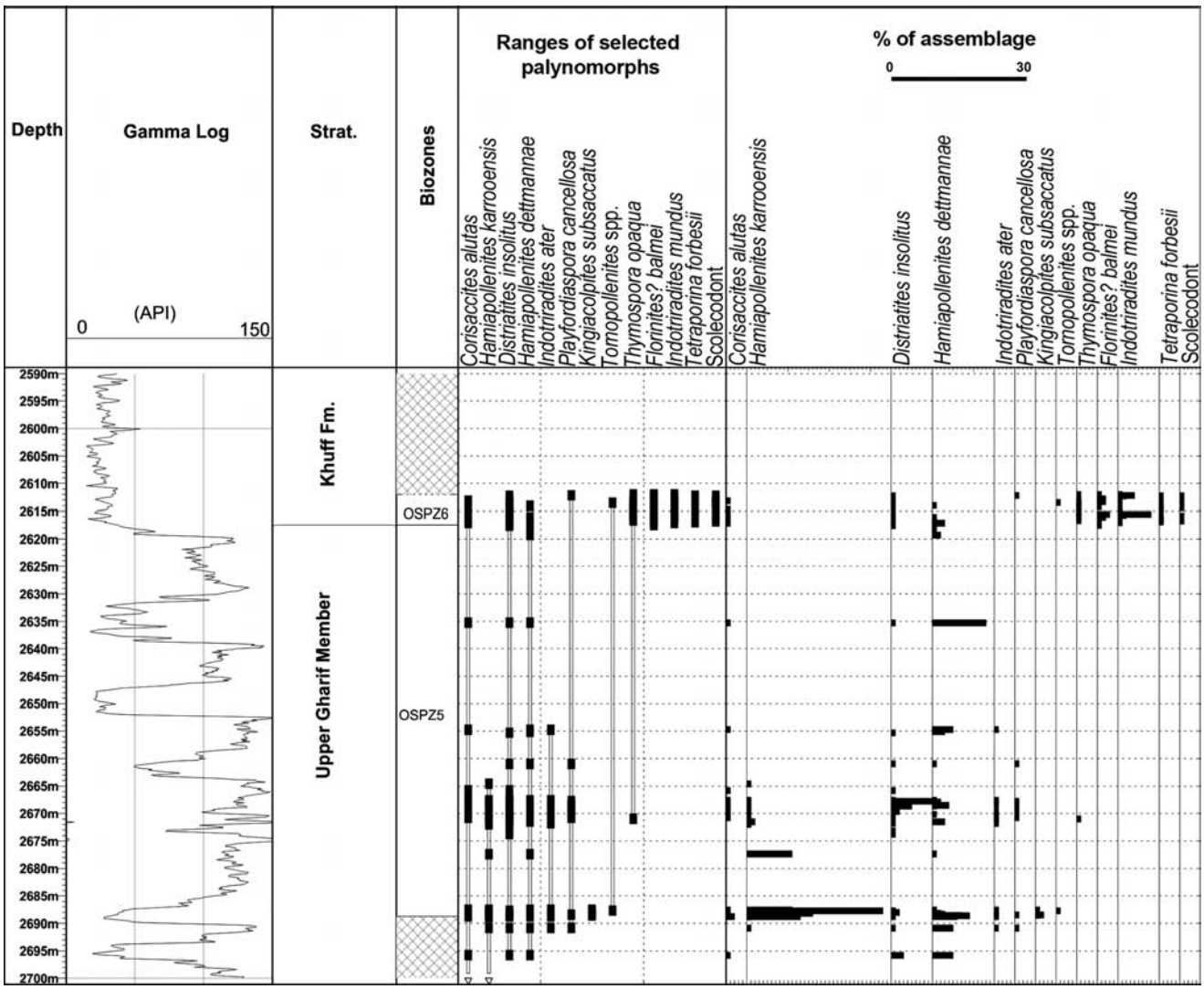

Fig. 2 - Stratigraphy and ranges of selected palynomorphs in Barik-36.

Derivation of name: After Petroleum Development Oman palynologist Randall Penney.

Description. Palynomorph; amb circular or oval but in three dimensions oblate or spheroidal, splitting equatorially into two saucer-shaped symmetrical halves. Single detached halves are most common but occasionally both are preserved partially or completely attached. The edge of each half ('equatorial margin' using the terminology of Head, 1992) is thickened slightly into a rim 1 µm wide and splitting appears to occur in the narrow zone or cleft between the thickened rims when they are joined (e.g. Pl. 1, figs. 10, 11). The exine is single-layered though rare specimens show delicate plications that suggest that parts of the exine bear a thin outer perine-like layer that is variably adpressed to the main body. The exine of one of the two halves is comprehensively delicately ornamented with small (<1 µm wide and high) evenly spaced (2-5 µm apart) cones which are sometimes arranged in lines, while the other half appears to be more weakly ornamented. Thirty to fifty cones are present on the strongly ornamented half.

Dimensions. 32(37)50 µm; 30 specimens.

Remarks and comparison. Common at 'Outcrop 8' but absent from Barik-36 (Fig. 3).

Cookson and Dettmann (1959) diagnosed *Schizosporis* as '...microspores, medium to large, with an equatorial line or furrow along which a separation into two approximately equal parts takes place'. The sparse apiculate ornament of the present taxon may not be entirely consistent with the concept of *Schizosporis* and thus it is only tentatively assigned there.

Though the present specimens have a distinct equatorial line or furrow, they also have characteristics of *Peltacystia* Balme and Segroves, 1966 and *Lecaniella* Cookson and Eisenack, 1962. Balme & Segroves (1966) diagnosed *Peltacystia* as oblate or spheroidal with an equatorial line of weakness, but also referred to each half as having a polar and equatorial zone demarcated

by a circumpolar ridge or ring of sculptural processes about half way between the pole and the equator. The present specimens have only a weakly developed linear pattern of cones visible in only a minority of specimens and this line is closer to the equator than to the pole. The specimens also lack the more elaborate circumpolar ridges and rings of processes that for example characterise *P. venosa* Balme and Segroves, 1966, *P. monile* Balme and Segroves, 1966 and *P. calvitium* Balme and Segroves, 1966. Head (1992) and Zavattieri and Prámparo (2006) commented on the difficulty of distinguishing *Lecaniella* and *Peltacystia*, however the former appears to have a single circumpolar ridge and is clearly more coherently and strongly sculptured than the present taxon.

Various authors, e.g. van Geel (1979), van Geel & Grenfell (1996), Head (1992), Zippi (1998) and Zavattieri and Prámparo (2006) noted the similarities between fossil forms such as *Peltacystia*, *Lecaniella* and *Schizosporis* and modern algal zygospores, and there seems little doubt that they are freshwater algal in origin.

Previous records. Recorded informally by Stephenson (2006) as *Micrhystridium* sp. A from the Barik-36 well section because its ornament was originally considered spinose.

Genus *Quadrisporites* Hennelly 1958 emend. Potonié and Lele, 1961

Quadrisporites horridus Hennelly 1958 emend. Potonié & Lele, 1961

Pl. 2, figs 1-6

Remarks. This taxon is a common component of samples from 'Outcrop 8' of BRGM/TOTAL (1998) but is absent from Barik-36 (Fig. 3). Brenner & Foster (1994) considered *Q. horridus* to be similar to living crucigenoid species, and therefore freshwater in origin.

Genus *Tetraporina* Naumova emend. Lindgren

Remarks. Playford (1963) stated that *Tetraporina* is 'rather an unsatisfactory taxon, in that the supposedly diagnostic four 'pores' are often either incompletely or not developed...'. Lindgren (1980) emended the genus to include forms with or without an obvious dehiscence mechanism and with a single- or double-layered wall.

Tetraporina forbesii n. sp.

Pl. 2, figs 7-18

Tetraporina sp. A Stephenson, 2006; pl. 1, figs. 3, 4 [no description]

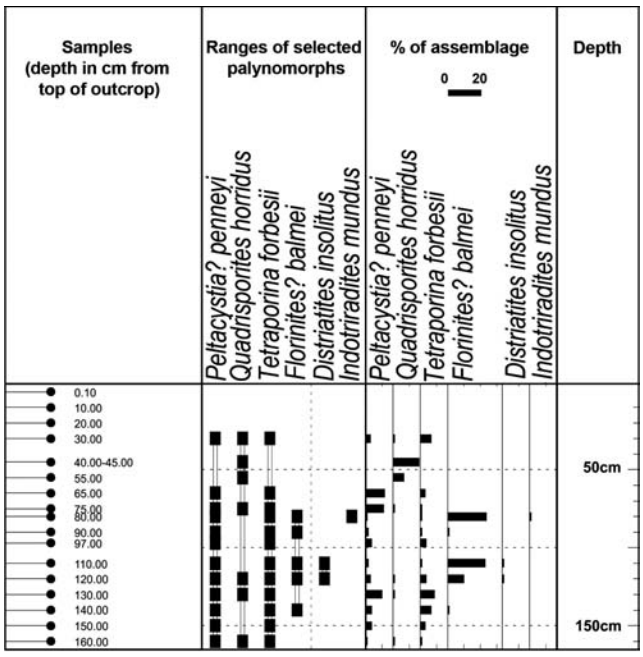

Fig. 3 - Stratigraphy and ranges of selected palynomorphs at 'Outcrop 8' of BRGM/TOTAL (1998).

Holotype: Pl. 2, figs. 7-8.

Paratype: Pl. 2, figs. 9-10.

Type locality: Huqf outcrop area 'Outcrop 8' of BRGM/TOTAL (1998) GPS coordinates E569999 N2324404.

Derivation of name: After Petroleum Development Oman palynologist Gordon Forbes.

Description. Palynomorph; amb rounded-square, rarely circular or pentagonal. Exine two layered; outer layer very thin, perine-like, punctate, adpressed only partially to the inner layer; elsewhere the outer layer is minutely and finely plicate. The outer layer often protrudes or appears slightly inflated close to pores or at a right angle margin in the underlying thicker exine layer. Inner layer thicker, laevigate, slightly thickened at the margins, sometimes spongeous in appearance where a pore appears to be present, or at a right angle margin. In many specimens a line of pits or a narrow cleft extends around the inner body very close to its margin (Pl. 2, figs. 9, 14).

Dimensions. 30(36)45 μm; 30 specimens

Remarks and comparison. Present at 'Outcrop 8' but rare in Barik-36 (Figs. 2 and 3).

Tetraporina forbesii differs from *T. incrassata* Naumova, 1950, *T. glabra* Naumova, 1950 and *T. horologia* (Staplin) Playford, 1963 in being two layered and in having a marginal line of pits or cleft, and in having variably expanded and spongeous regions often corresponding to the right angle margins of the inner body. *Tetraporina protrusa* Brenner and Foster, 1994 has very large expanded protrusions from the central rectangular body and well marked pores.

Fig. 4 - 'Outcrop 8' of BRGM/TOTAL (1998).

Brenner and Foster (1994) noted similarities between *Tetraporina* and specimens associated with the zygnematacean cysts of *Mougeotia*.

Previous records. Recorded informally by Stephenson (2006) as *Tetraporina* sp. A from the Barik-36 well section.

Palaeoecology

The palaeoenvironment and palaeoecology of the Upper Gharif Member Subunit B of BRGM/TOTAL (1998; see also Berthelin et al. 2006) are well known from several studies (Berthelin et al. 2003, 2006; Broutin et al. 1995; Angiolini et al. 2004). The deposits are interpreted '...as the infill of a large valley by a system of coalescent and sandy estuarine point-bars...' (Berthelin et al. 2006), on which a rich flora of Gondwanan glossopterids and lycopsids, Euramerican conifers, and Cathysian gigantopterids, lycopsids and Noeggerathiales grew. The argillaceous parts of Subunit B, in which the freshwater non-haptotypic palynomorphs described here are common, were considered by Broutin et al. (1995) to represent 'swamp claystone' and crevasse splay deposits suggesting impersistent and stagnant water bodies. The abundance of the freshwater non-haptotypic palynomorphs is probably due to zygospore production to survive periods of desiccation. The modern 'pondweed' zygnemataceaen alga *Spirogyra*, for example, produces zygospores that are composed of a tough substance similar to the sporopollenin, of which spores and pollen are composed (van Geel & Grenfell 1996). The zygospore can withstand considerable drying, but on the reappearance of freshwater – and immersion – it germinates and a new filamentous algal chain develops. Thus the zygospore allows the alga to survive periods of desiccation. The algal spores described here are morphologically similar to extant zygospores hence their prevalence in the Subunit B section may reflect impermanent stagnant ponds in a coastal plain or estuarine palaeoenvironment.

The yield of palynomorphs in the beds immediately below the Khuff Formation in Barik-36 well appears to be controlled partly by pedogenesis (see Stephenson 2008). The argillaceous sediments that are probably the equivalent of the 'swamp claystone' and crevasse splay deposits of Subunit B are largely barren of palynomorphs, and only the heterolithic beds 1-2 m above yield rich assemblages. This might reflect the more landward palaeo-position of the Barik-36 section since the sea that deposited the Khuff Formation transgressed from east to west (Konert et al. 2001). The few freshwater non-haptotypic palynomorphs that are present (e.g. *T.? forbesii*, Fig. 2) were probably washed in by rivers draining the nearby coastal plain.

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PLATE 1

Specimen locations are given first by the England Finder coordinate, then by BGS collection number (MPA, MPK), then by slide number. Scale bar for all figures equals 30 µm.
Schizosporis? *pennyi* n. sp.

Fig. 1 - MPA 52571, MPK 14160, D33/3, high focus, a single separated half;
Fig. 2 - MPA 52571, MPK 14160, D33/3, low focus;
Fig. 3 - MPA 52571, MPK 14161, E41/2, high focus, a single separated half;
Fig. 4 - MPA 52571, MPK 14161, E41/2, low focus;
Fig. 5 - MPA 52571, MPK 14162, E41;
Fig. 6 - MPA 52571, MPK 14163, E50, high focus, a single separated half;
Fig. 7 - MPA 52571, MPK 14163, E50, low focus;
Fig. 8 - MPA 52571, MPK 14164, E50, high focus, a single separated half;
Fig. 9 - MPA 52571, MPK 14164, E50, low focus;
Fig. 10 - MPA 52571, MPK 14165, F31/3, high focus, a single separated half, ridge present lower right;
Fig. 11 - MPA 52571, MPK 14165, F31/3, low focus,
Fig. 12 - MPA 52571, MPK 14166, J52;
Fig. 13 - MPA 52571, MPK 14167, J50/4, high focus, a single separated half;
Fig. 14 - MPA 52571, MPK 14167, J50/4, low focus;
Fig. 15 - MPA 52571, MPK 14168, J36/4, high focus, a single separated half;
Fig. 16 - MPA 52571, MPK 14168, J36/4, low focus;
Fig. 17 - MPA 52571, MPK 14169, J26/3, two halves together.
Fig. 18 - MPA 52571, MPK 14170, M48/1, two halves together, high focus;
Fig. 19 - MPA 52571, MPK 14170, M48/1, low focus;
Fig. 20 - MPA 52571, MPK 14171, M47/2, two halves together, high focus;
Fig. 21 - MPA 52571, MPK 14171, M47/2, low focus;
Fig. 22 - MPA 52571, MPK 14172, M43/3, two halves together, high focus;
Fig. 23 - MPA 52571, MPK 14172, M43/3, low focus;
Fig. 24 - MPA 52571, MPK 14173, N41/1, two halves together, high focus;
Fig. 25 - MPA 52571, MPK 14173, N41/1.

PLATE 2

Scale bar for all figures equals 30 µm.

Figs 1-6 - *Quadrisporites horridus*.
1) MPA 52579, MPK 14174, M40; 2) MPA 52579, MPK 14175, D50; 3) MPA 52579, MPK 14176, D26/4; 4) MPA 52579, MPK 14177, M33/2; 5) MPA 52579, MPK 14178, L33/2; 6) MPA 52579, MPK 14179, J34.

Figs 7-18 - *Tetraporina forbesii* n. sp.
7) MPA 52572, MPK 14180, D50/1, high focus, showing expanded spongeous exine at the four right angles of the inner body; 8) MPA 52572, MPK 14180, D50/1, low focus; 9) MPA 52572, MPK 14181, D24/3, high focus, showing delicate expanded perine at the four right angles of the inner body; 10) MPA 52572, MPK 14181, D24/3, low focus; 11) MPA 52572, MPK 14182, E25/3; 12) MPA 52572, MPK 14183, O37, showing irregular perine detachment from the inner body; 13) MPA 52572, MPK 14184, O38, showing expanded perine; 14) MPA 52572, MPK 14185, P53/1, showing very delicate expanded perine at the four right angles of the inner body; 15) MPA 52572, MPK 14186, O34/3, showing expanded perine at upper right and lower left; 16) MPA 52572, MPK 14187, O25/4, showing delicate expanded perine at the four right angles of the inner body; 17) MPA 52572, MPK 14188, U26/4, showing unexpanded plicate perine; 18) MPA 52572, MPK 14189, W30/4, showing unexpanded plicate perine.

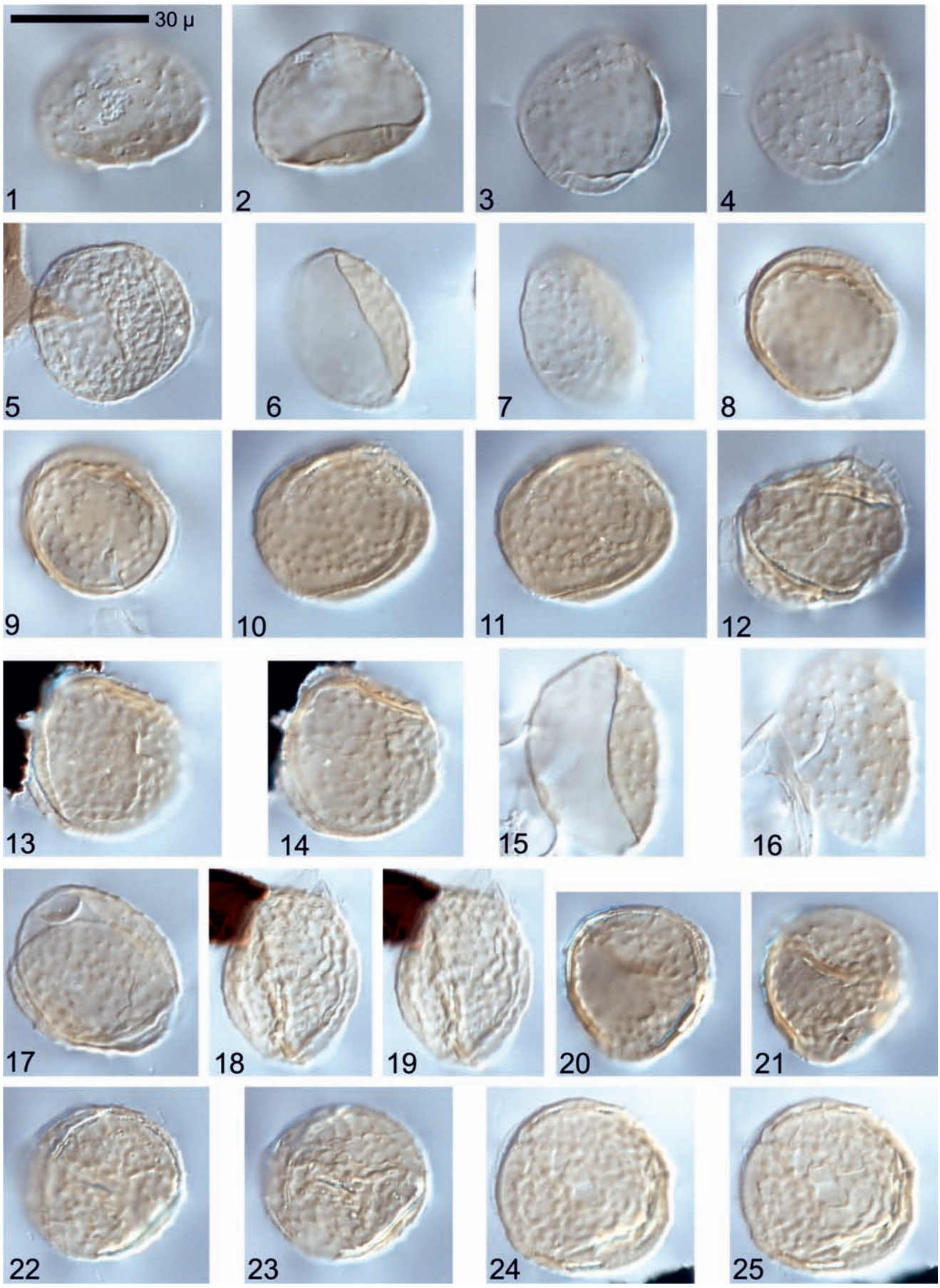

PLATE 1

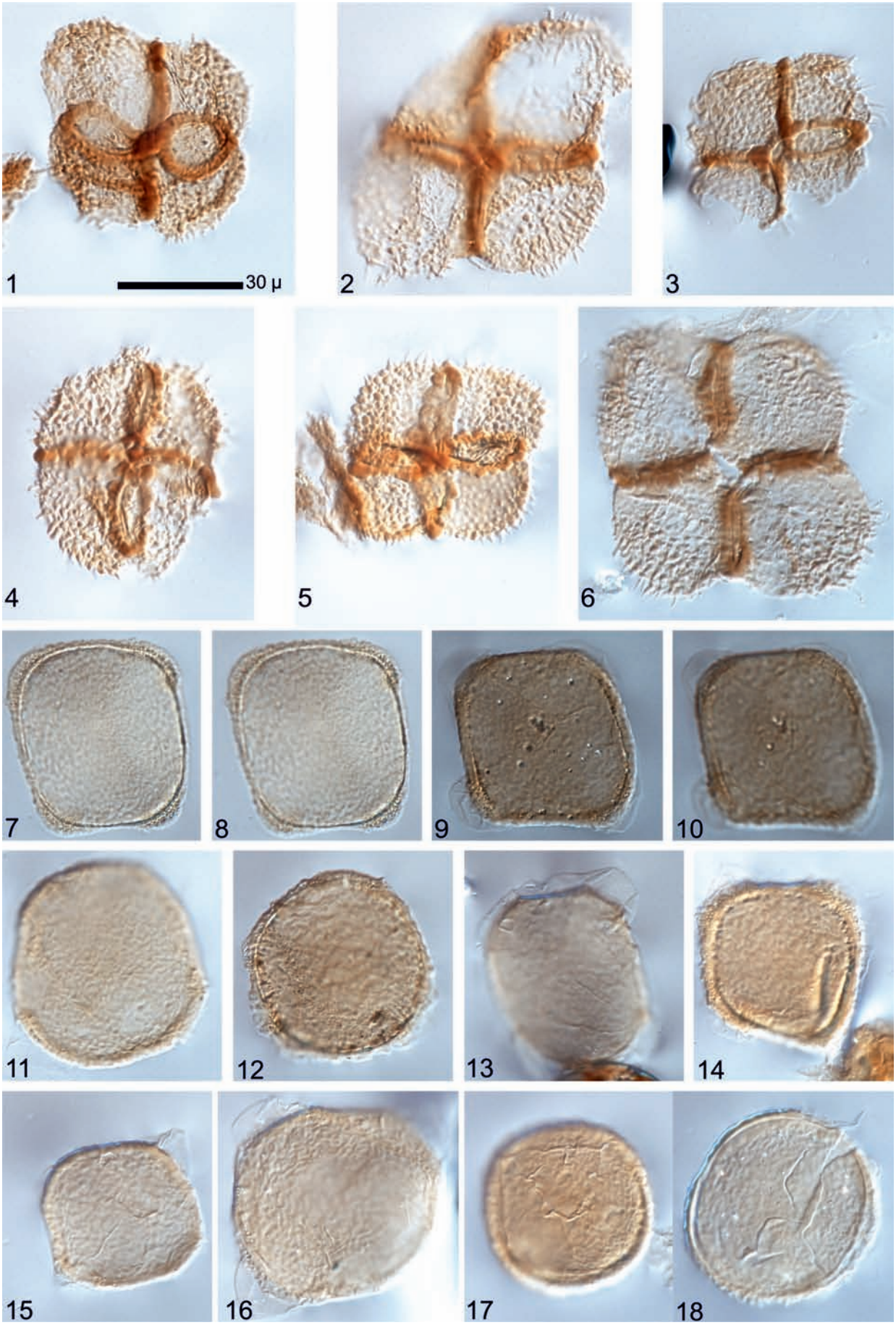

PLATE 2

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