Palynological correlation of the Arqov and Saad formations of the Negev, Israel, with the Umm Irna Formation of the eastern Dead Sea, Jordan

Michael H. Stephenson, British Geological Survey, Keyworth, Nottingham, NG12 5GG, United Kingdom. Email: mhste@bgs.ac.uk.

Dorit Korngreen, Geological Survey of Israel, 32 Yesha'yahu Leibowitz St., Givat Ram, Jerusalem 9692100, Israel

Abstract

Palynological study of the Arqov and Saad formations of the Negev, Israel, in Avdat-1 borehole has allowed comparison with the assemblages of the Umm Irna Formation of the Dead Sea, Jordan. Core 7 of Avdat-1 (Saad Formation) contains common Hamiapollenites dettmannae and Distriatites insolitus indicating that it correlates with the Arabian Peninsula OSPZ5 Biozone and therefore has a likely Roadian-Wordian age, rather than a Westphalian age as previously suggested. Core 6 contains Indotriradites mundus, whose first appearance indicates the base of OSPZ6 (Wordian, extending into the Capitanian), but also contains common Protohaploxypinus uttingii, Pretricolpipollenites bharadwajii and Thymospora spp. As such, the assemblages of Core 6 are most similar to those of the Umm Irna Formation, while those of Core 7 are older, as implied by the correlation of Core 7 with OSPZ5. An interesting difference between typical OSPZ6 assemblages and those of Avdat-1 Core 6 is the common presence of Falcisporites stabilis in the latter. This pollen was produced by the corystosperm plant Dicroidium and its presence in Core 6 further indirectly confirms previous suggestions that Dicroidium (once considered confined to the Triassic) existed in the pre-Triassic in the Middle East. The difference in thickness in Permian sediments between Avdat-1, eastern 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.

Introduction

Permian of Israel

The Permian in Israel is known only from the subsurface in boreholes in the southern and central Coastal Plain, the Judean Desert and the northern Negev. The succession consists of a basal sandstone overlain by alternating sandstones, shales, and carbonates, and in the Negev ranges between 300 and 500 m thick. Permian rocks in these areas unconformably overlie the Precambrian arkosic siliciclastic Zenifim Formation and are overlain conformably by marine Triassic strata (Eshet, 1983; 1990; Eshet and Cousminer, 1986; Weissbrod, 1969, 1981, 2005).

During the Permian, the Levant was dominated by a NE-SW depocenter crossing Israel from northern Sinai in Egypt to the Palmyrian Basin in Syria (Freund et al., 1975, Garfunkel, 1998; Flexer et al., 2005). The Permian depocentre fill includes the clastic sedimentary Saad and Umm Irna formations of Israel and Jordan overlain in Israel by the fusulinid limestones of the Arqov Formation, which according to Orlova and Hirsch (2005) compare well with the Khuff Formation of the circum-Arabian belt.

The thickness of the Saad and Arqov formations (Fig. 1a, b) varies across Israel. The Saad Formation is thickest in the southern Negev and in the east of the country adjacent to the Dead Sea Fault (DSF) zone. The Arqov Formation is thickest in the north where is reaches over 400m thick in an area considered a depocenter related to SW extension of the Syrian Palmyra aulacogen, rifted from the Late Carboniferous–Permian to the late Jurassic (Ponikarov and Kazmin, 1965; Ponikarov et al., 1967; McBride et al., 1990; Garfunkel, 1998; Flexer et al., 2005).

According to Weissbrod (2005), the Saad Formation consists of white, poorly sorted, fine- to medium-grained sandstone alternating with beds of carbonaceous shales and clayey siltstone with rare dolomite or limestone. Sandstones are massive or thinly cross-bedded and include small lenses and thin horizons of carbonaceous siltstone (containing plant remains), occasionally displaying upward-fining sequences. The shale units are tens of cm to 4 m thick, massive or laminated, containing streaks of bituminous coal and small lenses of coarse sand. The Saad Formation was deposited in a marginal fluvio-deltaic setting. The sandstones with the carbonized plants were deposited in the distal part of the fluviatile system, possibly as point bars in moderate to high-sinuosity meandering channels, whereas the carbonaceous shales with their occasional coal seams suggest deposition in a littoral swamp, either in a delta or in a coastal barrier zone or in lagoons. The presence of carbonate layers between the sandy units suggest intermittent lagoonal environments.

Weissbrod (2005) described the Arqov Formation as consisting of sandstone, shale and limestone deposited in the littoral zone, in lagoons, and coastal sand barriers. The three lithofacies types consist of mixed units of alternating calcareous shales, sandstones and coaly horizons; cross-stratified sandstone units with gypsiferous or dolomitic cement; and biomicrite, micrite, intrabiomicrite, pelbiomicrite and biosparite carbonate units with skeletal fragments of pelycypods, ostracods, echinoids, foraminifers, and calcareous algae.

According to Weissbrod (2005) and Orlova and Hirsch (2005), the age of the Saad and Arqov formations is based on palynomorphs, partly supported by ostracod and foraminifer data. The ages based on palynology are mainly from Eshet and Cousminer (1986) and Eshet (1990) who studied assemblages from eleven boreholes across Israel. Importantly the only core palynology samples came from Makhtesh Qatan-2 (Fig. 1a, b; Eshet and Cousminer, 1986) and thus the data from cuttings samples on which the majority of work was done could be regarded as being vulnerable to caving, causing difficulties for precise palynological dating and biozonation. Eshet and Cousminer (1986) processed samples from cores 16-19, 14-15, 11-13 and 10 within what they regarded as the Permian sequence, spanning the Saad and Arqov formations.

Within the lower part of the section in Makhtesh Qatan-2 well, Eshet and Cousminer (1986) give palynological details only of cores 14 and 15 just above the top of the Saad Formation. Cores 16-19 from within the Saad Formation appear to have been barren or contained no notable palynomorphs (see Eshet and Cousminer, 1986; their text-figure 3). Within the upper part of the Arqov Formation two levels appear to have yielded palynomorphs (at depths of 2099 m and 2084 m). Cores 14 and 15 yielded amongst others *Potonieisporites novicus*, *Falcisporites* (*Alisporites*) *nuthallensis*, *Hamiapollenites* (*Distriatites*) *insolitus*, *Vittatina* spp., *Lueckisporites virkkiae* and *Falcisporites stabilis.*

Eshet (1990) established two Permian biozones, the *Potoniesporites novicus* Zone, which coincides with the Saad and lower Arqov formations, and with the *Punctatosporites minutus* zone of Horowitz (1973). The *Potoniesporites novicus* Zone is characterized by *Distriatites insolitus*, *Vittatina ovalis*, *Laevigatosporites callosus*, *Pretricolpipollenites bharadwajii* and the eponymous species, and was assigned by Eshet (1990) to the 'Autunian stage' (approximately Asselian to Sakmarian, Early Permian; Lucas and Shen 2018).

Eshet (1990) described his younger Permian biozone, the *Lueckisporites virkkiae* Zone as coinciding with the majority of the Arqov and lower Yamin formations and being characterized by the eponymous species as well as *Protohaploxypinus* spp. and *Striatopodocarpites* spp. To this biozone, he assigned a Thuringian age (approx. Lopingian, Late Permian; Lucas and Shen 2018).

Horowitz (1974) sampled cuttings and core from the Avdat-1 borehole though it is not clear from the paper which samples were core and which cuttings. Horowitz (1974) defined two Permian biozones. A lower *Punctatosporites minutus* Zone (from 3025-3050m to TD) was assigned a Westphalian age on the basis of the eponymous species and taxa such as *Laevigatosporites maximus*. His *Klausipollenites schaubergeri* Zone of Thuringian age occurs between 3025-3050 and 2485-2490m and its age is based on the eponymous species and taxa such as *Sulcatisporites kraeuseli* and *Falcisporites zapfei*.

Regional tectonic setting

The study area is located on the northern margins of the Arabian-Nubian shield, part of the northern edge of the Palaeozoic Gondwana continent. During pre-Permian times (Late Devonian–Early Carboniferous), what is now the eastern Mediterranean Sea was affected by the so called 'Hercynian orogeny' (Weissbrod 2005), which formed regional, broad (ca. 1000 km width) SW-NE basins and swells (Abbo et al., 2018). A Carboniferous-Permian-filled basin of the Palmyrides belt appears to extend southward from Syria through Israel to Sinai in Egypt (Freund et al., 1975, Garfunkel, 1998; Flexer et al., 2005). This basin may have formed in a zone of late Proterozoic crustal weakness (Stoesser and Camp, 1985; Best et al., 1990).

The Dead Sea Fault system (DSF), which cuts through the east of the study area, is a tectonic element in the Middle East (e.g., Ben-Menahem et al., 1976; Salamon et al., 2003; Garfunkel et al., 2014) which extends from the Red Sea to Turkey (ca. 1,000 km length), and contains evidence indicating ca. 107 km of strike-slip left-offset across the Israeli-Jordanian segment since the early to middle Miocene (e.g. Quennell, 1958; Freund et al., 1970; Bandel and Khoury, 1981; Garfunkel, 1981; Sneh and Weinberger, 2003; Nuriel et al., 2017; Kohn et al., 2019). Although the DSF and its sinistral movements are widely accepted as Miocene in age, evidence suggests the DSF may relate to an older pre-existing deformed zone as revealed from Eocene – Oligocene successions (see Avni et al., 2012), the early Cretaceous (Weissbrod, 2002), and the Precambrian (Garfunkel, 1970; Bartov et al., 2004; Avni, 2010).

Umm Irna Formation

The Umm Irna Formation, exposed on the eastern shore of the Dead Sea (Fig. 1a, b), consists of a mixed arenaceous – argillaceous clastic succession. Makhlouf et al. (1991) recognized an informal Lower Member, about 10 m thick, consisting of sandstones and silty shales in upward-fining sequences, which they attributed to a distal braidplain setting. Their Upper Member comprises five fining-upward cycles with elements of both braided and meandering stream deposits, with silty beds deposited in abandoned channels. Palaeosols with ferruginous globules are developed in the middle and upper part of the formation (Makhlouf et al. 1991, Powell and Moh'd 1993, Stephenson and Powell 2013).

Palaeontological work in the Umm Irna Formation has mainly focused on the well-preserved plant fossils and their depositional environments (Kerp et al. 2006, Uhl et al. 2007, Abu Hamad et al. 2008). More recently, Stephenson and Powell (2013, 2014) synthesised palynology and sedimentology into a depositional model and correlated the Umm Irna Formation with successions elsewhere in the Arabian Peninsula and tentatively with Israel. The palaeontology of the Permian-Triassic boundary section of the eastern Dead Sea shore including the Umm Irna Formation has been reported by Powell et al. (2016, 2019).

The palynological assemblages of the Umm Irna Formation are very variable but in general contain common non-taeniate bisaccate pollen (often fragmentary or too poorly preserved to be identified); those that are determinable include *Falcisporites stabilis*, *Alisporites nuthallensis*, *A. indarraensis*, and *Cedripites priscus*. The most common taeniate bisaccate pollen is *Protohaploxypinus uttingii* and *P. limpidus*. Monosaccate pollen is rare, as are spores. Details of the quantitative character of the assemblages and the stratigraphic ranges of taxa are given in Stephenson and Powell (2013, 2014).

In the absence of independent paleontological evidence, it is difficult to accurately date the Umm Irna Formation, however its overall palynological character suggests an age range within the Guadalupian (mid Permian) to Lopingian (late Permian), and the presence of the pollen *Pretricolpipollenites bharadwajii* mainly recorded from the very latest Permian of the Salt Range of Pakistan and the Triassic in the Middle East and North Africa suggests an age within the later part of that range (Stephenson and Powell, 2014; Tekleva et al. 2019).

Recent fieldwork on the Umm Irna Formation, exposed along the eastern shore of the Dead Sea (Fig. 1a, b) in Jordan revealed palynological assemblages of sufficient abundance and preservation to allow fairly detailed comparisons and correlations to be made with other Middle Eastern stratigraphic successions on the Arabian Plate, however comparisons with more close-by successions in Israel was hampered by a lack of palynological data, crucially from cored Israeli successions (Stephenson and Powell 2013). Cored samples recently made available from the Avdat-1 borehole

(Fig. 1a, b) in the central Negev Desert have allowed a reappraisal of preliminary correlations between the Umm Irna Formation and Israeli Permian formations. The aim of this paper is to describe the palynology of the Avdat-1 borehole samples and compare the assemblages with the well-established Umm Irna Formation assemblages.

Materials and methods

Avdat-1 well was drilled and completed by the Israeli Lapidot company between October 1965 and June 1966 to a total depth of 3146.7m within the Saad Formation. The Saad - Arqov Formation boundary was placed by Druckman et al. (1983) at a depth of approx. 3020m, and the Permian Triassic boundary at 2851.5 m (Sandler et al., 2006; Korngreen and Zilberman, 2017). Two cores are of interest in this section: Core 6 (2987.6 - 2993.7 m) and Core 7 (3122.0 - 3138.8 m); the cores are stored in boxes at the Geological Survey of Israel. Intensive sampling since the core was recovered has meant that there are gaps in the core and so it was not possible to accurately position sample levels within core boxes, so composite samples were taken, in the form of several 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.

Two samples from the Avdat-1 core boxes (3128.25-3129.1; MPA 69088 and 3129.1-3130.0; MPA 69087) were barren of palynomorphs but the other 11 samples yielded large populations of palynomorphs which were moderately - to well-preserved. For details of samples taken from the Umm Irna Formation in Jordan, see Stephenson and Powell (2013).

Description and correlation of the palynological assemblages

Assemblages from Core 7 (Saad Formation)

Indeterminate bisaccate and monosaccate pollen, *Pteruchipollenites indarraensis* and *Distriatites insolitus* dominate the assemblages (Fig. 2; Plates I-V), though *Thymospora* spp., *Alisporites nuthallensis*, *Protohaploxypinus uttingii*, *Densipollenites* spp., *Hamiapollenites dettmannae*, *Potonieisporites novicus* and *Plicatipollenites* spp. also occur. A distinctive small apiculate spore, *Brevitriletes* cf. *leptoacaina*, is present in Core 7 and Core 6 in significant numbers.

Assemblages form Core 6 (Arqov Formation)

Core 6 has similar diversity and preservation and a similar set of dominant pollen and spore types including common indeterminate bisaccate and monosaccate pollen, *Alisporites nuthallensis*, *Pteruchipollenites indarraensis* and *Alisporites nuthallensis* (Fig. 2; Plates I-V). However a number of pollen and spore taxa are more common in Core 6 than Core 7 including *Falcisporites stablilis* and *Thymospora opaqua*. A number of significant taxa only occur in Core 6 including *Cedripites priscus*, *Reduviasporonites chalastus*, *Indotriradites mundus*, *Pretricolpipollenites bharadwajii* and *Playfordiaspora cancellosa*. Microforaminiferal linings occur quite commonly in the upper part of Core 6.

Correlation of the Avdat-1 core material

Jordan

The assemblages of Core 6 are closely similar, in relation to stratigraphically significant taxa (see Stephenson and Powell 2013, table 2; Stephenson and Powell 2014), to the Umm Irna Formation assemblages in that the following are common to both: *Falcisporites stablilis*, *Thymospora opaqua*, *Cedripites priscus*, *Reduviasporonites chalastus*, *Pretricolpipollenites bharadwajii*, *Playfordiaspora cancellosa*, *Distriatites insolitus* and *Protohaploxypinus uttingii*. Although the Jordanian Dead Sea assemblages are remarkably variable quantitatively, the Core 6 assemblages are again similar in that both sets contain *Falcisporites stablilis* and indeterminate bisaccate pollen as the two dominant types. Perhaps the most notable quantitative difference between the Core 6 and Jordanian Dead Sea assemblages is the presence of microforaminiferal linings in the former, though this is likely for palaeoenvironmental rather than stratigraphic reasons. On the basis of this similar composition, Core 6 assemblages are likely to be of a similar age and from a general stratigraphic position similar to those of the Umm Irna Formation, but with a marine affinity.

Core 7, whose top is 130.9m below the base of Core 6, though similar in general composition, lacks significant Umm Irna Formation taxa. Given that the Umm Irna Formation in the Dead Sea area is around 70 m thick, it seems likely that Core 7 assemblages do not have a counterpart (i.e. are significantly older) than the Jordanian Permian successions which are unconformably underlain by the Cambrian Umm Ishrin Sandstone Formation (Powell, 1989).

The presence of microforaminiferal linings in the Core 6 assemblages and the occurrence of limestone beds above and below Core 6 (Fig. 2) indicate marine conditions. Weissbrod (2005) suggested that the Arqov Formation was deposited in a nearshore marine environment with coastal lagoons. The Umm Irna Formation however contains no lithological or palynological indicators of marine conditions. If the location of Avdat-1 borehole is restored in relation to estimated DSF movement, palinspastically its position would have been roughly 100 km due northwest of the Dead Sea location (see fig. 2b Stephenson and Powell 2013). Palaeogeographic reconstructions for Permian-Triassic times indicate that the region lay about 15 to 20 degrees south of the paleo-equator at the northern margin of the Arabian Platform in a continental to marginal marine setting with the Neo-Tethys Ocean located to the North (Stampfli and Borel 2002). During high relative sea-level stands, marine transgressions advanced to the south but clearly not far enough to establish marine conditions in the Jordanian location. It seems likely that the palaeo-shoreline was situated somewhere between Avdat-1 and the Dead Sea Umm Irna Formation locations.

Arabian Peninsula

Core 6 and 7 contain characteristics in common with the Oman and Saudi Arabian Palynological Zones (OSPZ; Stephenson et al. 2003). Core 6 contains *Indotriradites mundus*, whose first appearance indicates the base of OSPZ6 (Wordian, extending into the Capitanian; Stephenson 2008, Spina et al 2018), as well as being quantitatively and qualitatively similar to OSPZ6 in that it also contains common *Protohaploxypinus uttingii*, *Pretricolpipollenites bharadwajii*, *Alisporites nuthallensis*, *Thymospora* spp. and *Playfordiaspora cancellosa*. An interesting difference between typical OSPZ6 assemblages and those of Core 6 is the common presence of *Falcisporites stabilis* in the latter. This pollen taxon was produced by the corystosperm plant *Dicroidium* (see Kerp et al. 2006) and plant fossils of *Dicroidium* are common in the Jordanian Umm Irna Formation. Kerp et al. (2006) argued on the basis of the Permian date for the Umm Irna Formation that these Jordanian occurrences were the earliest in the fossil record, *Dicroidium* only ever having been reported previously from the Triassic. The presence of *Falcisporites stabilis* in Core 6 further confirms indirectly that *Dicroidium* also existed in the pre-Triassic in Israel.

Core 7 lacks *Indotriradites mundus*, *Protohaploxypinus uttingi* and *Pretricolpipollenites bharadwajii* but contains common *Hamiapollenites dettmannae* and *Distriatites insolitus*, indicating that Core 7 correlates with the OSPZ5 Biozone (Stephenson et al. 2003; Stephenson 2006) and therefore has a likely Roadian-Wordian age (Stephenson 2006, Spina et al 2018).

Modifications in the ages of Horowitz's (1974) biozones

Horowitz (1974) regarded his *Punctatosporites minutus* Zone (from 3025-3050m to TD in Avdat-1) as Westphalian (Pennsylvanian). The assignment to OSPZ5 clearly indicates that at least the section in Core 7 (3124.6 to 3131.8m) is ?Roadian-Wordian age. At least some of the samples from which Horowitz (1974) established his *Punctatosporites minutus* Zone were cuttings and so it is not possible to safely interpret the stratigraphic chart of Horowitz (1974; text-figure 3).

Horowitz's *Klausipollenites schaubergeri* Zone (3025-3050 to 2485-2490m) was considered of Thuringian age (approx. Lopingian, Late Permian; Lucas and Shen 2018). This age is broadly consistent with an OSPZ6 age.

Given the age differences suggested by Horowitz (1974) between the *Punctatosporites minutus* Zone and the *Klausipollenites schaubergeri* Zone, a rather large unconformity and associated temporal hiatus might be implied. The ages suggested from this study, though not implying completely continuous sedimentation do not indicate the presence of a major unconformity, at least between Core 7 and Core 6.

Difference in thickness between Permian sedimentary successions in Avdat-1 and the Umm Irna Formation

Palynological analysis indicates that at least from 3131.8 m (the base of Core 7, and probably from TD) to 2987.6m is Permian. Taking into account the position of the Permian - Triassic boundary in Avdat-1 (Sandler et al., 2006; Korngreen and Zilberman, 2017), the Permian succession should be extended upward to 2851.5 m. This suggests that a maximum of approximately 300m of Permian (likely mainly Guadalupian and Lopingian) succession is present. Assuming that ages determined in this paper for the Saad and Arqov formations are consistent in boreholes Ramon-1 and Hameishar-1 to the southeast of Avdat-1 (Fig. 3a, b), the Permian continues to thicken to the southeast close to the DSF in the Negev.

This thick succession compares with a succession of similarly-aged Permian in the Jordanian sections (approx. 50km distant from Hameishar-1 in a restored palaeogeography; Fig. 1a, b) around 70m thick (Stephenson and Powell 2013). The difference in thickness may simply indicate the presence of greater accommodation space to the west (palinspastic north) relating to the southwestward extension of the Palaeozoic Palmyrid depocenter (Frizon de Lamotte et al., 2011). The subsidence may also be related to a fault in a similar position to the present DSF or a fault ancestral to the DSF.

In the case of a fault influencing differential thickness, the sequence of events could have been initiated by fault downthrow to the palinspastic north in Saad Formation times allowing sediments to accumulate in the ?Roadian-Wordian. To the south of the fault (where today, Saad Formation-equivalent sediments are absent), there was not enough accommodation space for sediments to accumulate. Following the deposition of Saad Formation sediments to north of the fault, marine transgression resulted in Arqov Formation sediments which cap those of the Saad Formation. Greater accommodation space perhaps due to local subsidence south of the fault allowed Arqov Formation equivalent sediments to accumulate (the Umm Irna Formation). Any marine transgression appears not, however, to have reached south of the fault because the Umm Irna Formation contains no marine indicators.

Conclusions

1. Avdat-1 cores from the Arqov and Saad formations of the Negev, Israel, provided relatively well preserved palynological assemblages that allow comparison with well-studied assemblages from the Umm Irna Formation of the eastern Dead Sea Jordan.
2. Core 7 of Avdat-1 (Saad Formation) correlates with the Arabian Peninsular OSPZ5 Biozone and therefore has a likely Roadian-Wordian age, rather than a Westphalian age as previously suggested. Core 6 correlates with OSPZ6 (Wordian, extending into the Capitanian).
3. The common presence of *Falcisporites stabilis* in Core 6 indirectly confirms previous suggestions that the plant taxon *Dicroidium* (once considered confined to the Triassic) existed in the pre-Triassic in Israel.
4. The difference in thickness in Permian sediments between Avdat-1, and in eastern Negev boreholes, and the Umm Irna Formation of the eastern Dead Sea, may relate to the presence of greater accommodation space to the west (palinspastic north) either because of a southwestward extension of the Palaeozoic Palmyrid depocenter or perhaps subsidence related to a fault ancestral to the DSF.

Appendix 1

List of taxa in the text

Alisporites nuthallensis Clarke 1965

Brevitriletes cf. *leptoacaina* Jones and Truswell 1992

Cedripites priscus Balme 1970

Distriatites insolitus Bharadwaj and Salujah 1964

Falcisporites stabilis Balme 1970

Falcisporites zapfei (Potonié and Klaus) Leschik 1956

Hamiapollenites dettmannae Segroves 1969

Indotriradites mundus Stephenson 2008

Laevigatosporites callosus Balme 1970

Laevigatosporites maximus (Loose) Potonié and Kremp 1954

Lueckisporites virkkiae (Potonié and Klaus) Clarke 1965

Protohaploxypinus limpidus (Balme and Hennelly) Balme and Playford 1967

Playfordiaspora cancellosa (Playford and Dettmann) Maheshwari and Banerji 1975

Potonieisporites novicus Bharadwaj 1954

Pretricolpipollenites bharadwajii Balme 1970

Protohaploxypinus uttingii Stephenson and Filatoff 2000

Pteruchipollenites indarraensis (Segroves) Foster 1979

Reduviasporonites chalastus (Foster) Elsik 1999

Sulcatisporites kraeuseli Mädler 1964

Thymospora opaqua Singh 1964

Vittatina ovalis Klaus 1963

Appendix 2

Brevitriletes cf. *leptoacaina* Jones and Truswell 1992 (Plate II, 7-21)

Description: Spores radial, trilete; amb circular with numerous projecting pila and spinae. Laesurae distinct, straight, sometimes raised; extend 80-100% of the spore radius, with or without lips. Laesurae connect with distinct to indistinct curvatural ridges. Curvatural ridges often fold over close to the termini of laesurae. Exine 1-2µm thick; proximal face planar or depressed in the contact areas; exine laevigate. Distal face slightly convex; ornamented with, evenly spaced, slender spinae and pila (2-4 µm apart, 2-6 µm high, <1 µm wide above the base, 1-1.5 µm wide at the base). Up to 40 elements commonly project from the margin.

Dimensions: 29(35)37 µm; 12 specimens.

Remarks: The specimens are similar to *Brevitriletes leptoacaina* Jones and Truswell 1992 but generally have a larger number of ornament elements that are longer. Previous records of *Brevitriletes leptoacaina* generally suggest a Cisuralian age (e.g. Jones and Truswell, 1992; Stephenson et al., 2003). *Brevitriletes hennellyi* Foster 1979 appears to have broad-based, cone-shaped ornament elements.

Brevitriletes cf. *leptoacaina* is particularly common in Core 6 (Arqov Formation) but it is of note that the probably-equivalent Umm Irna Formation does not contain this taxon, perhaps for palaeoecological reasons.

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Figure captions

Fig. 1 a, b. Location of the studied sections and boreholes, showing restoration of Avdat-1 taking into account the post-Cretaceous 107 km sinistral displacement along the Dead Sea Fault (Freund et al., 1970); (a) Saad Formation, (b) Arqov Formation.

Fig. 2. Lithology and palynology of core 6 and 7 of Avdat-1.

Fig. 3. Tentative correlation of Negev boreholes containing the Arqov and Saad formations with the Dead Sea succession. Stratigraphic details from Weissbrod (1981, 1969, 2005) and Powell et al. (2016).

Table caption

Table 1. Sample details.

Plate explanations

Plate I. 1, 2, *F. stablilis*, H59, 69079(2); 3, 4, *F. stablilis*, L63, 69079(2); 5, 6, *F. stablilis*, L50/4, 69079(2); 7, *F. stablilis*, L65/4, 69079(2); 8, *F. stablilis*, K44, 69079(2); 9, 10, *F. stablilis*, G48, 69080(2).

Plate II. 1, 2, *T. opaqua*, J55, 69080(2); 3, 4, *T. opaqua*, J55, 69080(2); 5, 6, *T. opaqua*, D58/2, 69081(2); 7-9, *Brevitriletes* cf. *leptoacaina*, M48/4, 69081(2); 10 *Brevitriletes* cf. *leptoacaina*, O64/3, 69081(2); 11, 12, *Brevitriletes* cf. *leptoacaina*, M66/1, 69084(3); 13, 14, *Brevitriletes* cf. *leptoacaina*, L30/2, 69084(3); 15, 16, *Brevitriletes* cf. *leptoacaina*, L48/1, 69084(3); 17, 18, *Brevitriletes* cf. *leptoacaina*, K52/4, 69084(3); 19, 20, 21 *Brevitriletes* cf. *leptoacaina*, K54/4, 69084(3); 22, *P. cancellosa*, E57/4, 69084(3); 23, *P. cancellosa*, H69, 69084(3).

Plate III. 1, Microforaminiferal lining, L63/4, 69079(2); 2, *R. chalastus*, M61/1, 69080(2); 3, 4, *P. bharadwajii*, E57/2, 69080(2); 5, 6, *P. bharadwajii*, E41/4, 69083(2); 7, 8, *A. nuthallensis*, G47, 69080(2); 9, *L. virkkiae*, S48, 69080(2); 10, 11 *L. virkkiae*, J39/2, 69080(2); 12, 13, *Thymospora* sp., E57/2P52/2, 69080(2).

Plate IV. 1, 2, *I. mundus*, P67, 69080(2); 3, *I. mundus*, L43/1, 69080(2); 4, 5, *P. uttingii*, S67/3, 69080(2); 6, *P. uttingii*, D60, 69081(2); 7, *P. uttingii*, O40, 69081(2).8, 9, *P. indarraensis*, R59, 69080(2); 10, *P. indarraensis*, E40, 69085(2); 11, 12 *D. insolitus*, Q60, 69085(2); 13, *D. insolitus*, T39, 69085(2); 14, *D. insolitus*, F45, 69085(2).

Plate V. 1, 2, *A. nuthallensis*, E48, 69084(3); 3, *I. mundus*, H57/1, 69083(2); 4, ?*Densipollenites* sp. , V58/2, 69089(3); 5, ?*Densipollenites* sp. , V62, 69089(3).