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PALYNOLOGY OF THE PERMIAN OF THE MAKHTESH QATAN-2, RAMON-1 AND BOQER-1 BOREHOLES, ARQOV FORMATION, NEGEV, ISRAEL

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Abstract. Palynological assemblages from cores 11 to 14 of Makhtesh Qatan-2, core 3 of Ramon-1 and core 3 of Boqer-1 boreholes from the Arqov Formation of the subsurface of the Negev, southern Israel, suggest that at least part of the Arqov Formation can be characterised by *Cedripites priscus, Reduviasporonites chalastus* and particularly *Pretricolpipollenites bharadwajii,* while the Saad Formation contains a slightly less diverse assemblage lacking the three taxa above. Palynological evidence is broadly consistent with other palaeontological evidence suggesting that the Saad Formation is in part likely to be Wuchiapingian in age, and the Arqov Formation is at least in part Changhsingian. These conclusions are tentative because core data is restricted to very few well penetrations and a total lack of surface exposure of the Permian.

Introduction

The Permian succession in Israel is known from the subsurface only. Twenty boreholes have penetrated the succession, in the northern Negev desert, the Judean desert, the southern Coastal Plain, and one in the central Coastal Plain (Fig. 1). The southern part of the Negev desert lacks Permian sedimentary rocks because of a regional Mesozoic truncation and because boreholes in northern Israel have not penetrated deep enough to reach the Permian. Therefore, the character of the Permian succession is known from the northern Negev and the southern Coastal Plain only. In these areas it overlies an unconformity equivalent to the Hercynian unconformity, and below that the late Precambrian arkosic Zenifim Formation (Avigad et al. 2015). Eleven of the boreholes that penetrated the Zenifim Formation give the complete Permian succession (Fig. 1).

The lower part of the Permian succession in the Negev and in the southern Coastal Plain is named the Saad Formation and it consists mainly of coarse silicic sandstone with some intercalations of calcareous shales attributed to distal fluvial, lagoon and deltaic depositional environments (Weissbrod 2005); however, such alternation between coarse and fine sandstones with calcareous shales may also indicate turbidites. Laterally across the Negev and in the southern Coastal Plain, the Saad Formation is relatively uniform with minor thinning to the northwest and local thickening in shallow basins to reach thicknesses of just over 150 m, for example in basins close to Ramon-1, Agur-1 and Pleshet-1 (see Stephenson & Korngreen 2020, their fig. 1).

The Arqov Formation conformably overlies the Saad Formation and in the northern Negev it

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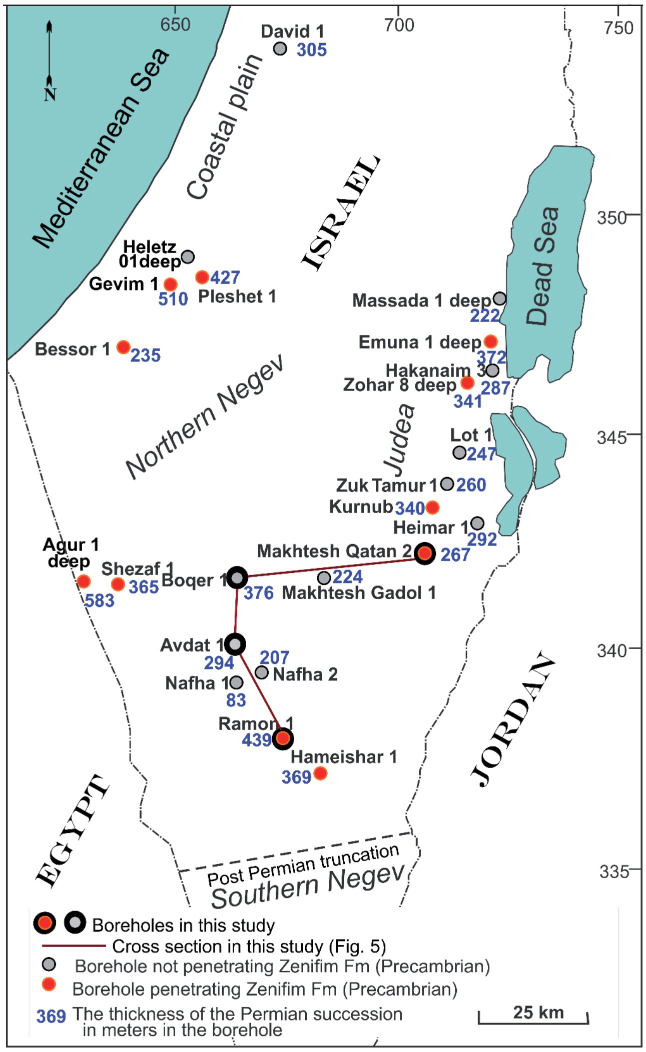


Fig. 1 - Location of the studied sections and boreholes.

consists mainly of sandstones and shales, with increasing carbonate content up-section, associated with skeletal remains, foraminifera and calcareous algae. Carbonate content also increases northward and is seen in Judean desert boreholes (to the north) with scarce occurrence of Lopingian foraminifera. Carbonate content also increases dramatically toward the Coastal Plain boreholes (Bessor-1, Gevim-1, Pleshet-1 and David-1), forming horizons rich with benthic fauna which allow a foraminifera-based biostratigraphy (Orlov-Labkovsky 2004; Orlov-Labkovsky & Hirsch 2005).

Because of the lithological change to carbonates in the upper part of the Arqov Formation in the Coastal Plain and Judean desert, a tentative division into two formations has been suggested for that area (Y. Druckman, unpublished reports; Fig. 5). The siliciclastic lower part that retains the character of the Arqov Formation in the Negev, continues to bear that name and is assigned to a near-shore transgressive marine environment (Weissbrod 2005). The upper carbonate-rich part although still bearing shale horizons, is proposed as the Sheizaf Formation. This part shows a deepening marine trend, and exhibits tempestites close to the Permian-Triassic boundary (Korngreen et al. 2013). The Arqov Formation in the Negev (and the Arqov and Sheizaf formations in the north taken together) range in thickness from 200 m in the Northern Negev to over 400m in the Coastal Plain (see Stephenson & Korngreen 2020; fig. 1).

This thick succession compares with a ~70m thick succession of similarly-aged Permian in the Jordanian sections of the eastern Dead Sea shore, which following restoration in relation to the Dead Sea Fault would be located fairly close (within 50-100 km) to the Negev succession (see Stephenson & Korngreen 2020; their fig. 1). Stephenson & Korngreen (2020) considered that the difference in thickness in Permian sediments between Negev boreholes, and the Umm Irna Formation may be due to greater accommodation space provided by a southwestward extension of the Palmyrid depocenter, or perhaps subsidence related to a fault in a similar position to the present Dead Sea Fault, or a fault ancestral to the Dead Sea Fault. The Saad and Arqov formations and particularly the latter are markedly more marine influenced than the contemporaneous Umm Irna Formation, perhaps due the more basinward position of the Negev sections but perhaps also because of subsidence to the west of the Dead Sea Fault (Stephenson & Korngreen 2020).

The age of the Saad and Arqov formations in the Negev is based mainly on palynomorphs, partly supported by ostracod and foraminiferal data (see review in Stephenson & Korngreen 2020). Eshet (1983) and Eshet & Cousminer (1986) described palynology samples from cores 16-19, 14-15, 11-13 and 10 in Makhtesh Qatan-2 (Fig. 1), spanning the Saad and Arqov formations. Cores 16-19 from within the Saad Formation appear to have been barren or contained no notable palynomorphs (see Eshet & Cousminer 1986; their text-figure 3). Eshet & Cousminer (1986) reported that cores 14 and 15 yielded amongst others *Falcisporites* (*Alisporites*) *nuthallensis*, *Hamiapollenites* (*Distriatites*) *insolitus*, *Klausipollenites schaubergeri, Lueckisporites virkkiae*, *Potonieisporites novicus* and *Vittatina* spp. Within the upper part of the Arqov Formation again only brief details of palynology were given: two levels appear to have yielded palynomorphs (at depths of 2099 m and 2084 m).

Based on some core but mainly cuttings data from Makhtesh Qatan-2, Eshet (1990) established two Permian biozones, the *Potonieisporites novicus* Zone, which coincides with the Saad and lower Arqov formations, and a younger Permian biozone, the *Lueckisporites virkkiae* Zone which coincides with the majority of the Arqov and lower Yamin formations and is characterized by the eponymous species as well as *Protohaploxypinus* spp. and *Striatopodocarpites* spp. Eshet (1990) assigned the *Potonieisporites novicus* Zone to the 'Autunian stage' (approximately Ghzelian to Sakmarian, Pennsylvanian to Cisuralian; Lucas & Shen 2018) and the *Lueckisporites virkkiae* Zone to the 'Thuringian' (approx. Lopingian; Lucas & Shen 2018).

Further north in the coastal plain of Israel, foraminifera from the Pleshet-1 and Gevim-1 boreholes suggest Midian (approx. Wordian - Capitanian; Lucas & Shen 2018) and Djulfian (approx. Wuchiapingian; Lucas & Shen 2018) ages for the Saad and Arqov formations respectively (Labkovsky-Orlov 2004; Labkovsky-Orlov & Hirsch 2005).

In January 2020, core samples were made available from Makhtesh Qatan-2, Boqer-1 and Ramon-1. The purpose of this paper is to refine the palynological succession in the Permian of the Negev, and to further develop correlations in the Guadalupian and Lopingian between Israel and Jordan.

Top	Base	BGS MPA number	Core and box number
Makhtesh Qatan-2			
2051	2052.5	71291	Core 9 Box 3
2052.5	2054	71290	Core 9 Box 2
2054	2055.1	71289	Core 9 Box 1
2106.4	2107.3	71276	Core 10 Box 12
2115.3	2115.9	71275	Core 10 Box 3
2116.3	2117.3	71274	Core 10 Box 2
2118.3	2119.3	71273	Core 10 Box 1
2203.5	2204.5	71278	Core 11 Box 2
2204.5	2205.5	71277	Core 11 Box 1
2205.5	2209	71279	Core 12 Box 1
2209	2210.1	71285	Core 13 Box 6
2210.1	2211.2	71284	Core 13 Box 5
2211.2	2212.3	71283	Core 13 Box 4
2212.3	2213.4	71282	Core 13 Box 3
2213.4	2214.5	71281	Core 13 Box 2
2214.5	2215.7	71280	Core 13 Box 1
2251.7	2253	71287	Core 14 Box 2
2253	2253.6	71286	Core 14 Box 1
2253.6	2254.5	71294	Core 15 Box 5
2254.5	2256.5	71293	Core 15 Box 4
2256.5	2257.5	71292	Core 15 Box 2
2257.5	2259.1	71288	Core 15 Box 1
2277	2278.1	71296	Core 16 Box 1
2307.5	2308.5	71295	Core 20 Box 1
Boqer-1			
3525	3526	71308	core 3 box 1
3524	3525	71309	core 3 box 2
3523	3524	71310	core 3 box 3
Ramon-1			
1198.5	1199.5	71301	core 3 box 1
1197.4	1198.5	71302	core 3 box 2
1196.3	1197.4	71303	core 3 box 3
1195.2	1196.3	71304	core 3 box 4
1194.2	1195.2	71305	core 3 box 5
1192	1193.1	71306	core 3 box 7
1260.5	1269	71307	core 5 box 3

Tab. 1 - Sample details.

Materials and methods

Makhtesh Qatan-2, Boqer-1 and Ramon-1 wells were drilled and completed by the Israel National Oil Company LTD in 1959-60, OIL Explorations LTD in 1976, and NAPHTHA Israel Petroleum Corporation LTD in 1965, respectively. The Saad - Arqov Formation boundary is placed at approx. 2270 m in Makhtesh Qatan-2, 3560 m in Boqer-1 and 1245 m in Ramon-1 (Fig. 1).

Cores 11 to 15 were sampled from Makhtesh Qatan-2; cores 3 and 5 from Ramon-1 and core 3 from Boqer-1. The cores are stored in boxes at the core store of the Geological Survey of Israel. Previous intensive sampling has meant that there are gaps in the core, and rock material has settled within individual core boxes. This meant that it was not possible to accurately position sample levels within core boxes, so composite samples were taken in the form of single representative samples from each box (Table 1). The preparation of strew mounts for palynological analysis comprised crushing, followed by hydrochloric and hydrofluoric acid treatments of the rock samples (Wood et al. 1996). The palynological slides bear the British Geological Survey code prefix 'MPA' and are curated in the BGS collections in Keyworth, Nottingham, UK.

Three samples collected from Makhtesh Qatan-2 were barren of palynomorphs but the other 12 samples yielded palynomorphs which were moderately- to well-preserved. Samples from Ramon-1 and Boqer-1 generally yielded less abundant assemblages but were similarly well preserved. All the Boqer-1 samples yielded palynomorphs; three of the Ramon-1 samples were barren of palynomorphs. For details of samples taken from Avdat-1, see Stephenson & Korngreen (2020).

Description and correlation of the Makhtesh Qatan-2, Ramon-1 and Boqer-1 palynological assemblages

Makhtesh Qatan-2

Though broadly similar, the assemblages from cores 11-13 and 14-15 display small but significant differences; they will thus be described separately (Fig. 2).

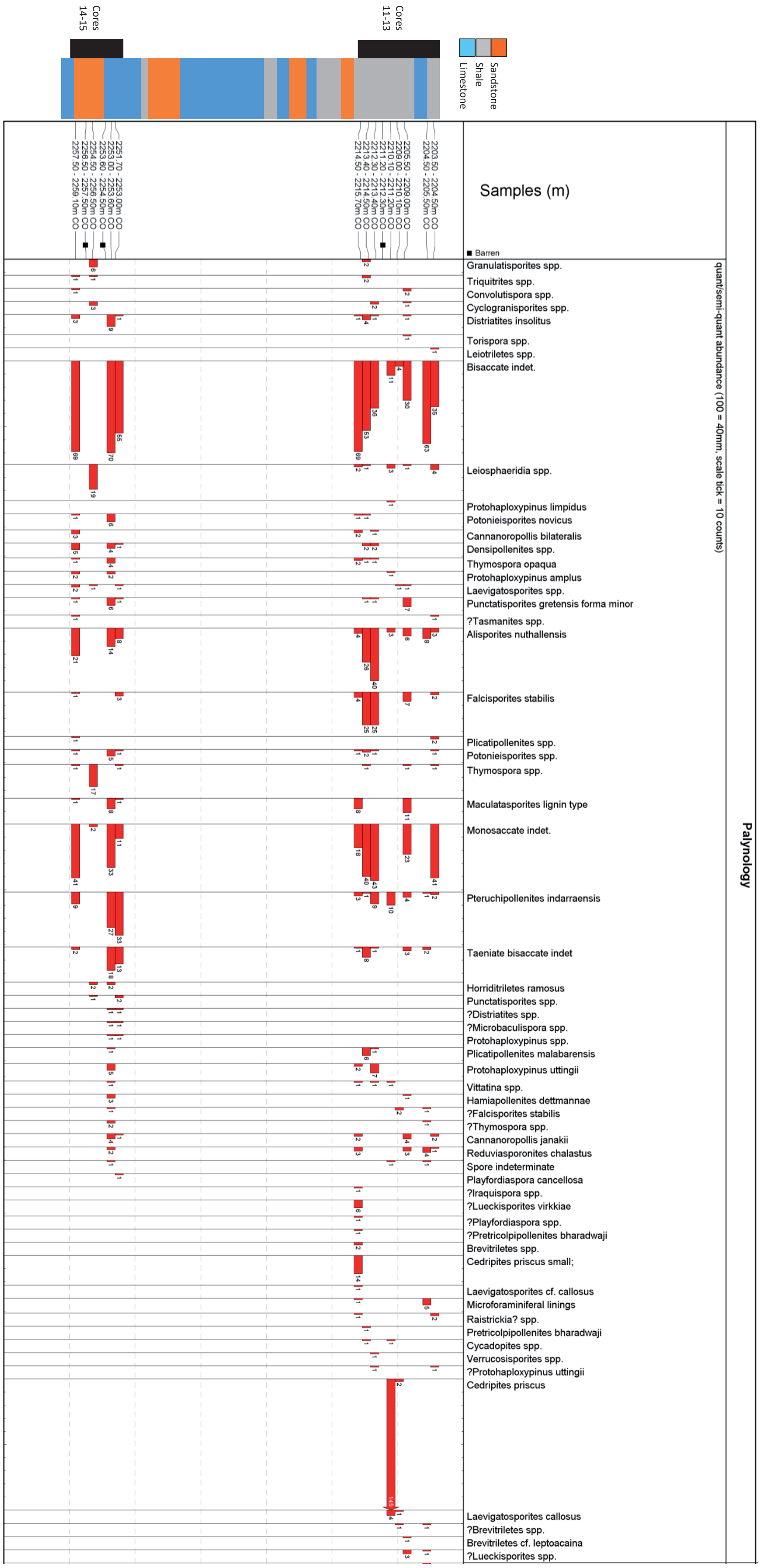


Fig. 2 - Lithology and palynology of cores 11-13 and 14-15 of Makhtesh Qatan-2.

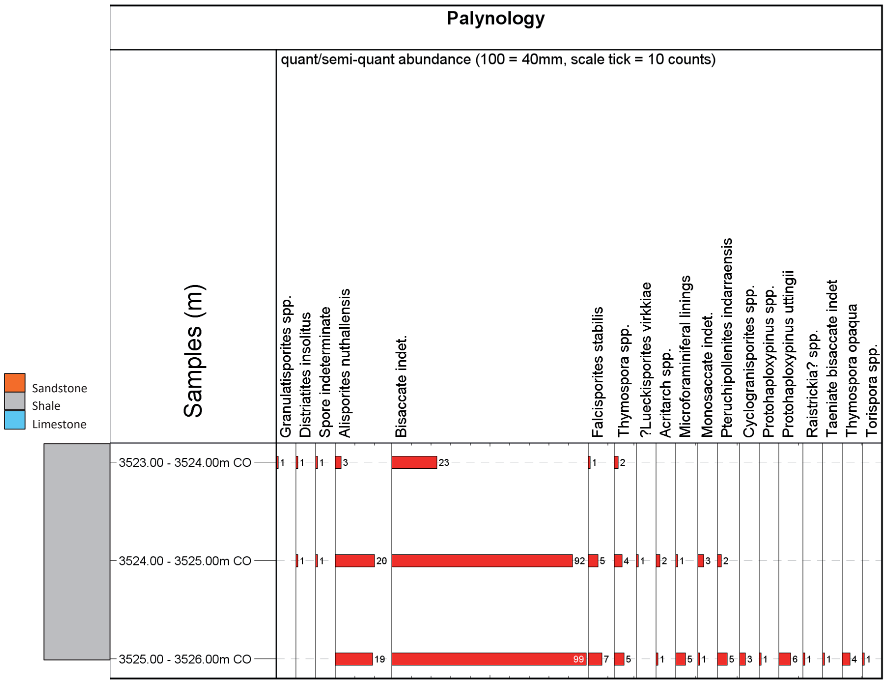


Fig. 3 - Lithology and palynology of core 3 from Boqer-1.

Cores 11-13 are dominated by indeterminate bisaccate and monosaccate pollen, *Alisporites nuthallensis* and *Falcisporites stabilis*; pollen with taeniae on proximal and distal surfaces (e.g. *Distriatites insolitus* and *Hamiapollenites dettmannae*) are common; also present in small numbers are *Pretricolpipollenites bharadwajii, Protohaploxypinus uttingii* and *Densipollenites* spp. *Cedripites priscus* is very common in one sample; palynomorphs that likely indicate shallow marine conditions include scolecodonts (the mouthparts of polychaete worms) and microforaminiferal test linings (Fig. 2; Plates 1-7).

In general cores 14-15 (Fig. 2; Plates 1-7) contain smaller numbers of *Falcisporites stabilis* and correspondingly larger numbers of *Pteruchipollenites indarraensis. Distriatites insolitus, Hamiapollenites dettmannae* and *Densipollenites* spp. are common. *Thymospora* spp. are very common in one sample. *Cedripites priscus* is absent from cores 14-15. A sample (from 2210.1 - 2211.2 m) from core 13 box 5 contains abundant plant cuticle including fragments of cuticle from the corystosperm *Dicroidium*, the most common plant fossil from the Jordanian Wadi Himara macroflora (Kerp et al. 2006; Abu Hamad et al. 2008). The presence of these fragments and the pollen of *Dicroidium* (*Falcisporites stabilis*) further directly confirms that *Dicroidium* (once thought to have earliest appearance in the Triassic) also existed in the Permian of Israel (see Stephenson & Korngreen 2020).

Boqer-1

The three samples are dominated by indeterminate bisaccate pollen and *Alisporites nuthallensis. Distriatites insolitus, Pteruchipollenites indarraensis, Protohaploxypinus uttingii* and *Falcisporites stablilis* and microforaminiferal test linings are also present (Fig. 3).

Ramon-1

Core 3 of Ramon-1 is dominated by indeterminate bisaccate pollen and *Alisporites nuthallensis* but *Falcisporites stablilis*, *Pteruchipollenites indarraensis* and *Densipollenites* spp. are also common (Fig. 4). *Protohaploxypinus uttingii*, *Distriatites insolitus* and *Playfordiaspora cancellosa* are present. Fragments of lignin with a characteristic reticulate structure occur, termed here informally '*Maculatasporites* lignin type'. A single sample from core 5 in Ramon-1 yielded indeterminate bisaccate pollen and *Alisporites nuthallensis.*

Comparison with Cores 6 and 7, Avdat-1 and palynological characterisation of the Arqov and Saad formations

Cores 11-13 and 14-15 of Makhtesh Qatan-2 are similar in general to cores 6 and 7 of Avdat-1 (Stephenson & Korngreen 2020) in containing common indeterminate bisaccate and monosaccate pollen, *Alisporites nuthallensis*, *Pteruchipollenites indarraensis* and *Falcisporites stabilis.* The main differences between the two groups of cores is between cores 11-13 and 14-15 of Makhtesh Qatan-2 and core 7

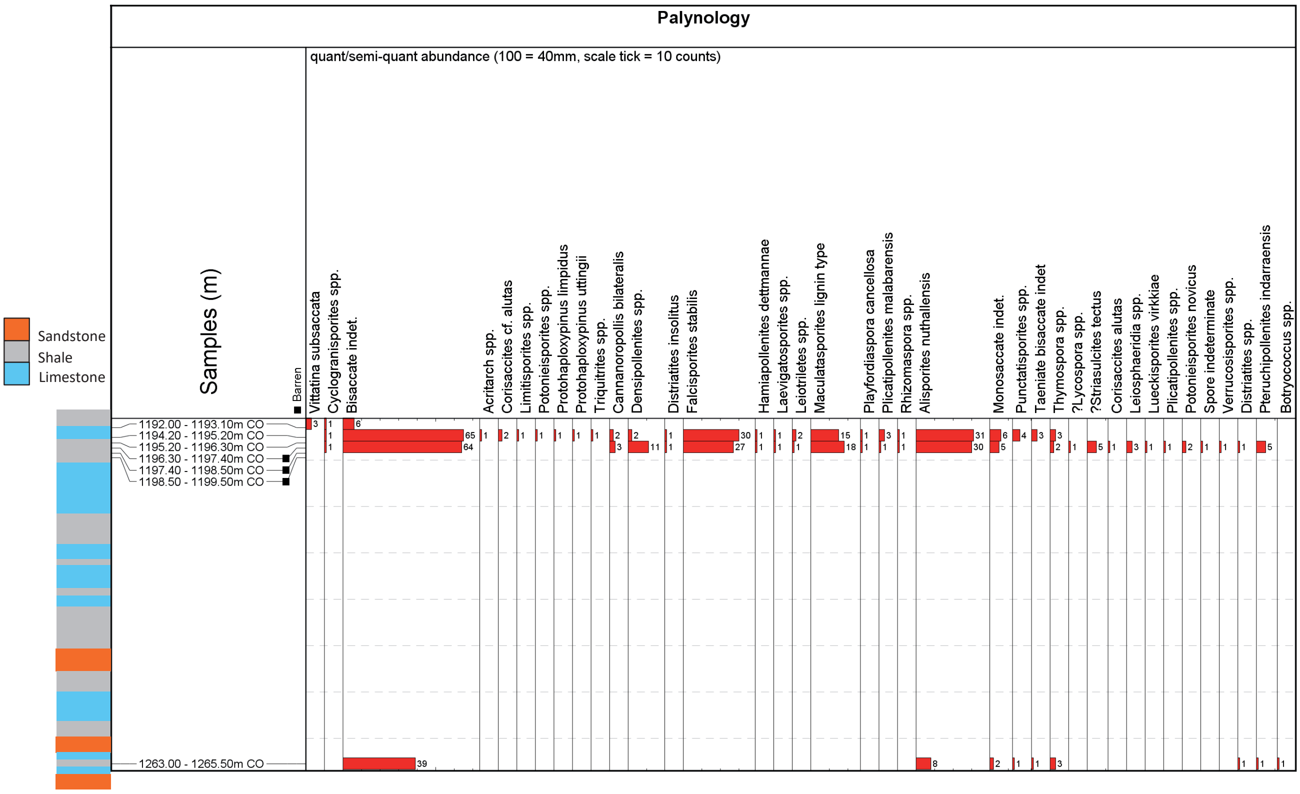


Fig. 4 - Lithology and palynology of cores 3 and 5 from Ramon-1.

of Avdat-1. It is notable that *Cedripites priscus, Reduviasporonites chalastus* and *Pretricolpipollenites bharadwajii* do not occur in core 7 of Avdat-1.

Core 3 of Boqer-1 has much lower diversity than Avdat-1 but contains taxa that suggest a general similarity with both cores of Avdat-1. Core 3 of Ramon-1 contains common *Falcisporites stabilis* indicating a closer affinity with core 6 of Avdat-1. The single poorly-yielding sample from core 5 of Ramon-1 cannot be correlated with any certainty.

The distribution of palynological assemblages on the basis of broad lithostratigraphy (Fig. 5) indicates a fairly consistent pattern of assemblages across the Arqov Formation and a distinction between Arqov and Saad Formation assemblages in that the four well-preserved and productive core 7 samples of Avdat-1 do not contain *Pretricolpipollenites bharadwajii, Reduviasporonites chalastus* and *Cedripites priscus.* The distribution of taxa as suggested by this study also reinforces the correlation of the Arqov Formation with the Umm Irna Formation of Jordan (Fig. 5; Stephenson & Korngreen 2020).

The well-preserved nature of palynological assemblages in Permian cores of the Negev suggests that a robust local palynological zonation would be possible if more core material with greater stratigraphic coverage could be made available from newly drilled boreholes. In particular, the ranges of the very distinctive and well-characterised taxa *Pretricolpipollenites bharadwajii* and *Protohaploxypinus uttingii* might allow local interval biozones to be developed. *Cedripites priscus* would perhaps be a useful supplementary palynological marker, though it is less well characterised and less morphologically distinct than *Pretricolpipollenites bharadwajii* and *Protohaploxypinus uttingii. Reduviasporonites chalastus* may also be a useful stratigraphic marker, though elsewhere its distribution is likely to be palaeoenvironmentally controlled (Foster et al. 2002; Stephenson et al. 2004; Spina et al. 2015).

Observations on the ages of the Arqov and Saad formations in the Negev

Eshet (1990) assigned the Saad and lower Arqov formations of the Negev to the 'Autunian stage' and the main part of the Arqov and lower Yamin formations to the 'Thuringian'. Stephenson & Korngreen (2020) suggested that core 7 of

Avdat-1 (Saad Formation) correlated with the Arabian Peninsula OSPZ5 Biozone, while core 6 of Avdat-1 (Arqov Formation) correlated with OSPZ6. These correlations would indicate approximate ages respectively of Roadian–Wordian for core 7 and Wordian-Capitanian for core 6 (Stephenson 2006). In the Negev, there is only limited independent palaeontological dating of the Arqov Formation and no independent data for the Saad Formation. In the Makhtesh Qatan-2 borehole, the Arqov Formation was considered by Derin (in Weissbrod 1981) to be 'Late Permian' based on the occurrence of the foraminifer *Codonfusiella* sp. and the ostracods *Kegeloites* sp. and *Amptissites* sp. The overlying Yamin Formation in the same borehole was determined by Hirsch & Gerry (1974) to be 'Late Permian–Early Triassic', based on a similar foraminifer assemblage and the conodont *Hadrodontina* cf. *H. adunca*, which was found in the upper part of the Yamin Formation.

Careful consideration of the palynological information allows a more refined age assessment of the two formations taking data from the Makhtesh Qatan-2, Ramon-1, Boqer-1, and Avdat-1 boreholes and from the Jordanian Umm Irna Formation.

In the Middle East, the tri-sulcate pollen *Pretricolpipollenites bharadwajii*, which appears to be broadly indicative of the Arqov Formation, is best known in the Triassic (e.g. Tunisia; Mazroui-Kilani et al. 1988; Kilani-Mazroui et al. 1990; Kamoun et al. 1994), but its earliest occurrence in well-dated sequences is in the Changhsingian (see Wardlaw & Pogue 1995) of the Salt Range of Pakistan where it reportedly occurs only in the 'upper 12 feet or so of the Chhidru Formation' (Balme 1970, p. 406). More recent studies in the same area (Hermann et al. 2012) record *P. bharadwajii* and *Pretricolpipollenites* spp. in their PTr1 and PTr2 units (earliest Triassic). The first appearance of *Pretricolpipollenites bharadwajii* may therefore be approximately Changhsingian in age (Fig. 5).

Evidence from the Umm Irna and Ma'in formation outcrops in Jordan supports a latest Permian age for the first appearance of *Pretricolpipollenites bharadwajii*. The Umm Irna Formation succession consists dominantly of a red-bed, alluvial lithofacies deposited in a humid-tropical climate by low-sinuosity rivers, although grey siltstone and claystone is also locally present. This is followed by the marine siliciclastic and thin carbonate beds of the Ma'in Formation; (Fig. 5). The two units are separated by a sequence boundary. There is no evidence of an angular unconformity at the level of the sequence boundary, nor is there palaeosol development at the upper surface of the alluvial lithofacies that might be expected if there were a long period of terrestrial emergence, thus any hiatus is considered of short duration (see Powell et al. 2016). The thin limestone (packstone) beds of the Ma'in Formation yield a low diversity assemblage of conodonts (e.g. *Hadrodontina aequabilis*) and foraminifera ('*Cornuspira*' *mahajeri*) that are interpreted as early Induan (Early Triassic; fig. 2 of Powell et al. 2016). At the 'Dyke Plateau section' along the Dead Sea shore (Powell et al. 2016) the Ma'in Formation rests on the upper part of the Umm Irna Formation, from which samples for palynology (Stephenson & Powell 2013) around 20m stratigraphically below the conodont-bearing beds in adjacent exposures, yielded *Pretricolpipollenites bharadwajii*. Thus a general latest Permian age could be considered for at least part of the range of *Pretricolpipollenites bharadwajii*.

The distinctive bisaccate pollen *Protohaploxypinus uttingii* has a characteristically shrunken intexinal body and is one of the smallest multi-taeniate bisaccate pollen known. In southern Arabia in Oman, the taxon is entirely absent from the many Gharif Formation sections and basal siliciclastic sections of the Khuff Formation examined (e.g. Stephenson 2008). It is known to occur in the overlying carbonates of the Khuff Formation in Oman as it often occurs in the caved components of assemblages derived from cuttings samples from wells that have penetrated the Khuff Formation (confidential Petroleum Development Oman reports). This indicates that *Protohaploxypinus uttingii* has a first appearance well above the likely Wordian first appearance of *Florinites*? *balmei* (i.e. above the base of OSPZ6; see Stephenson et al. 2003; Stephenson 2006). Having said this, the range of *Protohaploxypinus uttingii* is more difficult to date than that of *Pretricolpipollenites bharadwajii*. *Protohaploxypinus uttingii* was first described from the basal Khuff Formation siliciclastic beds in central Saudi Arabia (Stephenson & Filatoff 2000). There is no independent date for this unit, though its surface equivalent, the Ash-Shiqqah Member, may be Capitanian in age (personal communication, Denis Vaslet 2003), though it is known to range into the Wuchiapingian (personal communication, Nigel Hooker 2012) in Saudi Arabia.

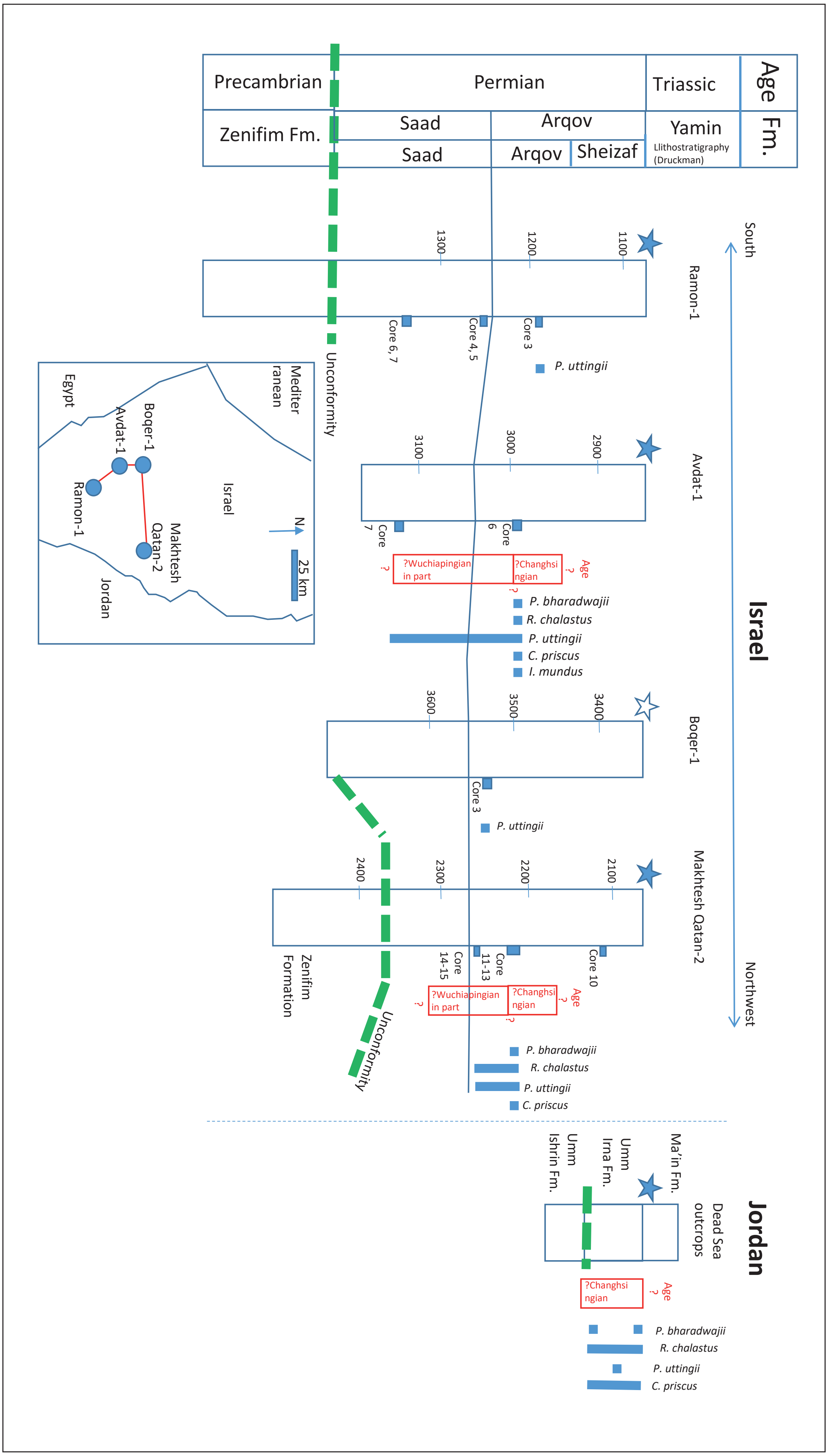


Fig. 5 - Lithostratigraphy, palynology and biozones of Makhtesh Qatan-2, Ramon-1, Boqer-1, Avdat-1 and Jordanian Dead Sea outcrops; solid star indicates Permian-Triassic boundary depth, blank star indicates approximate depth of Permian-Triassic boundary.

A consequence of the appearance of *Protohaploxypinus uttingii* in Core 7 of Avdat-1 is that it is likely younger than suggested by Stephenson and Korngreen (2020), perhaps Wuchiapingian, rather than Roadian–Wordian.

Conclusions

Palynological assemblages from cores 11 to 14 of Makhtesh Qatan-2, core 3 of Ramon-1 and core 3 of Boqer-1 boreholes from the Arqov Formation of the subsurface of the Negev, southern Israel, confirm a broad palynological succession in the Negev consistent with occurrences in Jordan. *Cedripites priscus, Reduviasporonites chalastus* and particularly *Pretricolpipollenites bharadwajii* characterise at least part of the Arqov Formation, while the Saad Formation contains a slightly less diverse assemblage lacking the three taxa above. Palynological evidence is broadly consistent with other palaeontological evidence suggesting that the Arqov Formation is at least in part Changhsingian in age, while the Saad Formation is likely Wuchiapingian in part.

These dates must be regarded as tentative because although assemblages from core samples are well preserved and diverse, they are only available from a very small part of both formations. Considering the importance of the Permian in Israel, in that it underlies much of the country forming possible reservoir rocks, there are relatively few well penetrations and very few penetrations with core. No surface exposure of the Permian exists, further restricting palynological investigation. Many of the cores that exist have been sampled many times and so are incomplete. Much of the palynology previously done, for example by Eshet (1990), Eshet & Cousminer (1986) and Horowitz (1974) was based almost exclusively on cuttings samples which are suitable for broad palynological divisions, but not for those of higher resolution. More wells and better core coverage would improve certainty attached to the palynological succession in the Negev. In addition, palynological investigation of the Pleshet-1 and Gevim-1 boreholes in the coastal plain of Israel north of the Negev, which have limited foraminiferal age control in the Arqov and Yamin formations may allow palynological occurrences to be calibrated more accurately against the standard Permian scale.

Appendix 1

List of palynological species in the text

Alisporites nuthallensis Clarke, 1965
Brevitriletes cf. *leptoacaina* Jones & Truswell, 1992
Cannanoropollis bilateralis (Tiwari) Lindström, 1995
Cannanoropollis janakii Potonié & Sah, 1960
Cedripites priscus Balme, 1970
Corisaccites cf. *alutas* Venkatachala & Kar, 1966
Distriatites insolitus Bharadwaj & Salujah, 1964
Falcisporites stabilis Balme, 1970
Hamiapollenites dettmannae Segroves, 1969
Horriditriletes ramosus (Balme & Hennelly) Bharadwaj & Salujah, 1964
Indotriradites mundus Stephenson, 2008
Laevigatosporites callosus Balme, 1970
Lueckisporites virkkiae (Potonié & Klaus) Clarke, 1965
Playfordiaspora cancellosa (Playford & Dettmann) Maheshwari & Banerji, 1975
Plicatipollenites malabarensis (Potonié & Sah) Foster, 1975
Potonieisporites novicus Bharadwaj, 1954
Pretricolpipollenites bharadwajii Balme, 1970
Protohaploxypinus amplus (Balme & Hennelly) Hart, 1964
Protohaploxypinus limpidus (Balme & Hennelly) Balme & Playford, 1967
Protohaploxypinus uttingii Stephenson & Filatoff, 2000
Pteruchipollenites indarraensis (Segroves) Foster, 1979
Punctatisporites gretensis forma *minor* Hart, 1965
Reduviasporonites chalastus (Foster) Elsik, 1999
?*Striasulcites tectus* Venkatachala & Kar, 1968
Thymospora opaqua Singh, 1964
Vittatina ovalis Klaus, 1963
Vittatina subsaccata (Samoilovich) Jansonius, 1962

Appendix 2

Systematic palaeontology

Genus *Densipollenites* Bharadwaj, 1962
Plate 7, 1-6

Type Species: *Densipollenites indicus* Bharadwaj, 1962.

?***Densipollenites*** sp.

?*Densipollenites* sp. Stephenson & Korngreen 2020; pl. V, figs. 4-5
?*Densipollenites* sp. Stephenson & Powell 2013; specimens not illustrated.

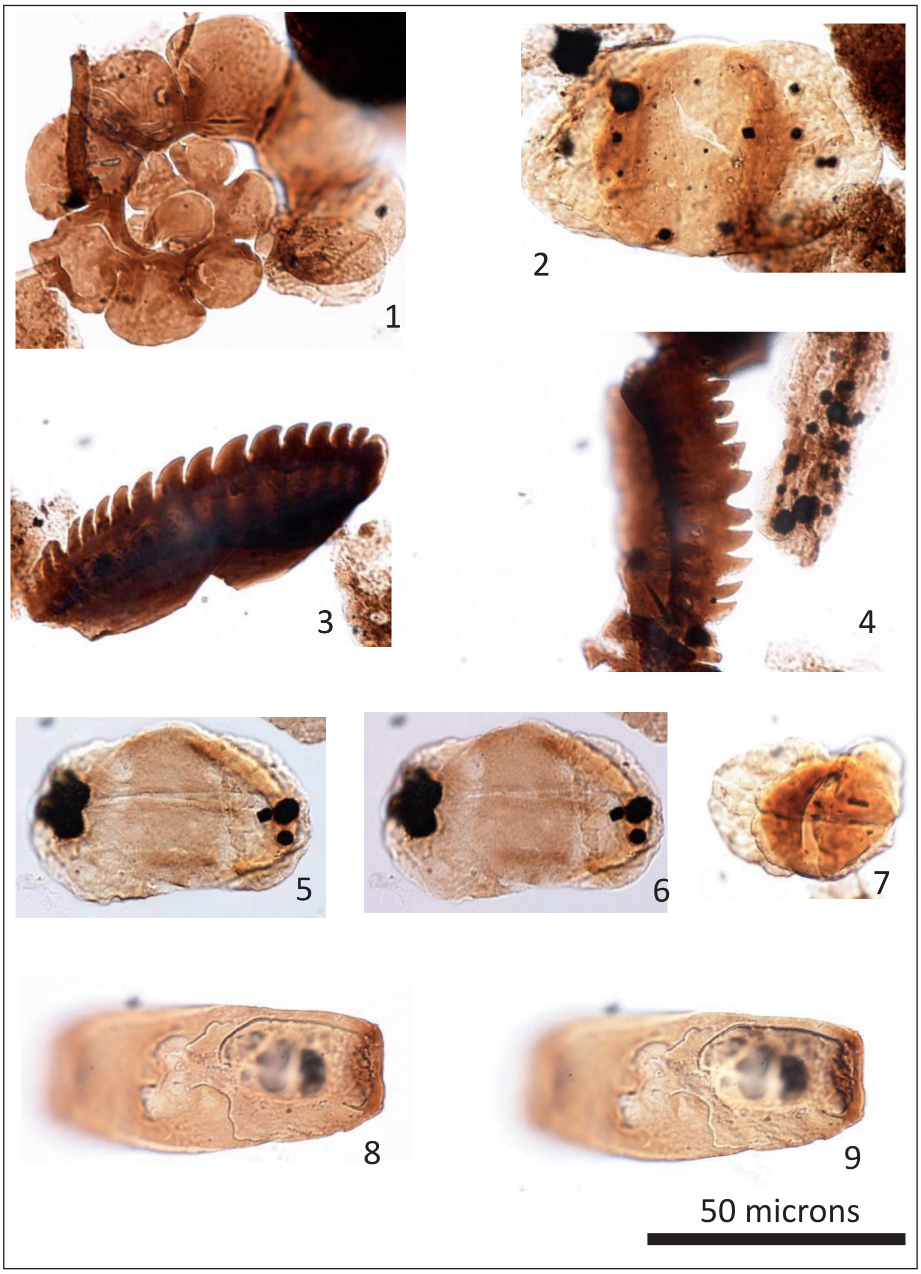
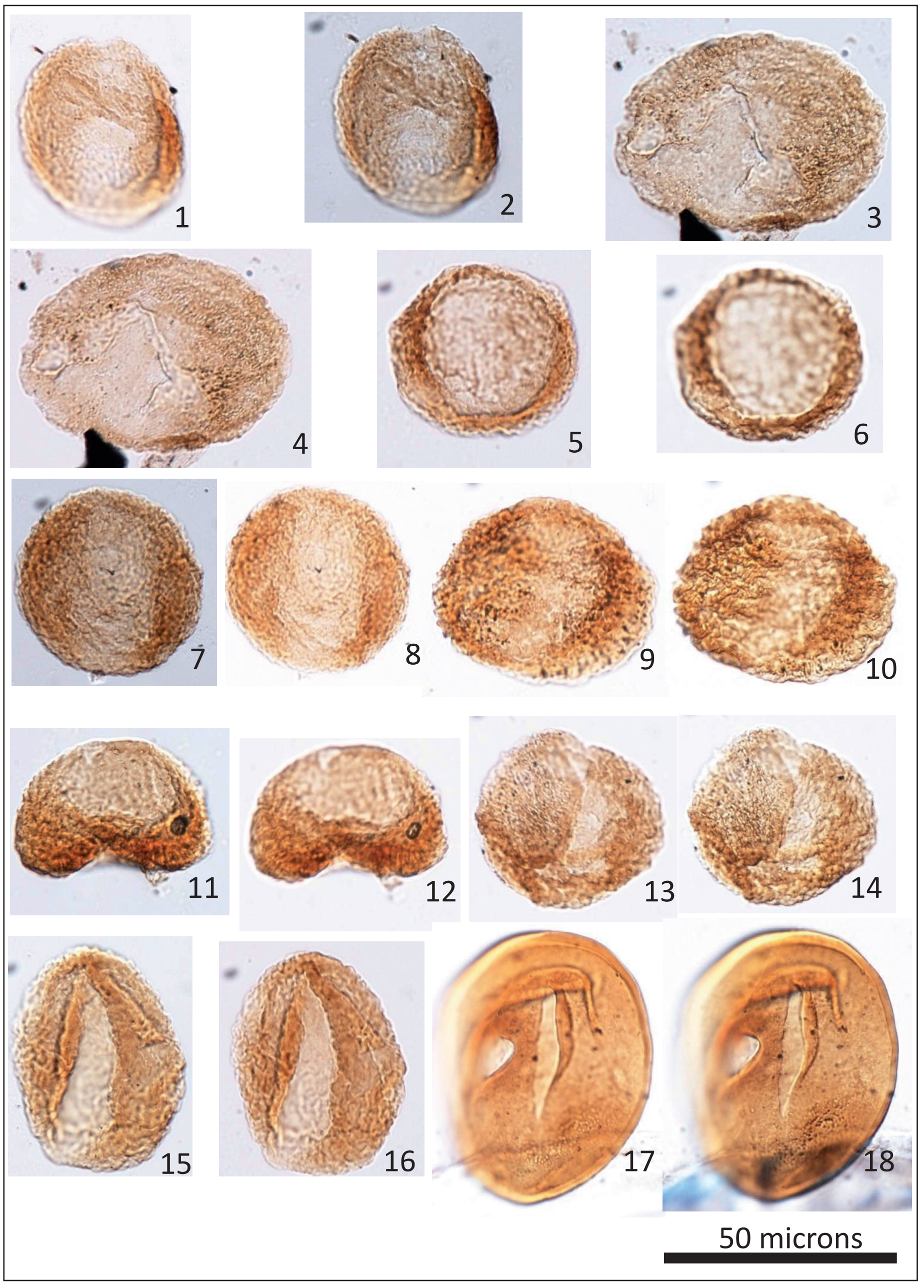


Plate 1

1) Microforaminiferal linings Q42, 71277; 2) *Alisporites nuthallensis* F50, 71277; 3) scolecodont U46, 71277; 4) scolecodont H54/3, 71277; 5) *Lueckisporites virkkiae* S37/1, 71279 (with Nomarski Interference Contrast, NIC); 6) *Lueckisporites virkkiae* S37/1, 71279; 7) *Lueckisporites* cf. *virkkiae* D44/4, 71279; 8) *Reduviasporonites chalastus* (NIC) F63/3, 71279; 9) *Reduviasporonites chalastus* F63/3, 71279.

Plate 2

1-16 - *Cedripites priscus*. 1) X59/3, 71284 (proximal); 2) X59/3, 71284 distal; 3) N41/4, 71284 (proximal); 4) N41/4, 71284 (distal); 5) M65/2, 71284 (medial); 6) M65/2, 71284 (distal); 7) M63/2, 71284 (NIC); 8) M63/2, 71284 (proximal); 9) B64/3, 71284 (distal); 10) B64/3, 71284 (NIC); 11) B65/2, 71284 (lateral shallow focus); 12) B65/2, 71284 (lateral deep focus); 13) B65/1, 71284 (oblique distal); 14) B65/1, 71284 (oblique proximal); 15) F52, 71284 (NIC shallow focus); 16) F52, 71284 (NIC deep focus); 17) *Laevigatosporites callosus* F52, 71284 (NIC distal); 18) *Laevigatosporites callosus* F52, 71284 (NIC proximal).



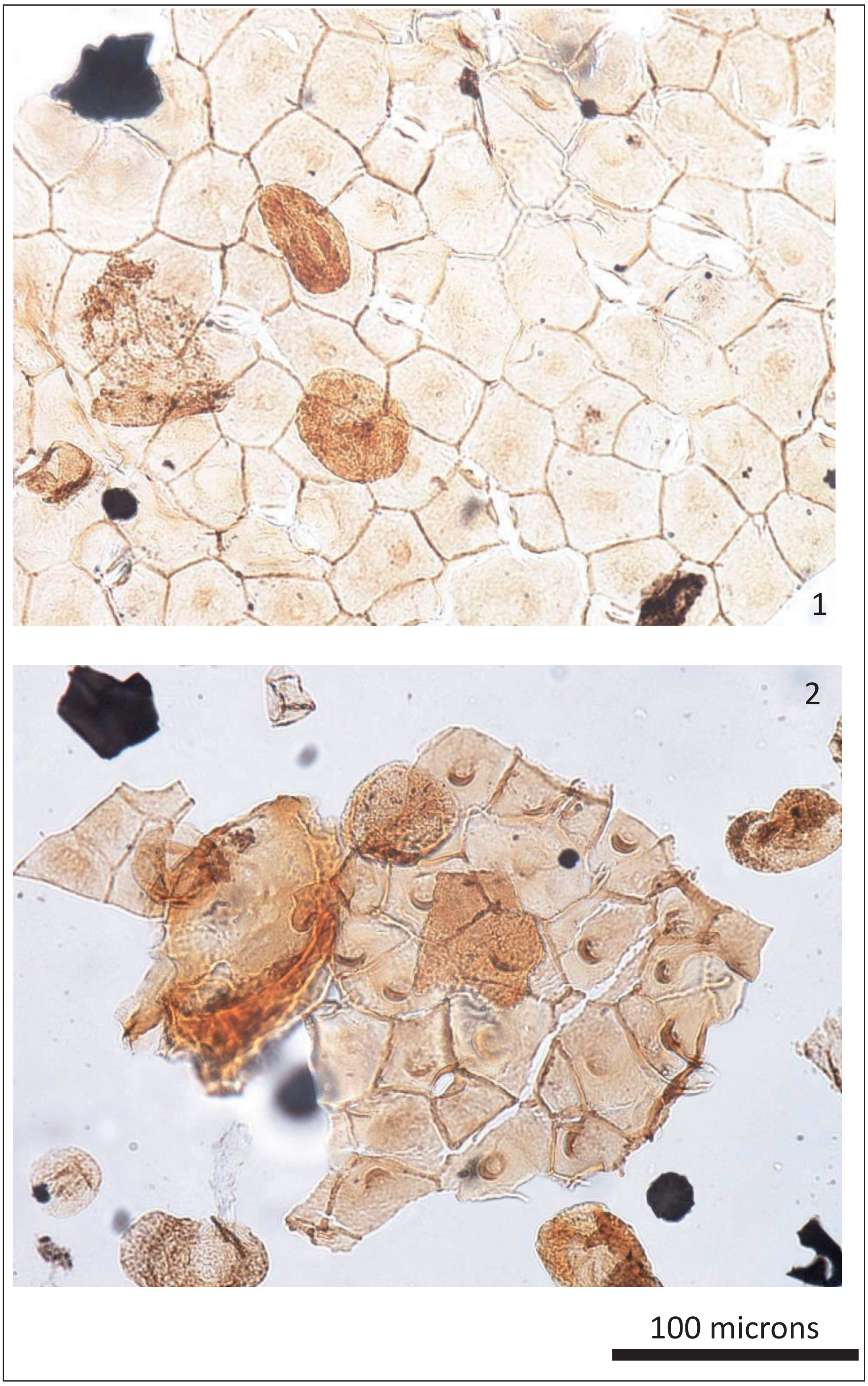
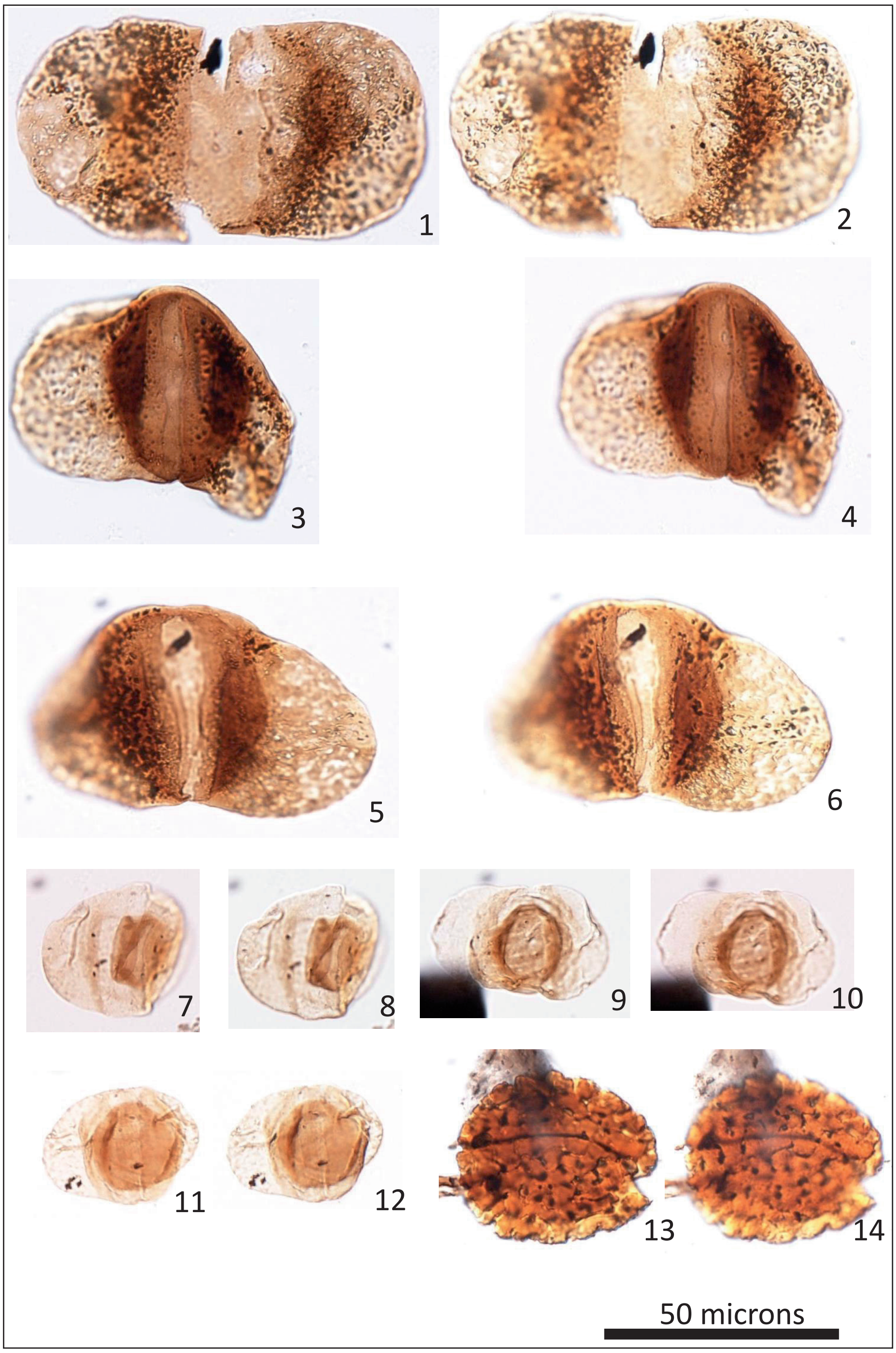


Plate 3

1) *Dicroidium* cuticle M60/2, 71284; 2) *Dicroidium* cuticle F56/4, 71284.

Plate 4

1) *Alisporites nuthallensis* C36/1, 71282 (non nomarski); 2) *Alisporites nuthallensis* C36/1, 71282 (NIC); 3) *Falcisporites stabilis* Y54/1, 71282 (NIC, focus on saccus); 4) *Falcisporites stabilis* Y54/1, 71282 (NIC, focus on cappula); 5) *Falcisporites stabilis* C49/1, 71282 (NIC, focus on saccus); 6) *Falcisporites stabilis* C49/1, 71282 (NIC, focus on cappula); 7) *Protohaploxypinus uttingii* K60, 71282; 8) *Protohaploxypinus uttingii* K60, 71282 (NIC); 9) *Protohaploxypinus uttingii* H56/4, 71282 (NIC); 10) *Protohaploxypinus uttingii* H56/4, 71282; 11) *Protohaploxypinus uttingii* D55/4, 71282; 12) *Protohaploxypinus uttingii* D55/4, 71282 (NIC); 13) *Thymospora opaqua* F51/3, 71286 (NIC, proximal focus); 14) *Thymospora opaqua* F51/3, 71286 (NIC distal focus).



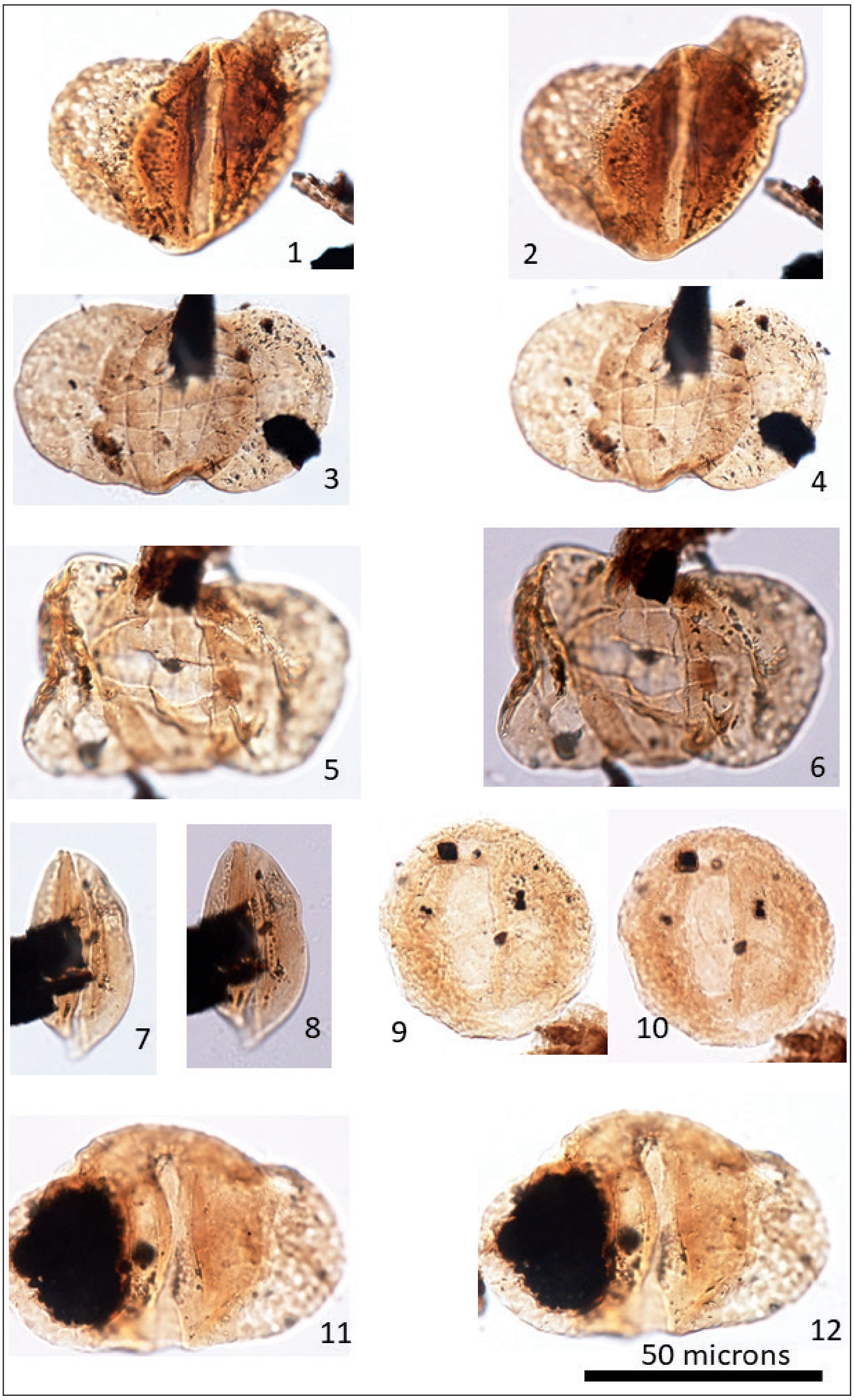
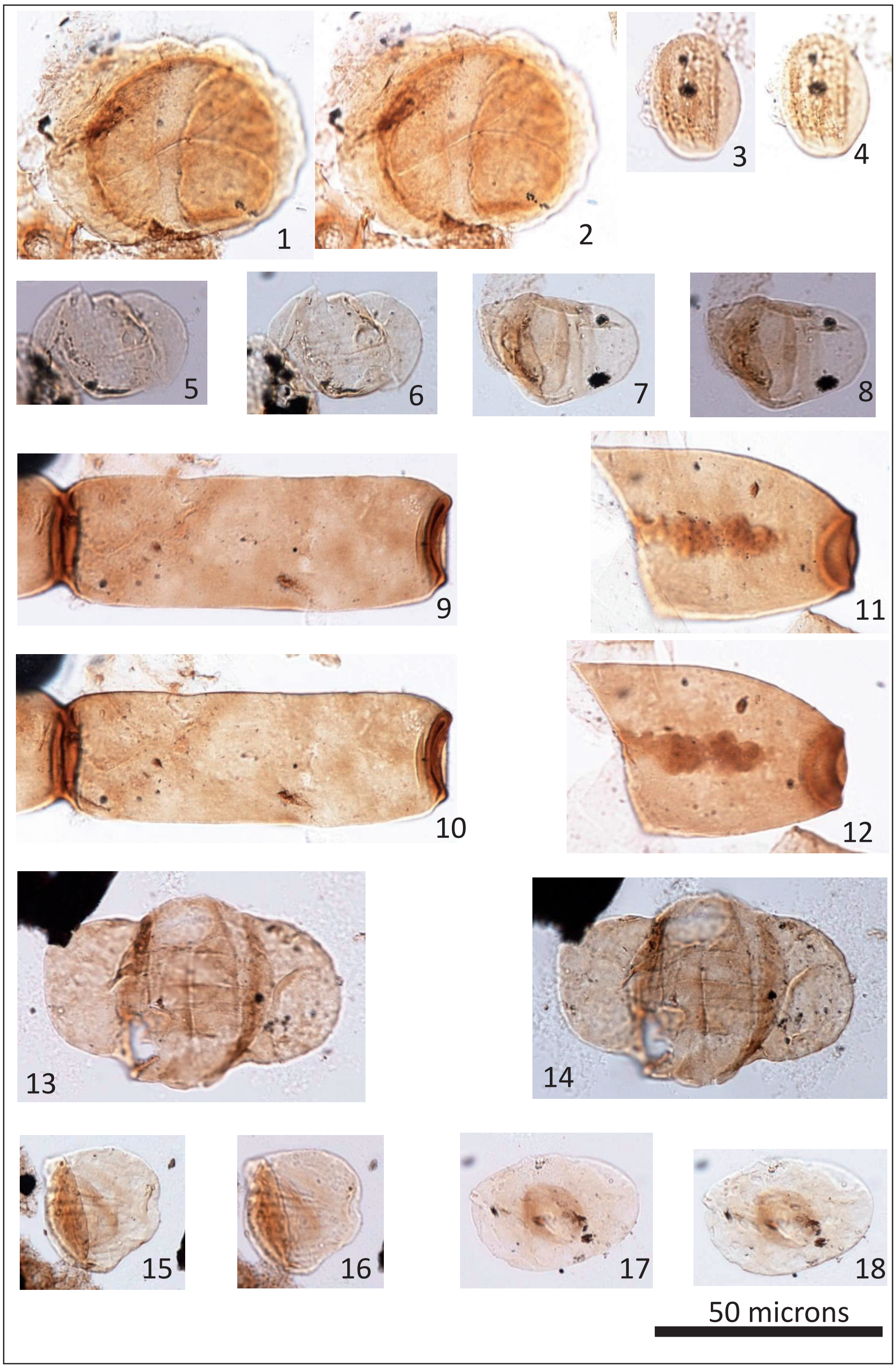


Plate 5

1) *Falcisporites stabilis* N43/1, 712 (NIC, focus on cappula); 2) *Falcisporites stabilis* N43/1, 712 (NIC, focus on sacci); 3) *Distriatites insolitus* E63/2, 71281 (NIC, distal focus); 4) *Distriatites insolitus* E63/2, 71281 (NIC, proximal focus); 5) *Distriatites insolitus* F57/4, 71281 (NIC, distal focus); 6) *Distriatites insolitus* F57/4, 71281 (NIC, proximal focus); 7) *Pretricolpipollenites bharadwajii* Q54/4, 71281 (distal focus); 8) *Pretricolpipollenites bharadwajii* Q54/4, 71281 (proximal focus); 9) *Cedripites priscus* G47, 71280 (proximal); 10) *Cedripites priscus* G47, 71280 (distal); 11) *Falcisporites stabilis* S58/1, 71280 (NIC, proximal focus); 12) *Falcisporites stabilis* S58/1, 71280 (NIC, distal focus).

Plate 6

1) *Corisaccites alutas* G57, 71280 (NIC, distal focus); 2) *Corisaccites alutas* G57, 71280 (NIC, proximal focus); 3) *Pretricolpipollenites bharadwajii* W36/4, 71280 (NIC); 4) *Pretricolpipollenites bharadwajii* W36/4, 71280; 5) *Protohaploxypinus uttingii* F40/3, 71280; 6) *Protohaploxypinus uttingii* F40/3, 71280 (NIC); 7) *Protohaploxypinus uttingii* D49/3, 71280 (NIC); 8) *Protohaploxypinus uttingii* D49/3, 71280; 9) *Reduviasporonites chalastus* J35, 71280 (NIC, shallow focus); 10) *Reduviasporonites chalastus* J35, 71280 (NIC, deep focus); 11) *Reduviasporonites chalastus* G43, 71280 (NIC, deep focus); 12) *Reduviasporonites chalastus* G43, 71280 (NIC, shallow focus); 13) *Hamiapollenites dettmannae* F34/4, 71286; 14) *Hamiapollenites dettmannae* F34/4, 71286 (NIC); 15) *Protohaploxypinus uttingii* T48, 71286; 16) *Protohaploxypinus uttingii* T48, 71286 (NIC); 17) *Protohaploxypinus uttingii* P62/3, 71286; 18) *Protohaploxypinus uttingii* P62/3, 71286 (NIC).



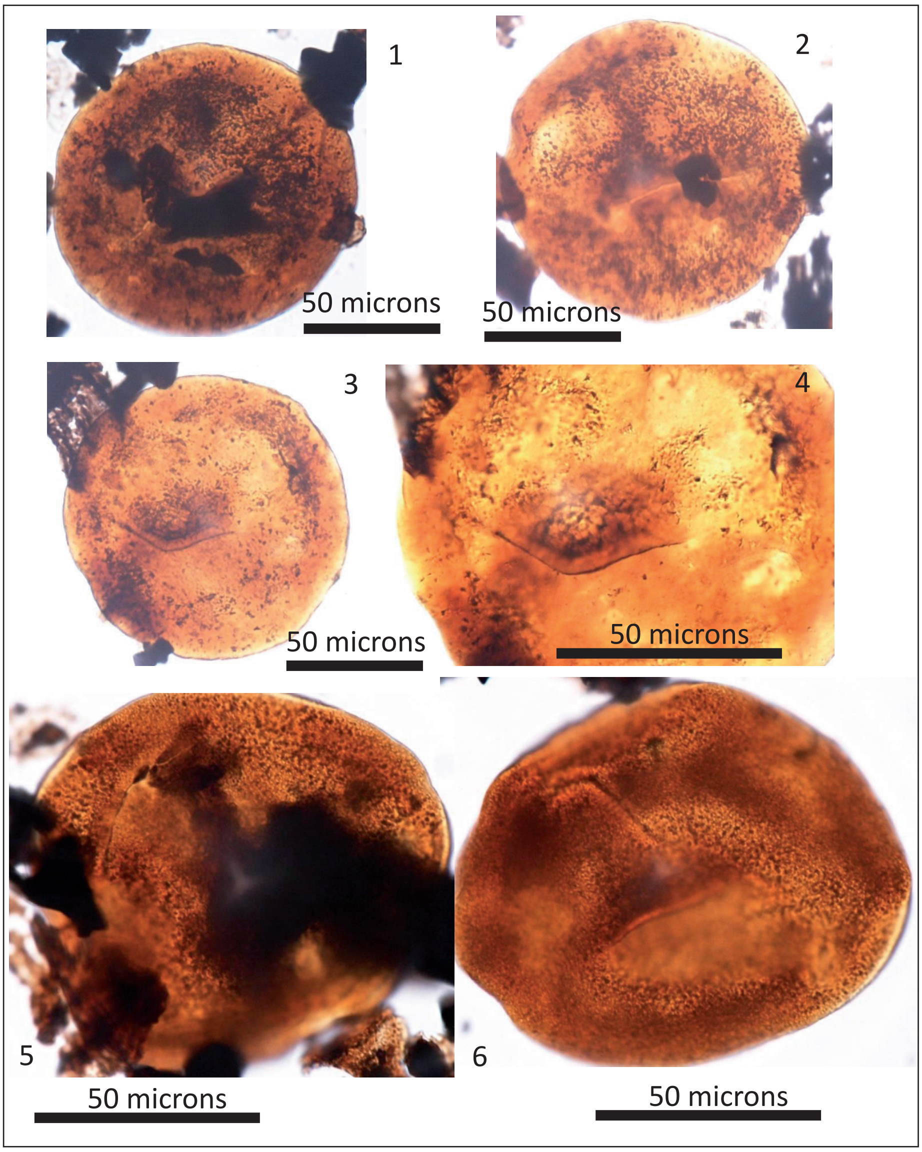


Plate 7

1) ?*Densipollenites* sp. R51/3, 71286; 2) ?*Densipollenites* sp. G60, 71286; 3) ?*Densipollenites* sp. D45/4, 71286; 4) ?*Densipollenites* sp. D45/4, 71286 (NIC, proximal detail); 5) ?*Densipollenites* sp. V62, 69089(3) Avdat-1 well; 6) ?*Densipollenites* sp. V58/2, 69089(3) Avdat-1 well).

Description. Pollen, monosaccate; amb circular or oval. Intexinal body usually indistinct; appears circular in outline; when visible, eccentrically placed within the saccus. Saccus appears to envelop one whole side of the intexinal body. On the other side, saccus detachment is close to the pole leaving a small exoexine-free area. An indistinct monolete or dilete mark may be present in some specimens. Detachment of saccus is occasionally associated with circumpolar intexinal folds. Saccus exoexine appears thick, dense and spongeous though at the margin an internally radial structure is sometimes visible. The density of the exoexine structure is such that at the saccus margin, the close superimposition of the proximal and distal surface of the saccus creates a comparatively opaque rim similar in appearance to a limbus.

Dimensions. 80(90)110 µm; 8 specimens

Remarks. Specimens of ?*Densipollenites* sp. are distinct and easily recognisable in assemblages from the Arqof Formation in Makhtesh Qatan-2, Ramon-1 and Avdat-1, and in assemblages from the Umm Irna Formation in Jordan, because of their dark and dense appearance and their relatively large size. The dark colour of specimens appears to be due to the densely spongeous and/or radially-structured enveloping saccus reducing the specimens' transparency. This also makes their internal structure difficult to discern and for a secure generic assignment to be made. Despite uncertainties over the assignment of this taxon, its distinctiveness and ease of recognition may make it a useful stratigraphic marker for the Arqov and Saad formations, following further studies and confirmation of its occurrence.

The closest genus appears to be *Densipollenites* Bharadwaj 1962 which was described as having exine which is 'densely granular to smooth' has a saccus which is 'finely intrareticulate on one side and coarsely intrareticulate on the other' (Bharadwaj 1962, p. 86), and is illustrated as having complete envelopment of one pole of the pollen grain Bharadwaj (1962, text-fig 7B). Bharadwaj (1962) also describes a 'wide zone along the equator in flattened specimens' that 'appears denser as if a limbus were present'. Although *Densipollenites* specimens described and illustrated by Bharadwaj (1962), Bharadwaj & Salujah (1964), Bharadwaj & Srivastava (1969), Tiwari & Rana (1981) and Bharadwaj & Dwivedi (1981) often contain a distinct inner body, and five species of *Densipollenites* are defined mainly on the basis of the configuration of the inner body, Bharadwaj (1962) also described specimens that have indistinct inner bodies, as in the present specimens.

Previous records. ?*Densipollenites* sp. is present in Makhtesh Qatan-2 and Ramon-1 in the Arqov Formation (this study) and in Avdat-1 assemblages, from the Saad Formation. In the Umm Irna Formation ?*Densipollenites* sp. is present in the Panorama Road Section, east coast of the Dead Sea, Jordan.

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