Bisaccate pollen from the Early Permian OSPZ3a Sub-Biozone of the Lower Gharif Member, Oman

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Abstract

The OSPZ3a Sub-Biozone, associated with the lowest part of the Lower Gharif Member, is part of biozonal scheme that was intended to unify the palynological schemes across Arabia. This paper describes and illustrates the main bisaccate pollen taxa from the OSPZ3a Sub-Biozone of the Well A cored well, Oman, between 2842.69 and 2852.82 m, where they are unusually well preserved. *Pteruchipollenites indarraensis* which is the most common bisaccate pollen taxon, reaching 40 to 50% of assemblages, is here placed in synonymy with *Alisporites tenuicorpus* Balme, 1970, the latter being its junior synonym. *Striatopodocarpites cancellatus* consistently first occurs in the OSPZ3a Sub-Biozone, and well-preserved specimens are present in Well A, but Arabian specimens appear to have a wider range of morphology, mainly in the arrangement of taeniae, than the type material. The relationship of the genus *Striatopodocarpites* to *Verticipollenites* Bharadwaj, 1962, *Lahirites* Bharadwaj, 1962 and *Hindipollenites* Bharadwaj, 1962 is also examined with the result that *Striatopodocarpites* is asserted as the senior synonym. The taeniate bisaccate pollen *Hamiapollenites fusiformis* Marques-Toigo, 1974 is unusually common in the Well A

assemblages and its morphology is found to be distinct from the similar multi-taeniate bisaccate taxon *Striatoabieites multistriatus* (Balme and Hennelly) Hart, 1964, with which it is sometimes placed in synonymy.

Key words:

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1. Introduction

The Gharif Formation (the upper formation of the Haushi Group, Hughes Clarke, 1988) overlies the Al Khlata Formation both disconformably and conformably and is in turn overlain conformably by the marine carbonates and marginal marine to non-marine ‘red-bed’ clastics of the Khuff Formation (Osterloff et al., 2004). The formation is subdivided into 3 members: the Lower, Middle and Upper Gharif members, using subsurface sections (Forbes et al., 2010; Fig. 1). In South Oman, the lower part of the Lower Gharif Member is a complex of fluvial and fluviodeltaic clastics succeeded by marginal marine clastics toward the top; while in North Oman similar lower clastics give way to bioclastic limestone, known locally as the Haushi limestone (Fig. 1). The surface equivalent of the Lower Gharif Member was termed the Saiwan Formation by the Bureau de Recherches Géologiques et Minières (BRGM) (Dubreuilh et al., 1992; Platel et al., 1992; Roger et al., 1992). The Middle Gharif Member is a sequence of marginal marine clastics overlain by lacustrine and fluvial units, capped by stacked palaeosols (the ‘Playa Shale’ sensu Guit et al., 1995), deposited in a semi-arid climate. Lying unconformably above the Middle Gharif Member is the Upper Gharif Member. The upper part of this clastic unit contains abundant plant remains (Broutin et al., 1995) in the outcrops of the Northern Huqf area.

Age determinations for the Lower Gharif member rely mainly on macropaleontological dates from the Haushi Limestone. Miller and Furnish (1957) and Hudson and Sudbury (1959) suggested Mid Permian and Sakmarian-Artinskian ages respectively for fauna from the Haushi limestone. More recent foraminiferal evidence (Angiolini et al., 2006) suggests a Sakmarian age for the Haushi limestone, providing an upper age limit for the Lower Gharif Member.

2. OSPZ3a

The OSPZ3a Sub-Biozone, is part of biozonal scheme that was intended to unify the palynological schemes across Arabia (Stephenson et al., 2003). The OSPZ3a Sub-Biozone is succeeded by the OSPZ3b and OSPZ3c sub-biozones. Compared with the other biozones of the OSPZ scheme, the three sub-biozones are smaller in scale and somewhat localised in geographical extent, and appear not to be recognisable throughout Arabia either due to palaeophytogeographical variation or hiatus.

The base of OSPZ3a Sub-Biozone is marked by the most distinct palynological discontinuity in the Lower Permian section, which corresponds closely to the transition between the Rahab Shale Bed of the Al Khlata Formation and the Lower Gharif Member, and may also be linked with post-glacial climatic change (Stephenson and Osterloff, 2002; Stephenson et al., 2005). The base is defined by the abrupt increase of the small non-taeniate bisaccate pollen *Pteruchipollenites indarraensis* from approximately 10 to 50 or 60% of assemblages. This increase is accompanied by an increase in coarsely ornamented forms of *Cristatisporites* (to a maximum of approximately 4% of assemblages)**.** Other taxa that occur first consistently in OSPZ3a Sub-Biozone are the taeniate bisaccate pollen *Striatopodocarpites cancellatus* and *S. fusus*, and the taeniate 'circumstriate' pollen taxa such as *Circumstriatites talchirensis* and *Striasulcites tectus*. The colpate pollen *Kingiacolpites subcircularis* is common throughout, occasionally reaching 50% of assemblages, but more typically 5-10% of assemblages. The base of OSPZ3b Sub-Biozone is defined by the first uphole appearance of the algal cyst *Ulanisphaeridium omanensis* Stephenson and Osterloff, 2002.

It is difficult to generalise about the relationship between the 2141C Biozone of Penney et al. (2008) and OSPZ3a, and there may be some overlap in character. However 2141C contains more common *Cycadopites cymbatus*, and coarsely ornamented triangular fern spores such as *Converrucosiporites grandegranulatus* and *Converrucosiporites* sp. A of Stephenson and Osterloff (2002) (see also Stephenson, 2004). 2141C is regarded as an approximate equivalent of the *Converrucosiporites* sp. A – *Microbaculispora grandegranulata* Biozone of Stephenson and Osterloff (2002).

This paper describes the main bisaccate pollen taxa from the OSPZ3a Sub-Biozone of the Well A cored well (Fig. 2) between 2842.69 and 2852.82 m (driller’s depths) within the Lower Gharif Member. Well A assemblages represent a typical post-glacial Lower Gharif Member flora. The simple bisaccate pollen may have been produced by upland plants, while the lowland may have been populated by colpate pollen-producing cycad-like plants (Stephenson and Osterloff, 2002; Stephenson et al., 2005). Spores of the Lower Permian succession have been described previously (Stephenson, 2004), but pollen have not, mainly because preservation is generally poor amongst the bisaccate pollen of the Lower Gharif Member. However the core of Well A yielded relatively well-preserved bisaccate pollen from the OSPZ3a Sub-Biozone, allowing this part of the palynological succession in Oman to be described and illustrated.

3. Materials and methods

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 oxidised with Schulze's Solution and dilute nitric acid. Slides are held in the collection of the British Geological Survey, Keyworth, Nottingham, NG12 5GG.

The terminology used is that of Punt et al. (1994) and Smith and Butterworth (1967). Maximum equatorial dimensions are given in microns (μm); and the scheme of dimensions as given in Fig 3. Previous records of taxa given here are not meant to be exhaustive, but to focus on Middle Eastern occurrences. Stratigraphical ages for these occurrences are those suggested by the respective authors.

4. Systematic palynology

Genus ***Pteruchipollenites*** Couper, 1958

Type species: *Pteruchipollenites thomasii* Couper, 1958.

Pteruchipollenites indarraensis (Segroves) Foster, 1979 (Plate I, 1–18)

1970 *Alisporites tenuicorpus* Balme; p. 394; pl. 15, figs. 1-4.

1988 *Pteruchipollenites* sp. 1 MacRae; p. 56-57; pl. 22, figs. 7-8, 11-13, 15-16, 18-19.

Description: Pollen bilaterally symmetrical, bisaccate, alete; amb haploxylonoid oval to slightly irregular due to flaccid sacci. Corpus latitudinally oval, circular or rarely longitudinally oval; intexine thin (<0.5µm); exoexine over corpus intexine infrareticulate. Cappula usually indistinct; when distinct, oval; margins sometimes imperceptible due to the similarity of corpus and saccus exine. Saccus inclination distal; proximal saccus detachment equatorial; distal saccus detachment 5-8µm in from the distal outer margin of the corpus. Sacci variable in size, usually with width 30% of the corpus width; crescentic in outline; flaccid; infrareticulation fine (brochi size less than 1µm in diameter).

Mean dimensions: (37 specimens): corpus width 36.8 µm; total length 34.26 µm; maximum offlap 7.05 µm; maximum onlap 10.06 µm; total width 51.11 µm.

Remarks: The rapid uphole increase in the abundance of *P. indarraensis* is not recorded in the cored section of Well A and thus the base of the OSPZ3a Sub-Biozone is not present, but Figure 4 serves to indicate its abundance. Figure 5 shows the base of the OSPZ3a Sub-Biozone across the Rahab-2, Thuleilat-42 and 16, and Marmul-151 wells (data from Stephenson and Osterloff, 2002). Due to its delicacy, it is often poorly preserved. The preservation is poorer in the upper part of the Well A core, between 2842.69 and 2852.82 m (Fig. 4), with the result that many likely specimens of *P. indarraensis* were recorded as 'bisaccate pollen indeterminate' (Fig. 4). Poorly preserved specimens of *P. indarraensis* usually occur as detached sacci or corpi.

Pteruchipollenites indarraensis is similar to *Alisporites tenuicorpus* Balme, 1970, as noted by Foster (1979). *Alisporites tenuicorpus* is diagnosed as having minor distal saccus inclination and an oval cappula of width about half that of the corpus. *P. indarraensis* is diagnosed as having a parallel-sided cappula of width 1/5-2/3 the width of the corpus. Segroves' description of the cappula as parallel-sided is inconsistent, however, with the cappulae figured (Segroves 1969; pl. 6, figs. A-E), which are oval in outline.

A careful study of a large number of the present specimens has shown that the distally-inclined, flaccid sacci are compressed variably; sometimes inward toward the cappula, sometimes outward to expose the cappula. When the sacci are pushed inward, folding obscures the distal saccus roots and the cappula may appear to be narrow. When the sacci are pushed outward by compression the cappula is exposed and stretched sideways so that it may appear artificially wide. Furthermore, the similarity of saccus and corpus exine often makes the determination of saccus onlap and cappula shape difficult to discern.

In view of the fact that *P. indarraensis* and *A. tenuicorpus* are separated on minor size difference and cappula width (which may be influenced by preservation), it is suggested that the two species be placed in synonymy with *P. indarraensis* as the senior synonym.

Pteruchipollenites sp. 1 MacRae, 1988 is also synonymous with *P. indarraensis*.

Previous records: Iran, Permian (Chateauneuf and Stampfli, 1979); Africa, Permian (MacRae, 1988); Pakistan, Permian (Balme, 1970); Australia, Permian (Foster, 1979; Segroves, 1969); Middle East, Permian (Stephenson and Osterloff, 2002; Stephenson et al., 2003, 2005).

Genus ***Hamiapollenites*** Wilson emend. Tshudy and Kosanke, 1966

Type species: *Hamiapollenites saccatus* Wilson, 1962.

Hamiapollenites fusiformis Marques-Toigo emend. Archangelsky and Gamerro, 1979 (Plate II, 1–10)

Description: Pollen bilaterally symmetrical, bisaccate, monolete, dilete or trilete, taeniate; amb oval or diploxylonoid with very small sacci. Corpus oval, dark in colour; intexine thin, punctate. Cappa has approximately 9 taeniae of dense, dark-coloured exoexine separated by narrow (0.5µm wide) clefts which are floored by intexine. Taeniae parallel. Central striation deepened in the polar part of the cappa to form distinct monolete, dilete or rarely trilete mark. Sacci small (width <20% of the width of the corpus); situated at the latitudinal extremities of the corpus only; sacci distally inclined. Occasionally thin unexpanded exoexine occurs at the margin of the corpus in the longitudinal positions; unexpanded exoexine 1-3µm thick. Distal exine of the corpus ?laevigate, usually with 2 indistinct longitudinal folds or ?thickenings; thickenings masked by the thick cappa.

Mean dimensions: (7 specimens): total length 35.57 µm; maximum offlap 5.57 µm; saccus length 10.71 µm; total width 46.14 µm.

Remarks: Marques-Toigo (1974) did not refer to haptotypic features in her diagnosis, but the figured holotype and a paratype (Marques-Toigo 1974; pl. 3, fig. 9 (holotype), fig. 7 (paratype) clearly have a monolete mark.

The present species is very similar to *Hamiapollenites karrooensis* (Hart, 1963) Hart, 1964. The latter species differs, however, in having a smaller number of wider proximal taeniae and in lacking a haptotypic mark (see Stephenson, 2008). *H. bullaeformis* differs from the present species in having a single distal, longitudinal keel-like thickening (see Samoilovich, 1953). Foster and Waterhouse (1988) tentatively considered *Hamiapollenites fusiformis* to be synonymous with *Striatoabieites multistriatus* (Balme and Hennelly) Hart, 1964. Marques-

Toigo (1974) did not compare her species with *S. multistriatus*. Via the respective diagnosis and description (Marques-Toigo, 1974, p. 611; Balme and Hennelly, 1955, p. 93) comparisons are difficult to make. A visual comparison of the respective figured specimens (Marques-Toigo, 1974; pl. 3, figs. 7-10 (holotype fig. 9): Balme and Hennelly, 1955; pl. 2, figs. 16-20 (lectotype fig. 17, designated by Hart (1964) however, show that the corpus of *S. multistriatus* bears a larger number of narrower taeniae (approximately 20 taeniae in each of the 5 figured specimens) than does that of *H. fusiformis*. Balme and Hennelly (1955) did not specify the number of taeniae in their 'description', but Hart (1964) in his later 'diagnosis' specified 12-16 taeniae. Marques-Toigo (1974) diagnosed 9-12 taeniae for *H. fusiformis*. In addition, the figures appear to indicate that *H. fusiformis* has a generally darker and more clearly oval corpus than *S. multistriatus*, and bears longitudinal distal thickenings which are absent in *S. multistriatus*. *Hamiapollenites fusiformis* bears a haptotypic mark (usually monolete) which appears to be absent in the figured specimens of *S. multistriatus*.

Previous records: Uruguay, Early Permian (Marques-Toigo, 1974); Argentina, Permo Carboniferous (Vergel, 1987; Archangelsky and Gamerro, 1979, Césari et al., 1995); Middle East, Permian (Stephenson and Osterloff, 2002).

Genus ***Striatopodocarpites*** Sedova emend. Hart, 1964

Type species: *Striatopodocarpites tojmensis* Sedova, 1956.

1962 *Verticipollenites* Bharadwaj: p. 90-91; pl. 9, figs. 126-127, 129-136; pl. 10, figs. 137-139, 143-146; pl. 11, figs. 158-159; pl. 12, figs. 160, 162-165, 168-171, 173; pl. 13, figs. 177-178, 180, 186.

1962 *Hindipollenites* Bharadwaj: p. 92-93; pl. 10, figs. 141-142.

1962 *Lahirites* Bharadwaj: p. 91-92; pl. 11, figs. 152-153; pl. 12, fig. 172; pl. 13, figs. 181, 183, 188.

Remarks: The present author concurs with Hart (1964) in placing *Verticipollenites* Bharadwaj 1962, *Lahirites* Bharadwaj, 1962 and *Hindipollenites* Bharadwaj, 1962 in synonymy with the present genus. Hart (1964) did not give reasons for his synonymisation. An attempt will be made here to justify synonymisation.

Bharadwaj (1962) did not compare *Verticipollenites* with *Striatopodocarpites* but his comparison with other diploxylonoid taeniate pollen indicates that he believed *Verticipollenites* to be distinct because of the outline of the saccus which is ‘pitcher’ or flask-shaped (see Bharadwaj, 1962, text-fig. 9). The figure of the holotype of the type species, *V. secretus* (Bharadwaj, 1962; pl. 12, fig. 160), does not clearly show this feature and the sacci outlines in other figured specimens are similarly obscure. In the absence of definite evidence to suggest that saccate arrangement in *Verticipollenites* is distinct, the latter genus, which has no other distinguishing features, is considered a junior synonym of the present genus.

Bharadwaj (1962) asserted that *Hindipollenites* is distinct from *Verticipollenites* only in its intrapuncate ?corpus exine because it also has ‘pitcher’ or flask-shaped sacci. Generic differentiation based solely on minor corpus exine- taeniae exine differences is considered unsafe because these may be of secondary origin. As in the figured specimens of *Verticipollenites*, the figured specimens of *Hindipollenites* (Bharadwaj, 1962; pl. 10, figs. 141-142) do not clearly show "pitcher" or flask-shaped sacci and so *Hindipollenites* is similarly considered to be a junior synonym of *Striatopodocarpites*. *Lahirites* purportedly differs from *Striatopodocarpites* in lacking the latter's structured corpus exine. As has been suggested above, the present author considers such differences as possibly secondary in origin and for this reason considers *Lahirites* to be synonymous with *Striatopodocarpites*.

Striatopodocarpites cancellatus (Balme and Hennelly) Hart, 1964 (Plate III, 1–8; Plate IV, 1–3)

Description: Pollen, bisaccate, bilaterally symmetrical taeniate; amb diploxylonoid. Corpus distinct, circular, dark in colour; cappa 1-2µm thick, distinctly taeniate. Cappula distinct, narrow (20% of the corpus width), parallel sided; delineated by narrow distal intexinal folds. Cappa with approximately 8 taeniae; taeniae narrow (2-3µm wide), parallel or sub-parallel; extend the width of the corpus; striations between <1µm wide. Proximal saccus detachment equatorial; distal saccus detachment close to distal pole; sacci distally inclined. Sacci outline is semi circular; sacci coarsely infrareticulate (brochi 1-2µm wide); sacci flaccid.

Mean dimensions (5 specimens): total width 40 µm, total length 23 µm, corpus width 16 µm, saccus offlap 12 µm, saccus onlap 7 µm, cappula width 4µm.

Remarks: *Striatopodocarpites cancellatus* is the most common diploxylonoid multitaeniate bisaccate pollen occurring in OSPZ3a. Though most specimens fit well within the concept of the species as described by, for example, Balme and Hennelly (1955) and Foster (1979), some vary from that concept in two ways: in the form of taeniae, and in the development of rudimentary haptotypic marks. Although this is not discussed by Balme and Hennelly (1955) and Foster (1979) and other authors, Australian specimens of *S. cancellatus* tend to show rather regular, parallel taeniae. In a small proportion of Oman specimens, and also in Saudi Arabian and Yemeni specimens, the taeniae are discontinuous or only sub-parallel. Some Pakistan specimens of *S. cancellatus* from the Salt Range also show non-parallel taeniae (see Balme, 1970). There is a continuum between such specimens and those with regular, parallel taeniae, and thus it was not thought judicious to separate the two groups taxonomically. Arabian specimens of *S. cancellatus* also sometimes bear a disruption of the taeniae in the central part of the cappa, suggesting a rudimentary haptotypic mark, usually a monolete or dilete mark. Again such structures are not shown in illustrations of Australian specimens of *S. cancellatus*, nor are they mentioned in descriptions. In cases where monolete marks are clear (e.g. Plate IV, 4–5), such specimens are assigned to *Strotersporites* (see below).

*Previous records***:** Israel, Late Permian (Eshet, 1990); Saudi Arabia, Late Permian (Hemer, 1965); Iran, Late Permian (Chateauneuf and Stampfli, 1979, Ghavidel-syooki, 1997); Oman, Permian (Love, 1994; Broutin et al., 1995). Middle East, Permian (Stephenson and Osterloff, 2002; Stephenson et al., 2003).

Genus ***Strotersporites*** Wilson emend. Klaus, 1963

Type species: *Strotersporites communis* Wilson, 1962.

Remarks: Klaus' (1963) emendation of *Strotersporites* Wilson created a useful category for monolete/dilete, taeniate, bisaccate grains otherwise similar to *Striatopodocarpites* Sedova emend. Hart, 1964.

Strotersporites indicus Tiwari, 1965 (Plate IV, 4–5)

Description: Pollen bilaterally symmetrical, bisaccate, monolete or dilete, taeniate; amb latitudinally elongate haploxylonoid. Corpus oval or barrel-shaped. Longitudinal margins of the corpus often flat and concordant with the longitudinal extremities of the sacci so that the grain overall has flat parallel longitudinal extremities. Intexine relatively thick <1μm; expanded infrareticulate exoexine occurs on the taeniae and in irregular patches on the corpus. Cappula distinct, parallel-sided or rarely fusiform; bounded by two distal intexinal folds marking distal saccus detachment zones. Intexinal folds lunate in shape ~10 µm wide in the central part of the corpus. Width of cappula about 40% of the corpus width. 7- 11 proximal taeniae occur, 3-7 µm wide, separated by narrow (1-2 µm wide) striations. Longitudinal extremities of corpus have narrower, convergent taeniae. Proximal saccus detachment equatorial; distal saccus detachment close to distal pole. Sacci distally inclined; outline greater than semi circular; robust, joined at the longitudinal extremities of the corpus by thin strips of expanded exoexine. Saccus infrareticulation coarse (brochi 1-2 µm, elongate, radially arranged on distal side close to the corpus edge). Monolete mark large, distinct, straight or geniculate; situated between the central two taeniae; length 50-80% of the corpus width; intexine of corpus visible along the commissures. Rarely a dilete mark or asymmetrical trilete mark is present.

Mean dimensions: (14 specimens): corpus width 44.78 µm; total length 51.64 µm; maximum offlap 17.36 µm; maximum onlap 16.64 µm; total width 78.36 µm.

Remarks: The present specimens show a wider range of variation than that permitted by Tiwari (1965). Tiwari allows 4-8 striations (=5-9 taeniae) whereas the present specimens have between 7 and 11 (mean 8) taeniae. The specimens of Tiwari (1965) are also considerably larger. These differences however are not considered to justify further separation.

Rare specimens have a large dilete or asymmetrical trilete mark which is similar to the "type 3" branching striation described by Jizba (1962) in specimens of *Complexisporites polymorphus* Jizba, 1962. The mark in the present specimens, however, is never associated with a circumpolar striation as in the latter species. Small specimens of the present species with poorly preserved corpi are however difficult to distinguish from *C. polymorphus*.

*Previous records***:** Libya, Ghzelian-Early Asselian (Loboziak and Clayton, 1988); India, Early Permian (Tiwari, 1965); Middle East, Permian (Stephenson and Osterloff, 2002).

Genus ***Protohaploxypinus*** Samoilovich emend. Morbey, 1975

Type species: *Protohaploxypinus latissimus* (Luber and Valts) Samoilovich 1953.
1962 *Faunipollenites* Bharadwaj: p. 95, text-fig. 12; pl. 17, figs. 220-228; pl. 18, figs. 229-234.

Remarks: Bharadwaj (1962) erected *Faunipollenites* to include taeniate, haploxylonoid pollen grains similar to *Protohaploxypinus* but with an ill-defined corpus and infrareticulate cappa. As defined, therefore, it appears to be similar to the type species of *Protohaploxypinus* Samoilovich 1953 (see Luber and Valts, 1941; pl. 13, fig. 221) and Samoilovich (1953; pl. 4, fig. 4) and presumably on this basis was rejected by Hart (1964).
Species of *Protohaploxypinus* in OSPZ3a consistently have thin, poorly defined corpi that make them very distinct from the diploxylonoid bisaccate pollen such as *Striatopodocarpites* which have smaller, darker, more distinct corpi.

Protohaploxypinus amplus (Balme and Hennelly) Hart, 1964 (Plate IV, 8)

Description: Pollen bilaterally symmetrical, bisaccate, alete, taeniate; amb oval to sub-rectangular, haploxylonoid. Corpus slightly elongate oval or circular; intexine thin. Cappa exoexine partly expanded, infrareticulate on the taeniae. Cappula parallel-sided to boat shaped, width about 50% of the corpus; delineated by a pair of distal intexinal folds. Approximately 8-10 latitudinal proximal taeniae occur; taeniae exoexine infrareticulate. Sacci distally inclined; proximal saccus detachment equatorial; distal saccus detachment close to distal pole. Sacci hemispherical in outline; appear to join adjacent to the longitudinal extremities of the corpus. Sacci robust; infrareticulation coarse, brochi 1-2µm in diameter.

Mean dimensions: (8 specimens): corpus width 72.25 µm; corpus length 72 µm; maximum offlap 22.37 µm; maximum onlap 24.87 µm; total width 109.25 µm.

Remarks: *Protohaploxypinus limpidus* (Balme and Hennelly) Balme and Playford, 1967 was considered by Balme and Hennelly (1955) to be distinct from *P. amplus* because of its smaller size and thinner, finely granulate body exine. Later workers (e.g. Powis, 1979; unpublished PhD thesis) have shown that the latter also has a larger number of taeniae.

Previous records: Iran, Permian (Ghavidel-syooki, 1997; Chateauneuf and Stampfli, 1979); Libya, Ghzelian-Artinskian (Brugman et al., 1985 (as *Striatoabietites amplus sic*); Gondwana, Permian (e.g. Balme and Hennelly, 1955; Bose and Kar, 1966; Balme and Playford, 1967; Foster, 1975; Backhouse, 1991; MacRae, 1988; Césari et al., 1995; Stephenson and Osterloff, 2002).

Protohaploxypinus limpidus (Balme and Hennelly) Balme and Playford, 1967 (Plate IV, 9)

Description: Pollen bilaterally symmetrical, bisaccate, taeniate, alete; amb oval haploxylonoid. Corpus latitudinally oval; intexine thin; taeniae exoexine partially infrareticulate. Cappula distinct, 5-10µm wide (approximately 10% of the width of the corpus); parallel-sided, extends the length of the corpus. Cappa with 5-8 taeniae; usually convergent, 3-14µm in width. Sacci strongly distally inclined with very narrow sacci connections at the longitudinal margins of the corpus. Sacci detached equatorially on proximal side of corpus, cappula margins mark the distal saccus detachment; saccus offlap dimension usually approximately equal to saccus onlap dimension. Sacci semicircular in outline, roughly the same size as the corpus; infrareticulation fine to coarse (0.5-2 µm brochi diameter).

Mean dimensions: (12 specimens): total width 69.33 µm; saccus offlap 14.83 µm; saccus onlap 14.42 µm; corpus width 43.67 µm; corpus length 50.83 µm; total length 51.67 µm.

Previous records: Iran, Permian (Ghavidel-syooki, 1997, Chateauneuf and Stampfli, 1979); Gondwana (e.g. Powis, 1979, Lindström, 1996, Backhouse, 1991; Stephenson and Osterloff, 2002; Stephenson et al., 2003).

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Figure captions

Fig. 1. Summary stratigraphy of the Carboniferous-Permian of Oman.

Fig. 2. Location of wells discussed in the text.

Fig. 3. Measurement and orientation scheme used for bisaccate pollen in this study, based on Segroves (1969).

Fig. 4. Quantitative character of bisaccate pollen assemblages in Well A, Oman.

Fig. 5. The base of the OSPZ3a Sub-Biozone across the Rahab-2, Thuleilat-42 and 16, and Marmul-151 wells (data from Stephenson and Osterloff, 2002).

Plate captions

Plate I. All figures with differential interference contrast (DIC) unless noted. Scale bar indicates 10 µm.

1–18. *Pteruchipollenites indarraensis*.

1. R36, MPA 51778 showing variable form of the cappula.
2. R36, MPA 51778 non-DIC.
3. Q35, MPA 51778.
4. P33/4, MPA 51778 non-DIC.
5. R33/2, MPA 51778 non-DIC.
6. Q29/2, MPA 51778 non-DIC, slightly oblique compression.
7. Q29, MPA 51778 non-DIC.
8. Q28/2, MPA 51778 non-DIC.

9. S29/1, MPA 51778 non-DIC, this specimen shows evidence of weak taeniae and may be transitional to *Protohaploxypinus limpidus*.

10. N28/3, MPA 51778 lateral compression non-DIC.

11. N28/2, MPA 51778 lateral compression non-DIC.

12. N28/2, MPA 51778 showing dense cappa.

13. M29/3, MPA 51778 non-DIC.

14. M29/3, MPA 51778.

15. K16, MPA 51778 non-DIC.

16. P8/1, MPA 51778 non-DIC.

17. F21/2, MPA 51778 non-DIC.

18. F21/2, MPA 51778.

Plate II. All figures with differential interference contrast (DIC) unless noted. Scale bar indicates 10 µm.

1–10. *Hamiapollenites fusiformis*.

1. J21/3, MPA 51777 proximal focus.

2. J21/3, MPA 51777 focus on distal saccus roots.

3. Q16, MPA 51777 proximal focus.

4. Q16, MPA 51777 focus on distal saccus roots.

5. Q21/1, MPA 51784 proximal focus.

6. Q21/1, MPA 51784 focus on distal saccus roots.

7. N22, MPA 51774 proximal focus.

8. N22, MPA 51774 focus on distal saccus roots.

9. P38, MPA 51795 non-DIC.

10. P38, MPA 51795.

Plate III. All figures with differential interference contrast (DIC) unless noted. Scale bar indicates 10 µm.

1–8. *Striatopodocarpites cancellatus*.

1. N27, MPA 51787 proximal focus.

2. N27, MPA 51787 focus on saccus.

3. S16, MPA 51787 proximal focus.

4. S16, MPA 51787 focus on saccus.

5. S12, MPA 51770 non-DIC.

6. S12, MPA 51770 focus on saccus.

7. M19/4, MPA 51790 proximal focus.

8. M19/4, MPA 51790 focus on distal saccus roots.

Plate IV. All figures with differential interference contrast (DIC) unless noted. Scale bar indicates 10 µm.

1–3. *Striatopodocarpites cancellatus*.

1. H9/1, MPA 51779 proximal focus.

2. H9/1, MPA 51779 focus on cappula.

3. H9/1, MPA 51779 focus on distal saccus roots.

4–5. *Strotersporites indicus*.

4. G35/2, MPA 51779.

5. G35/2, MPA 51779.

6–7. *Strotersporites* cf. *indicus*.

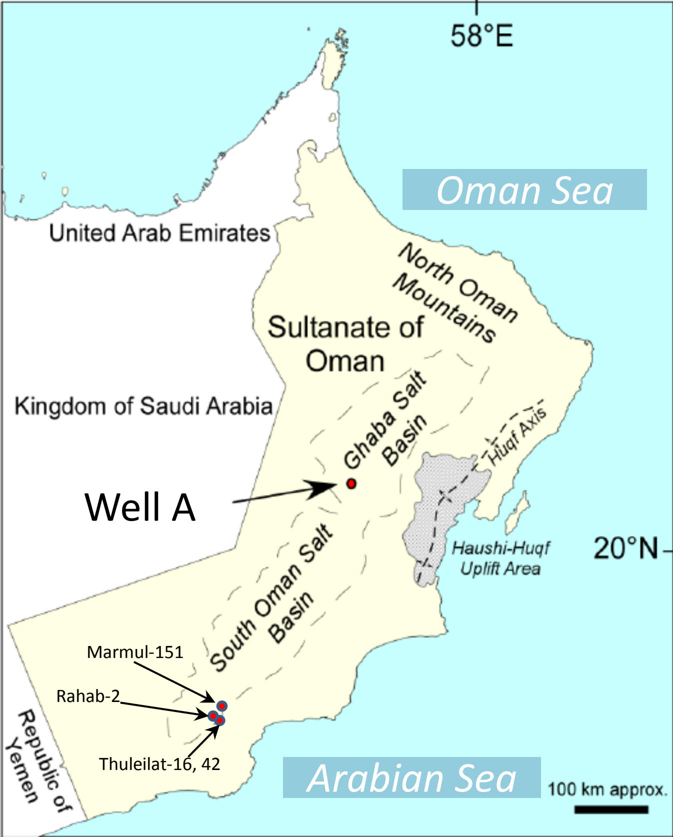
6. G35/1, MPA 51779 proximal focus.

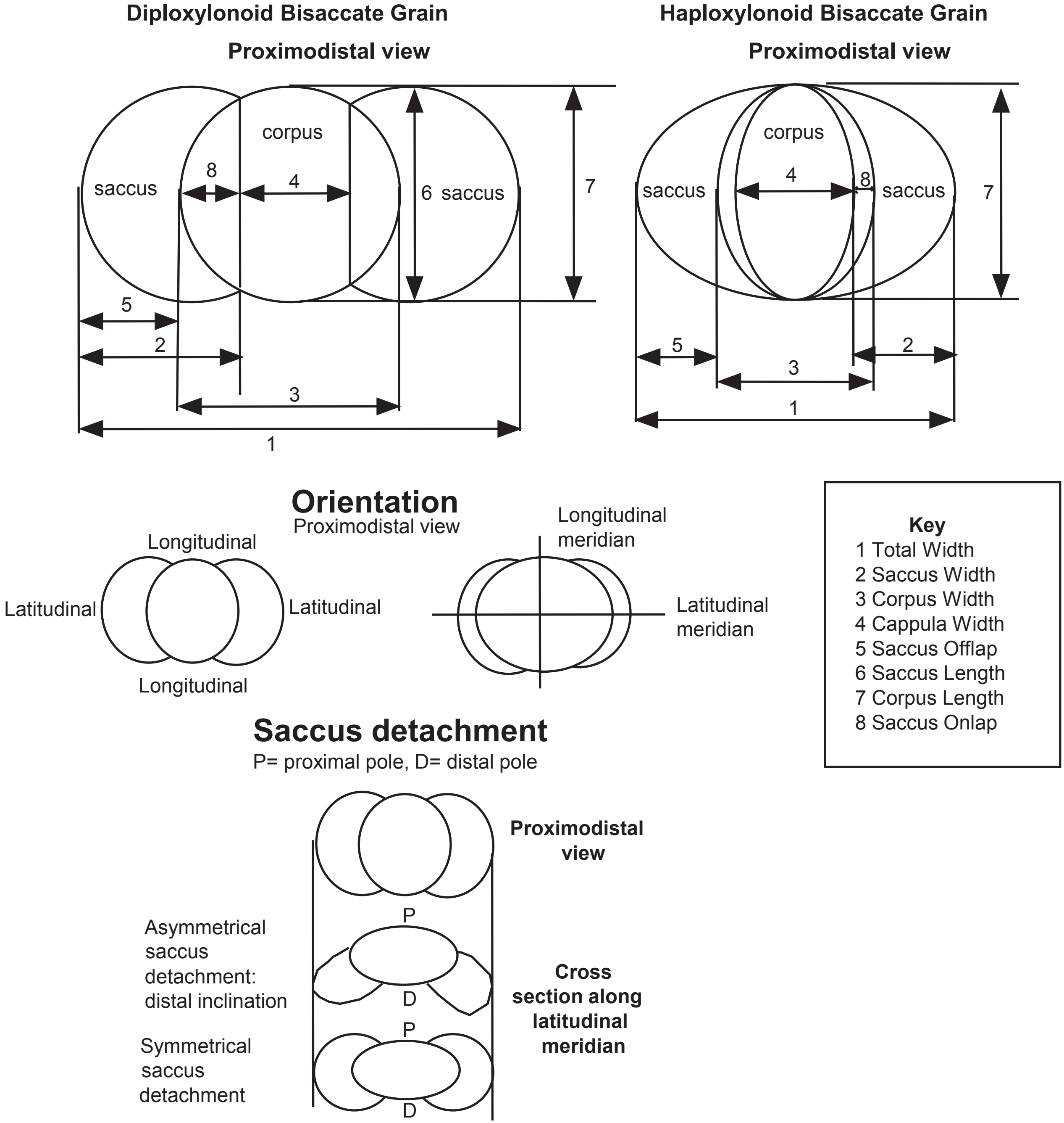
7. K23, MPA 51779 focus on folds at distal saccus roots.

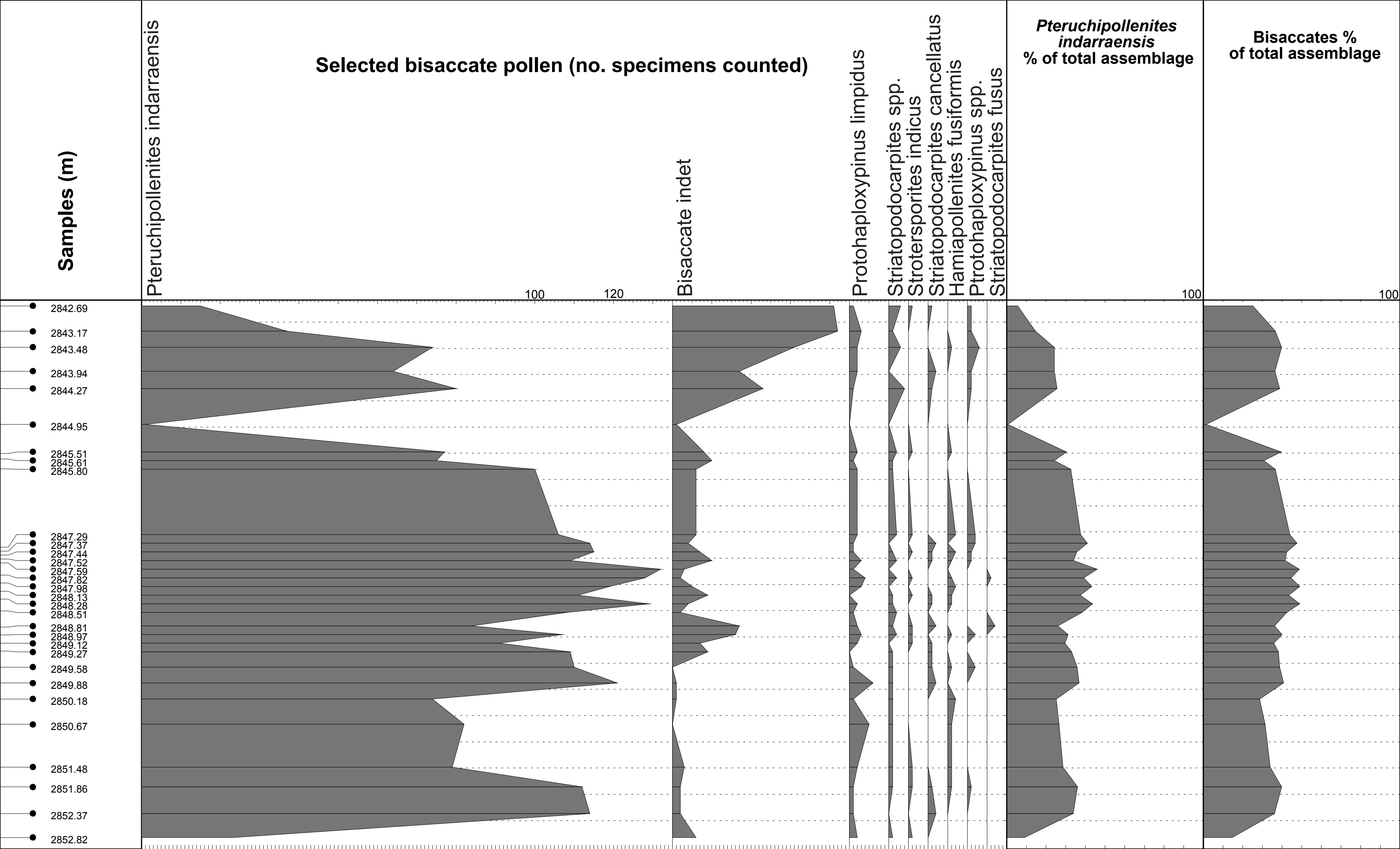
8. *Protohaploxypinus amplus*. F35/4, MPA 51779.

9. *Protohaploxypinus limpidus.* E27/4, MPA 51779.

Oman lithostratigraphic units: PDO usage		Oman lithostratigraphic units: BRGM usage	Chronostratigraphy		Palynostratigraphy, Stephenson et al., 2003		Palynostratigraphy, Stephenson and Osterloff, 2002	Palynostratigraphy, Penney et al., 2008
Khuff Formation (pars)		Khuff Formation (pars)	Capitanian	Guadalupian	OSPZ6			
			Wordian					
Gharif Formation	Upper Gharif Member	Gharif Fm.	Roadian		OSPZ5			
	Middle Gharif Member		Kungurian	Cisuralian	OSPZ4			
			Artinskian					
	Haushi limestone	Saiwan Fm.			OSPZ3	c		
						b	*U.omanensis* Biozone	
	Lower Gharif Member		Sakmarian			a	*P. indarraensis* Bz.	2141C
	Rahab Shale Bed	Al Khlata Formation			OSPZ2		*Conv.* sp. A – *M. grandegranulata* Bz.	2141B
Al Khlata Formation			Asselian/ Sakmarian				*M. tentula* Biozone ?	2141A
			?	Carb.?				2165B
								2165A
					OSPZ1			2159B
								2159A


58°E
Oman Sea
United Arab Emirates
North Oman Mountains
Sultanate of Oman
Kingdom of Saudi Arabia
Ghaba Salt Basin
Huqf Axis
Well A
Haushi-Huqf Uplift Area
20°N
South Oman Salt Basin
Marmul-151
Rahab-2
Thuleilat-16, 42
Republic of Yemen
Arabian Sea
100 km approx.


Diploxylonoid Bisaccate Grain
Proximodistal view
corpus
saccus
8
4
6 saccus
7
5
2
3
1
Haploxylonoid Bisaccate Grain
Proximodistal view
corpus
saccus
4
8
saccus
7
5
2
3
1
Orientation
Proximodistal view
Longitudinal
Latitudinal
Latitudinal
Longitudinal
Longitudinal meridian
Latitudinal meridian
Key
1 Total Width
2 Saccus Width
3 Corpus Width
4 Cappula Width
5 Saccus Offlap
6 Saccus Length
7 Corpus Length
8 Saccus Onlap
Saccus detachment
P= proximal pole, D= distal pole
Proximodistal view
P
D
Asymmetrical saccus detachment: distal inclination
Cross section along latitudinal meridian
P
D
Symmetrical saccus detachment


Samples (m)
Pteruchipollenites indarraensis
Selected bisaccate pollen (no. specimens counted)
Bisaccate indet
Protohaploxypinus limpidus
Striatopodocarpites spp.
Strotersporites indicus
Striatopodocarpites cancellatus
Hamiapollenites fusiformis
Ptrotohaploxypinus spp.
Striatopodocarpites fusus
Pteruchipollenites indarraensis % of total assemblage
Bisaccates % of total assemblage
100
120
100
100
2842.69
2843.17
2843.48
2843.94
2844.27
2844.95
2845.51
2845.61
2845.80
2847.29
2847.37
2847.44
2847.52
2847.59
2847.82
2847.98
2848.13
2848.28
2848.51
2848.81
2848.97
2849.12
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2849.58
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2850.18
2850.67
2851.48
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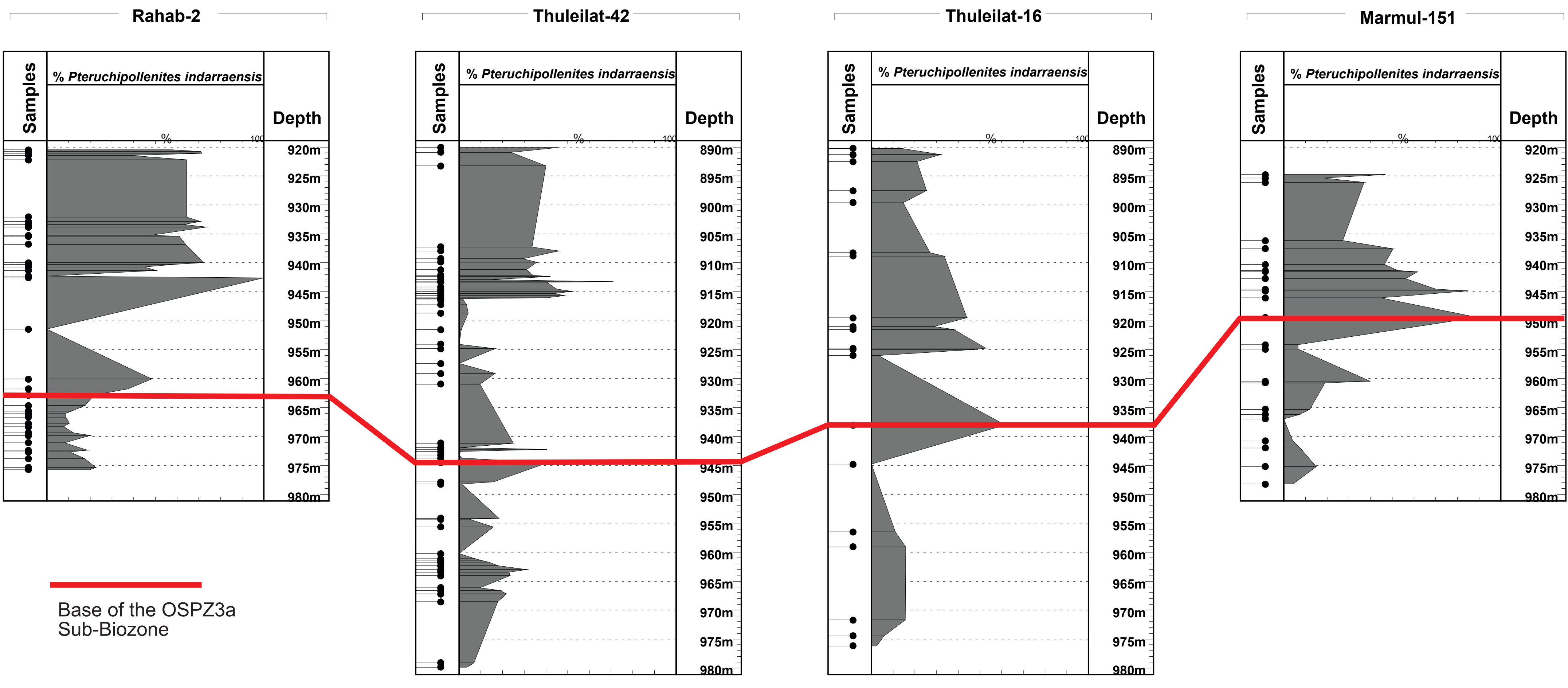
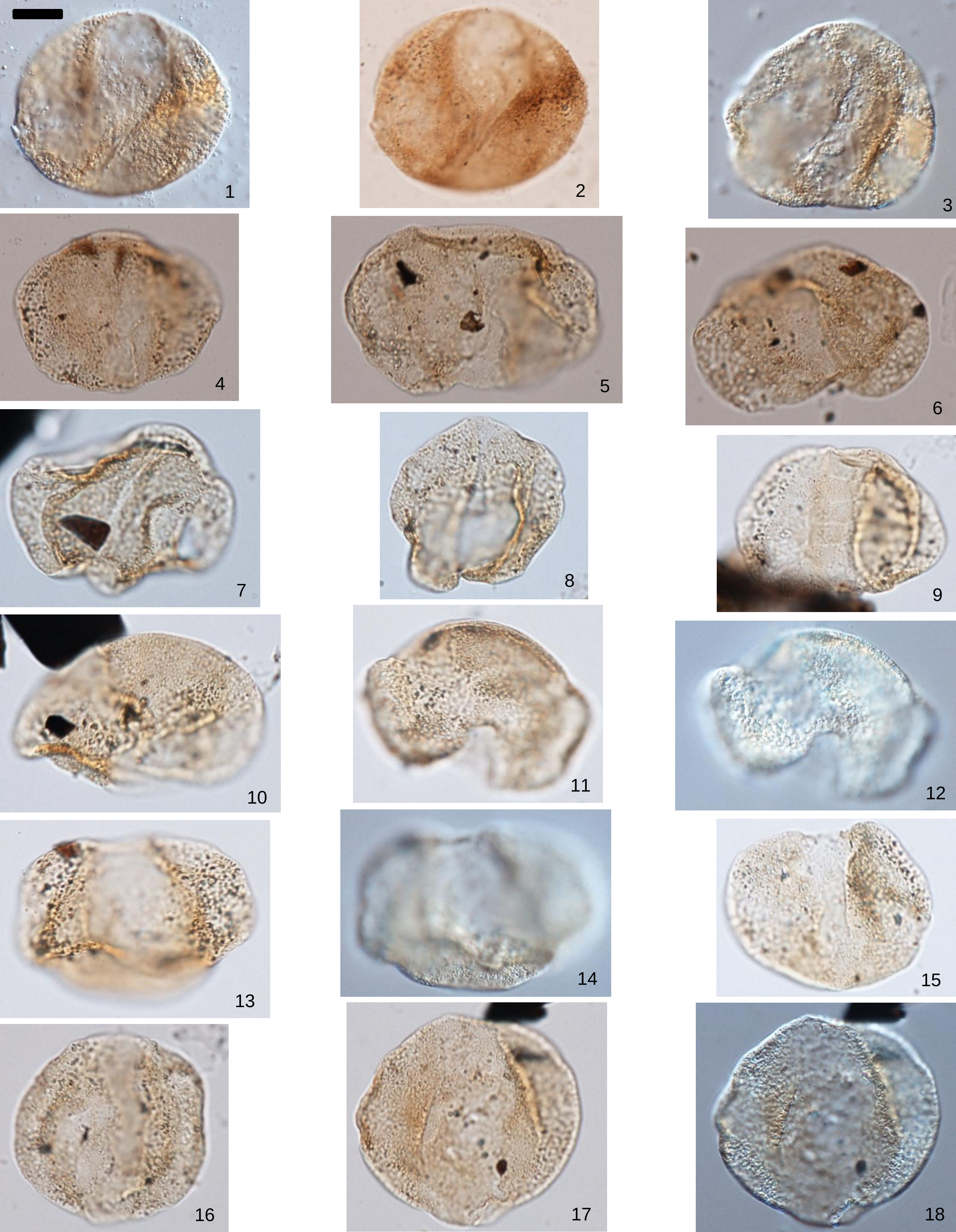
2852.37
2852.82



Rahab-2
Thuleilat-42
Thuleilat-16
Marmul-151
Samples
% Pteruchipollenites indarraensis
Depth
Base of the OSPZ3a
Sub-Biozone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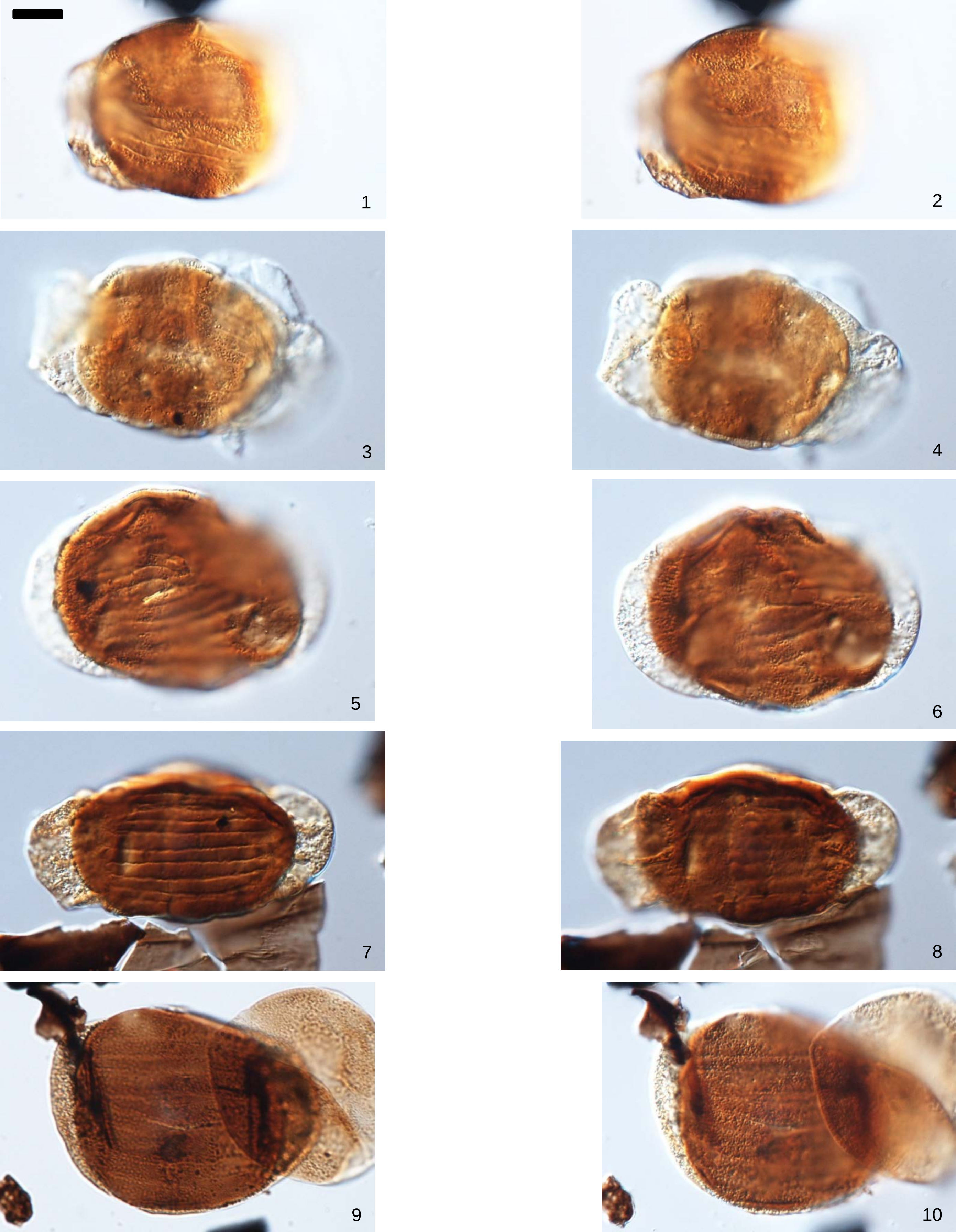
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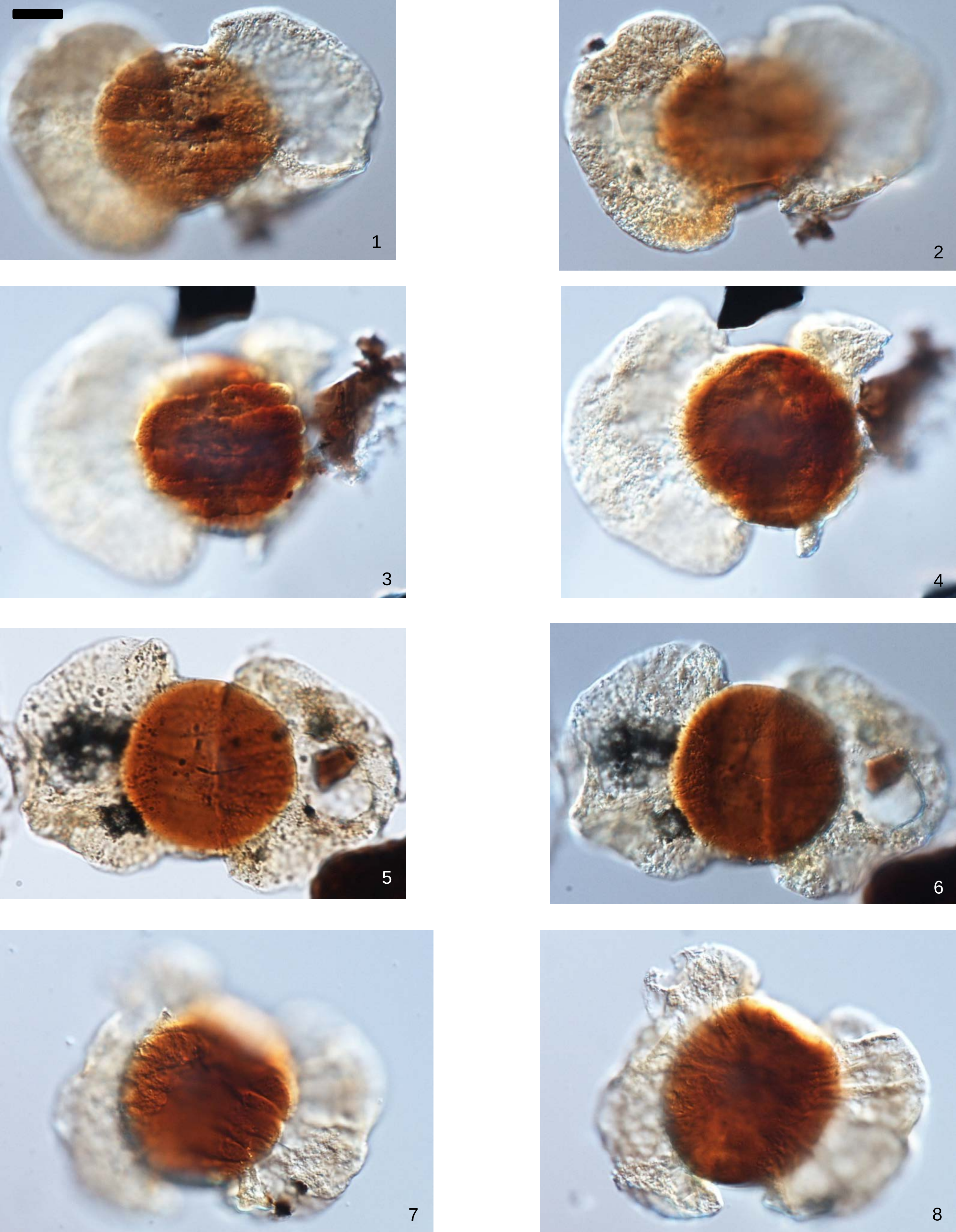

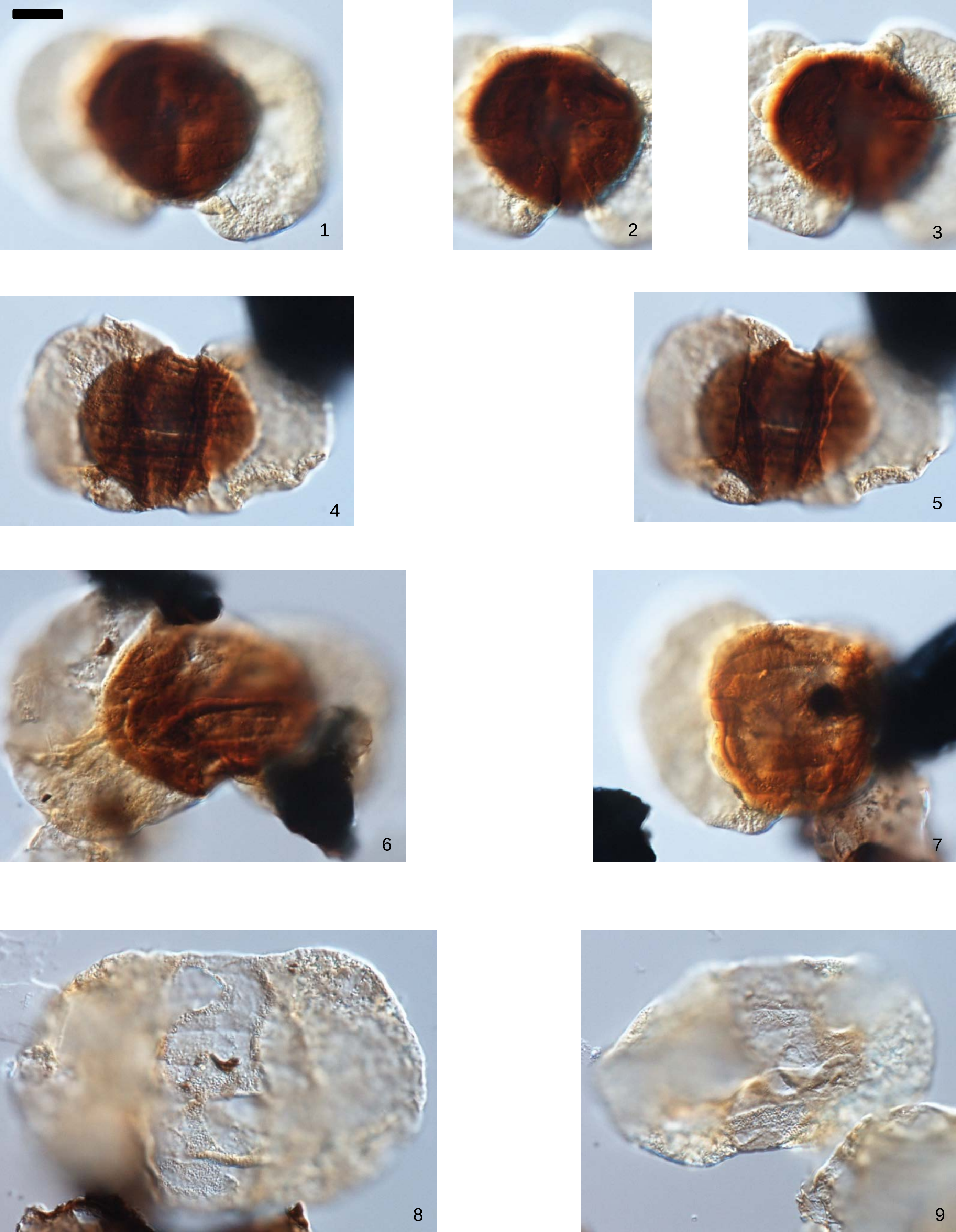
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