Tanner, L.H., Spielmann, J.A. and Lucas, S.G., eds., 2013, The Triassic System. New Mexico Museum of Natural History and Science, Bulletin 61.

PERMIAN AND TRIASSIC STRATA OF JORDAN

KLAUS BANDEL[1] AND ABDALLA M.B. ABU HAMAD[2]

[1] Universität Hamburg, Geologisch Paläontologisches Institut und Museum, Bundesstrasse 55, 20146, Hamburg, Germany, email: klausbandel@yahoo.com; [2] Department of Applied and Environmental Geology, University of Jordan, Amman, Jordan, email: a.abuhamad@ju.edu.jo

Abstract—Deposition of Upper Permian and Triassic sediments in central and northern Jordan took place on an ancient surface formed by Cambrian sandstones. In southern Jordan this surface is overlain by Cretaceous deposits, and Triassic rocks are not found south of the River Mujib. The Upper Permian Um Irna Formation consists of fluviatile deposits and paleosols that are characterized by iron-oxide pisolites. The 85 m of predominantly redbed sediments contain a well-preserved flora. The transition to the Triassic Ma'in Formation is gradational. The 50-m thick lowest Triassic was deposited in a near-coastal arid environment. The overlying 60-m thick Dardun Formation was deposited with increasing marine influence as documented by trace fossils and crinoid debris. The 100-m thick Ain Musa Formation shows evidence of deposition in lagoons and estuaries. The Middle Triassic is approximately 250 m thick and consists of three formations deposited with a strong marine influence. The Hisban Formation is predominantly limestone and approximately 35 m thick, and the succeeding 60-m thick Mukheiris Formation consists of intercalated marine deposits and plant-bearing continental deposits. The Ain Musa Formation, predominantly sandstone, contains beds that are fully marine with ceratitid ammonites, terebratulid brachiopods and diverse vertebrates. The Upper Triassic, consisting of two formations, measures about 550 m thick and is dominated by carbonate and evaporite deposits. The Um Tina Formation is predominantly dolomitic, while only the uppermost Abu Ruweis Formation, which consists largely of evaporites, is exposed. Here gypsum deposits are intercalated and overlain by estuarine mudstones and fluvial sandstones. This sequence, also called the "Arabian Keuper," marks the top of the Triassic, and is truncated by an erosional surface that was flooded by a Liassic transgression.

INTRODUCTION

In Jordan, outcrop exposures extend from the eastern shores of the Dead Sea, in the south from Wadi Mujib, to Wadi Zarqa in the middle portion of the Jordan valley in the north (Fig. 1). Here, the basal outcrops expose Permian strata unconformably overlying Cambrian sandstones. Thus, a major hiatus is present at the base of the Permo-Triassic, and another hiatus separates the Triassic from the Jurassic. In a general way the Jordanian Triassic resembles that of the Germanic basin, with a sandy base, a carbonate middle and a saline top.

PERMIAN

Following extensive exposure and erosion, alluvial sedimentation in Jordan resumed with sediment supplied by rivers from the south and east. Permian-Triassic exposures occur at the eastern rim of the Jordan-Dead Sea rift in the steep valleys and the slope above the northern shore of the Dead Sea. Bandel and Khoury (1981) described the unconformity between the Cambrian and Permian; paleosols from the uppermost Permian in the outcrops of the eastern Dead Sea area demonstrate a warm and humid paleoclimate in which iron-oxide pisolites formed, mediated by the activity of photosynthetic bacteria. Similar pisolites with a concentric structure of iron-hydroxide form today in the red soils in the South African Natal (Bandel and Khoury, 1981). Plants growing on this Upper Permian soil consisted of gymnosperms, including some common forms with fern-like bipinnate leaves, such as *Dicroidium*, characteristic of the Triassic of southern Gondwana (Abu Hamad, 2004; Kerp et al., 2006; Abu Hamad et al., 2008).

The Permian of Jordan is represented by the Um Irna Formation, named for the mountain range separating Wadi Zarqa Ma'in from Wadi Himara, both of which are located on the northeastern slope of the Dead Sea. The type section for the formation is located in Wadi Himara, about 3 km north of the Zarqa Ma'in hot springs. The base, which rests on Cambrian sandstone of the Um Ishrin Formation, consists of about 6 m of gray clay with plant fragments and has irregular bedding, overlain by brown clay with iron-oxide pisolites. The Um Irna Formation is about 85 m thick and is divided into six well-defined members representing fining-upward cycles. These consist of coarse-grained conglomerate or sandstone at the base, fining upwards to medium- and fine-grained sandstone. The sandstone passes gradually upwards to rippled reddish to gray siltstone, overlain by dark gray to green claystone with plant fossils and coals. The two first cycles have conglomerate at the base, and the finer sandstones have cross bedding, ripple marks, and occasional bioturbation. The upper four members or cycles begin with coarse-grained, cross-bedded sandstone, grading upward to thinly laminated (10 to 15 cm), light gray siltstone and brownish-greenish silty mudstone. The uppermost bed of each member consists of massive clay containing iron-oxide pisolites up to 20 mm in diameter. Mostly, these are autochthonous, having formed in the soil, but some were eroded and redeposited.

The Um Irna Formation has also been observed in wells in the north and northwest of Jordan (Bandel and Khoury, 1981; Andrews, 1992; Makhlouf et al., 1996). Equivalent sedimentary rocks were assigned an Early to Late Permian age (Kungurian to Kazanian) by Keegan et al. (1987). A distinct flora was found 4.5 km north of Wadi Mujib (Mustafa, 2003) and charcolified wood presents evidence for common wildfires (Uhl et al., 2007). Dill et al. (2010) reconstructed the depositional environment of the Um Irna Formation, based in part on organic geochemistry, as that of a sandy braided- to meandering- fluvial system with poorly aerated swamps and ponds in which plant debris accumulated. These sediments are overlain by floodplain deposits with paleosols incised by episodic channels of an anastomosing drainage system. In Israel, contemporaneous Permian sediments were deposited in a shallow marine environment, as in the Negev area, for example (Eshet, 1990).

Palynology

In Jordan, as well as in Israel, palynomorphs and sporomorphs of gymnosperms and ferns present evidence of a strong turnover from the

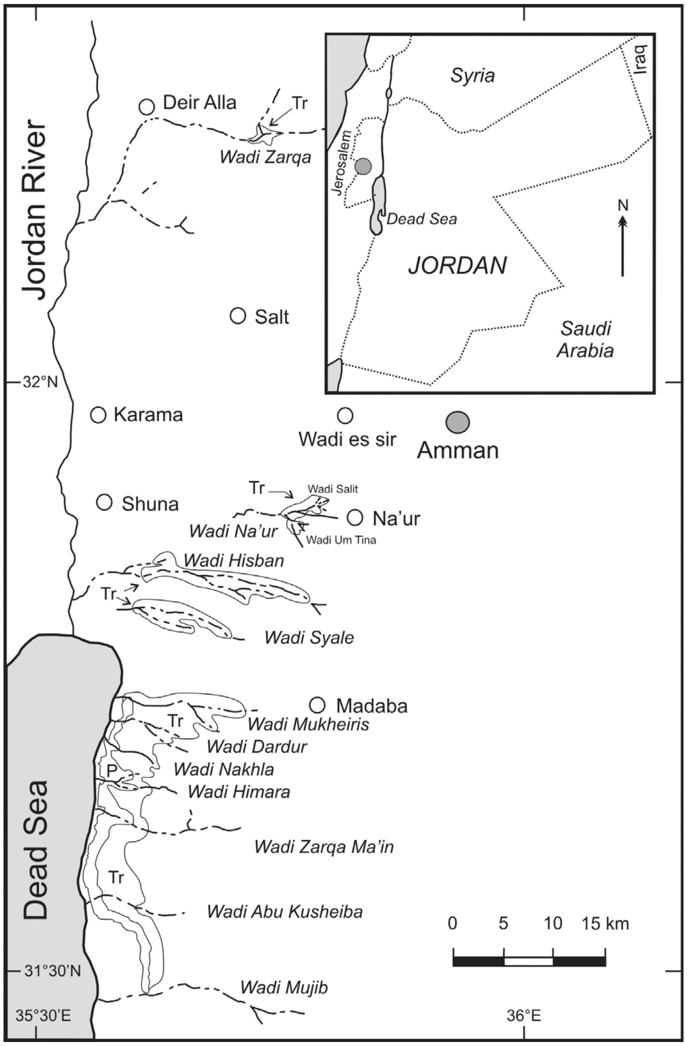

FIGURE 1. Map showing the Permian and Triassic outcrops in Jordan. **Abbreviations: P**, Permian rocks; **Tr**, Triassic rocks.

Late Permian to the Early Triassic (Eshet and Cousminer, 1986; Eshet, 1990; Abu Hamad, 2004). Most Late Permian species did not survive to the Early Triassic. The coaly beds include sporinite that contains pollen and spores with two morphologies, individual lens-shaped grains and bisaccate grains. The outer walls of the lens-shaped grains may display ornamentation, such as short, wide spines. Bisaccate forms display ornamented air sacks with characteristic reticulate ultrastructure (Dill et al., 2010). Additionally, fungal spores have a peak at the boundary (Eshet et al., 1995), although this is not observed in the outcrop near Wadi Zarqa Ma'in where the boundary is well exposed.

Palynomorph index taxa such as *Lueckisporites virkkiae*, *Klausipollenites schaubergeri*, *Falcisporites zapfei*, *Protohaploxypinus microcorpus*, *P. varius*, *Striatopodocarpites fusus*, *Hamiapollenites insolitus*, *Nuskoisporites klausii*, and *Potonieisporites novicus* document a Late Permian age for the Um Irna Formation and are characteristic of the *Lueckisporites virkkiae* zone as found in the Upper Permian of Israel, and other regions of the world (Abu Hamad, 2004; Fig. 2).

The presence of *Dicroidium* in the Permian of Jordan is puzzling, since these trees are best known from the Triassic of the southern regions of Gondwana. It has been assumed that it is related to *Glossopteris*, which lived in southern Gondwana and represents a group of gymnosperms with an unclear affinity. The wood resembles that of *Araucaria* living in South America. *Dicroidium* and *Glossopteris* are up to 6-m high trees of the Permian and Triassic that became extinct during the Jurassic. They have been reconstructed as intermediate between Cycadea and Coniferes.

Tectonics

Deposition of the Um Irna Formation coincided with the time of the Pangean supercontinent that resulted from the subduction of the Paleotethyan and the Rhaeic oceans during the Variscan orogeny. This fused the continents Laurussia and Palaeo-Gondwana, while the area that is now Jordan was not affected and lay on a stable (passive) margin of the Paleotethyan Ocean. It is thought that Gondwana rotated counterclockwise and drifted some 10^o north-westward, so that northeast Africa and the Arabian platform were situated between 10^o to 50^o paleolatitude, between 315 and 250 Ma (Carboniferous-Permian). Jordan lay at about 20° south of the paleoequator (Schandelmeier et al., 1997). During the Late Permian rifting commenced subparallel with the northern margin of Gondwana, initiating the Mesozoic break-up of Pangea.

Jordan was located on the continental shelf area that was inundated repeatedly by transgressions of the Tethyan Ocean since Late Permian time. The Permian-Triassic in Israel is relatively close to that of Jordan (Zak, 1963; Benjamini et al., 2005). Here, subsurface data document that the Precambrian is covered by a basal unit of Early Permian to early Anisian age (Zaslavskaya et al., 1995). The basal Sa'ad Formation is about 80 m thick, consisting predominantly of sandstone with some coaly shale with plant remains and a few layers of limestone and dolostone. The overlying Arqov Formation consists of 194 m of alternating sandstone, shale and carbonate units interpreted as near-shore marine deposits (Druckman, 1974; Druckman et al., 1982; Benjamini et al., 1993). Fusulinid limestone occurs in the subsurface of the coastal plain in Israel (Orlova and Hirsch, 2005). It is not clear whether the Late Permian hiatus in the areas adjacent to Jordan resulted from non-deposition or from post-Permian erosion. The deposits of the Um Irna Formation are overlain unconformably by the Lower Triassic Ma'in Formation, but the erosional surface is indistinct.

TRIASSIC

The Triassic in the Germanic Basin consists of the lower red sandstone series (Buntsandstein), the central limestone-evaporite series (Muschelkalk) and the upper series with sandstone, claystone and saline deposits (Keuper). The Triassic in Jordan also consists of three parts, a lower colorful sandy unit (Ma'in, Dardun and Ain Musa formations), a central unit with abundant limestones (Hisban and Mukheiris formations) and an upper unit deposited under mainly saline conditions (Iraq al Amir, Um Tina and Abu Ruweis formations). The depositional environment of the Triassic in Jordan, however, was an interior epicontinental sea, called the Sephardic Sea (Hirsch 1973, 1990), on the southern part of the supercontinent Pangea. It represents an expansion of the Tethyan Ocean onto the southern shelf of Pangea, unlike the Germanic Basin in northern Pangea. The distinct cyclicity in both areas suggests a global sea level control to sedimentation (Rüffer and Zühlke, 1995). Several cycles recognized in the Muschelkalk and Keuper of the Germanic Basin appear to correlate with those of the Hisban to Iraq al Amir formations (or the Zafir to Gevanim formations in the Negev), based on data by Aigner and Bachmann (1992) from the Germanic Basin, and Benjamini et al. (1993), Druckmann (1974), Eshet (1990) and Parnes (1986) from Israel.

Exposures of Triassic rocks in Jordan occur in the deep valleys that cut into the eastern slopes of the Dead Sea valley and the southern Jordan River valley, from south of Zarqa Ma'in (near Wadi Mujib) north to Naur and again in the lower reaches of Wadi Zarqa (Cox, 1924; Wagner, 1934; Blake, 1936; Quennell, 1951; Bender, 1968; Bandel and Khoury, 1981; Shawabekeh, 1998). The total thickness of the Triassic succession exposed in Jordan is around 660 m, but subsurface data indicate thicknesses of up to about 1000 m.

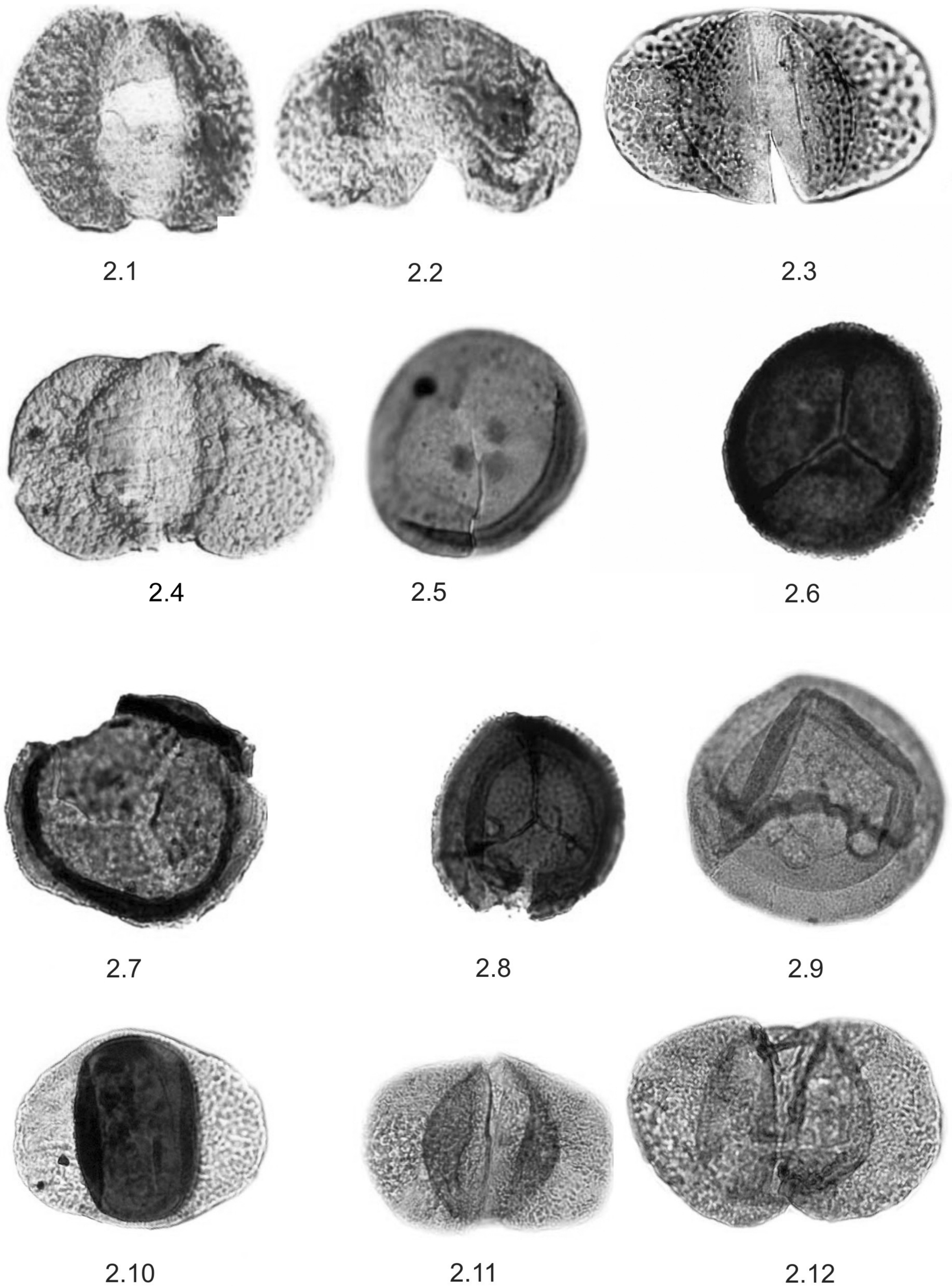

FIGURE 2. Palynomorphs of the Upper Permian through Middle Triassic of Jordan. **2.1-2.4**, from Um Irna Formation, Upper Permian; **2.5-2.8**, from Ma'in Formation, early Triassic; **2.9-2.12**, from Mukheiris Formation, middle Triassic (Anisian). **2.1**, *Lueckisporites virkkiae* Potonie and Klaus 1954, X 400. **2.2**, *Klausipollenites schaubergeri* (Potonie and Klaus 1954) Jansonius 1962, X 400. **2.3**, *Falcisporites zapfei* Potonie and Klaus 1954, X 400. **2.4**, *Protohaplloxypinus microcorpus* (Schaarschmidit 1963) Clarke 1965, X 400. **2.5**, *Endosporites papillatus* Jansonius 1962, X 600. **2.6**, *Densoisporites playfordii* Balme 1963, X 600. **2.7**, *Kraeuselisporites varius* Ouyang and Norris 1999, X 600. **2.8**, *Lundbladispora obsolete* Balme 1970, X 600. **2.9**, *Aratrisporites saturnii* (Thiergardt 1949) emend Madler 1964a, X 1000. **2.10**, *Triadispora plicata* Klaus 1964, X 1000. **2.11**, *Alisporites grauvogelii* Klaus 1964, X 1000. **2.12**, *Angustisulcites klausii* (Freudenthal 1964) emend. Visscher 1966, X 1000.

Lower Triassic

Biostratigraphy

Biostratigraphy of the succession is based on palynomorphs, mainly of gymnosperms, and sporomorphs, on microfossils, particularly conodonts (Huckriede, 1955; Hirsch, 1973; Eicher and Mosher, 1974; Bandel and Waksmundzki, 1985; Abu Hamad, 1994; Saddedin, 1990, 1998; Saddedin and Kozur, 1992), sclerites of holothuroids (Saddedin, 1991) and on ammonites (Cox, 1924; Parnes, 1986). The resemblance of the middle limestone (Hisban formation) to the Muschelkalk of the Germanic Basin has long been recognized (Wagner, 1934a) and was elaborated upon by Bender (1968). The similarity of the Triassic of the Sephardic Province of Jordan, Israel and the Sinai to the Germanic Province was noted by Blankenhorn (1912), who compared the Hisban Limestone to the Muschelkalk, and by Wagner (1934a) and Rüffer and Zühlke (1995).

An unconformity appears to be present between the Permian Um Irna Formation and the Early Triassic series, based on the lack of pollen and spores from the Induan (= Griesbachian and Dienerian). But the Scythian is palynologically poorly known and few regions have yielded well-preserved associations as large areas of Lower Triassic deposits are characterized by terrestrial red-bed facies (Abu Hamad, 2004).

The Lower Triassic sequence belongs to the *Endosporites papillatus* - *Veryhachium* spp. zone and probably equates to the Olenekian (= Smithian). This includes the Ma'in Formation (about 50 m thick), the Dardun Formation (about 60 m) and the Ain Musa Formation (about 100 m). Index taxa are *Aratrisporites paenulatus*, *Densoisporites nejburgii*, *D. playfordii*, *Endosporites papillatus*, *Kaeuselisporites apiculatus*, *K. varius*, *Lapposisporites echinatus*, *Lundbladispora obsoleta*, *Punctatisporites fungosus* and *Veryhachium* spp. Common are the sporomorph *Endosporites papillatus* and the acritarch *Veryhachium*, and the zone characterized by them ends with the Hisban Formation (Figs. 2-3).

Ma'in Formation

In Jordan the Scythian Ma'in Formation measures 35 to 45 m in thickness and overlies the Permian Um Irna Formation with indistinct unconformity that only expresses relief locally. The Ma'in Formation consists of the Himara and Nimra members, both well exposed in the neighboring Wadi Mukheiris, Wadi Himara and Wadi Nimra on the eastern slope of the northern Dead Sea valley. Dark purplish colors characterize the Himara Member, which consists of beds of thinly bedded sandstone, siltstone and lime rich claystone of about 26 m. Burrows of in-faunal organisms include *Rhizocorallium*, and bivalve resting and crawling traces occur on bedding planes. Ripple marks and mud dessication cracks, which demonstrate subaerial exposure, also occur on bedding planes. Some surfaces have abundant bivalve shells, while other layers are covered with the valves of conchostracans like *Estheria*. Parts of the carapace that can easily be mistaken for bivalves are common on some bedding surfaces. *Estheria*-like crustaceans occur today in puddles and pools that form during the rainy period in the eastern desert of Jordan. Thus, a similar environment of fresh water or brackish water ponds in dry surroundings was developed during Early Triassic time in Jordan. These deposits are found in the canyons along the northern shore of the Dead Sea, for example in Wadi Dardur.

During Scythian time this area was near the sea. Transgressions flooded the desert plains, covering it with clay and siltstone on and in which bivalves lived. Commonly, the valves are articulated, although more often they have become separated from each other due to transportation. The bivalves belong to the heterodont groups and are usually not well preserved because their aragonitic shell has become dissolved before the sediment was compacted and have thus been flattened and deformed.

The upper member of the Ma'in Formation (Nimra) is about 21 m thick. The base of this member consists of sandstone and siltstone beds, commonly with reddish and greenish clay flasers. Some carbonate-rich beds are present, some of which show evidence of beach rock formation and contain rip-up clasts. The top of this member consists of fine white sandstone arranged in cross-bedded units of 50 to 150 cm thickness. Bioturbation obscures the original bedding in some beds. Limestone beds in the upper portion of the member contain structures that may represent burrows.

Dardun Formation

Overlying the Ma'in Formation is the Dardun Formation, which is about 60 m thick at its type locality. This formation was deposited mostly within the intertidal to very shallow subtidal zone, but a marine influence is documented by the occurrence of crinoids, which indicate normal marine salinity. The Dardun Formation crops out at the northeastern margin of the Dead Sea and in the deep valleys between Wadi Mukheiris to the north and Wadi Abu Khusheiba to the south. The top of the Dardun Formation lies near the hot springs of Wadi Zarqa Ma'in. Its age is from Scythian to early Anisian, as documented by conodonts and palynomorphs (Huckriede, 1955; Abu Hamad, 2004). The lower limestone-rich unit, about 11 m in thickness, includes some thinly interbedded silty shale and fine-grained sandstone and dolomite. These layers show some bioturbation, but not enough to destroy the original bedding. This is overlain by 15 m of brown, cross-bedded sandstone and finely laminated dolomite and marl. Intraformational conglomerate of limestone and shale clasts occurring here suggests an intertidal environment.

The succeeding part of the Dardun Formation is about 23 m thick and is lithologically similar to the lower carbonate-rich unit. The uppermost sandy member, 12 to 20 m thick, consists of bioturbated sandstone with load casts, ripple marks and desiccation cracks. Channel-fills have quartz-pebble lags, but stromatolites and crinoidal grainstones are also present. These features provide evidence of deposition of the Dardun Formation in a coastal setting, primarily an intertidal mud flat environment in the basal member, deepening upward to a nearshore to shallow marine environment in the middle and upper units. The quartz pebbles in the channel lags are subround to subangular and were probably eroded from the Precambrian basement, which could not have been far away. Thus, the shoreline during deposition of the Dardun Formation was probably situated to the south and east of Jordan in an area where basement rocks were not covered by Paleozoic sediments.

Ain Musa Formation

The Ain Musa Formation is well exposed in Wadi Ain Musa (between Wadi Zarqa Ma'in and Wadi Mukheiris) where it cuts into the steep slope of the Jordanian highland facing the Dead Sea. The formation has three members, Muhtariqa, Jamala and Siyale, each of which has a type section at the localities of the same name. In Wadi Mukheiris the Ain Musa Formation is about 100 m thick, about 20 m thicker than in the type section further to the south. The basal Muhtariqa Member is about 45 m at its type locality at Rujm el Muhtariqa hill, situated at the end of the Wadi Ain Musa, and consists of thick sandstone with large cross-beds and some layers of cross-beds with flasers. Deposition is interpreted as occurring in a partly fluviatile environment bordering intertidal flats. Conglomeratic layers with quartz pebbles suggest an eroding upland area nearby. Several kilometers to the north of the type locality the basal sandstones are interbedded with limestone, marl, siltstone, and dolomitic limestone, indicating a lateral transition to an intertidal and shallow marine setting. Clay rip-up clasts document erosion and redeposition on intertidal surfaces. Glauconite-rich and stromatolitic beds also occur.

The type locality for the Jamala Member, which is 15 to 28 m thick, is below the confluence of Wadi Jamala with Wadi Ain Musa at the spring of Ain el Jamala. This member consists of intercalated sandstone and siltstone. The sandstone is cross-bedded and commonly displays rippled surfaces and channel-fills with lags of well-rounded quartz pebbles and tree trunks. Trace fossils, including potential burrows of crustacean

Chondrites traces, are present in the siltstone –marlstone and fine-grained sandstone. Ripple marks, flasers, load clasts, and sand-filled desiccation cracks are also present in the siltstone.

The Siyale Member is about 30 m thick and is composed mainly of greenish to gray intercalated marly claystone and siltstone. In some layers glauconite and the brachiopod *Lingula* are common. The common occurrence of wood, clay balls and quartz-pebble layers and alternating thinly laminated beds of sandstone, siltstone and marlstone is evidence for a nearshore shore environment. To the north this member is represented by a sequence consisting of sandstone, limestone layers, dolomitic limestone and siltstone, indicating increased marine influence in this area.

Middle Triassic

Hisban Formation

The Hisban Formation, ranging from 35 m thick at Wadi Dardur to 30 m at Wadi Hisban, consists predominantly of gray, stylolitic, limestone with wavy bedding that is very bioturbated, and contains many fossils, such as brachiopods, oyster-like bivalves and steinkern preservation of *Myophoria*-like bivalves and ceratitid ammonites. The rock is hard, often nodular and has a mottled appearance. The bulk of the limestone is characterized by calcareous, lithified burrows, all with an undulating morphology. The base and top of the Hisban Formation can be seen in Wadi Mukheiris and Wadi Dardun. The base is marked by a sharp contact between the green–gray marlstone–siltstone of the Ain Musa Formation and the massive limestone of the basal unit of the Hisban Formation, and the top is represented by the sharp transition from the limestone to marl to the cross-bedded sandstone of the base of the Mukheiris Formation, as is well exposed in Wadi Mukheiris. Conodonts document an Anisian age of the Hisban Formation.

The depositional environment of the Hisban limestone was a shallow marine environment, generally not proximal to land. Oolites, documented in the subsurface near Suweilih, demonstrate the presence of a shallow shoaling environment in part. Similarly, beds of oyster-like bivalves at Wadi Hisban indicate shallow water with high productivity. Intercalated crinoidal limestone beds at Wadi Dardun indicate normal marine conditions. The microfacies of these limestones were analyzed by Shinaq (1990).

The bivalve *Myophoria* occurs in both the Muschelkalk of the Germanic Basin and the Jordanian Triassic, especially in the Hisban and Mukheiris formations. *Myophoria* had an aragonitic shell with a somewhat triangular shape and sharp corners beginning at the umbo. There can be an ornamention on the posterior area of the shell surface and that distinguished different species. The hinge has a strong median tooth that may be split (schizodont). The preservation of *Myophoria* is as an internal mold or cast of the shell on mud, which was cemented before the aragonitic shell with nacreous composition dissolved, leaving a cavity which may have filled with cement carried by the pore water. *Myophoria* belongs to the same group of bivalves (with a hinge with heterodont teeth and a shell with an inner layer of nacre) as does *Trigonia*, which is common in the Jurassic of Jordan. Both are members of the Palaeoheterodonta, which are survived by the one genus *Neotrigonia*, which still lives in the Pacific along the west coast of Australia. Some bivalves from the Triassic in Israel were described by Lerman (1960) and are similar to those found in Jordan.

Some bivalves from the Hisban Formation were described by Cox (1924, 1932) and Wagner (1934a,b), and an Anisian to Early Ladinian age was suggested by Wetzel and Morton (1959). Parnes (1975) assigned an early Anisian age accepted by Bandel and Khoury (1981). Based on conodonts and holothurian sclerites Sadeddin and Kozur (1992) and Sadeddin (1998) confirmed an Anisian age for the Hisban Formation.

The Hisban Formation consists of several types of limestone. Some beds consist of lithified burrows, ammonites, bivalves with both valves together and crinoid ossicles (sometimes still connected to longer fragments of the stem) in a marly matrix. Other beds consist entirely of lithified burrows. Fine-grained carbonate beds are heavily stylolitic. Interbedded layers are predominantly coquinas of oyster-like bivalve and brachiopod shells, including *Lingula*, in marly matrix with glauconite. Some layers are lingulid-bearing dark marl to clay, and others are red clay with the trace fossil *Zoophycos* and scattered large bivalves. Locally, oolites and echinoidal limestone beds are present. The Hisban Formation between Wadi Hisban and Wadi Dardun thus was deposited in a shallow, subtidal environment, but close to shore, and possibly periodically in an intertidal setting.

Mukheiris Formation

The base of the Mukheiris Formation is defined where thick massive limestone beds of the Hisban Formation are conformably overlain by sandstone and marly claystone. This can be interpreted as an increased influence of siliciclastic sediment derived from erosion of the Gondwana continent spreading to Jordan. Some observations on the deposition of the Mukheiris Formation were presented by Makhlouf (2003).

Conodonts, holothurian sclerites, ammonites (Ceratitida), brachiopods (*Coenothyris*) and bivalves (similar to *Placunopsis)* are present in the Mukheiris Formation, and sporomorphs suggest an Anisian age (Saddedin and Kozur, 1992; Abu Hamad 1994, 2004). Great numbers of conodonts have been extracted from mid-Triassic limestones in the Wadi Shita area near Naur (Bandel and Waksmundzki, 1985). *Ceratites* and related ammonites from the Jordanian Triassic are similar to those of the Germanic Basin from the same time, although the species in the Sephardic Basin differ from those in the Germanic Basin (Parnes, 1986; Parnes et al., 1985). The small bivalve interpreted to be close to *Placunopsis* lived attached to the substrate and resembles modern *Anomia*, but the relationship to the Anomiidae among the bivalves is not clear since the Triassic species may instead be related to ancestral oysters (Ostraeidae). The preservation is excellent, as much of the shell was originally composed of lamellar calcite, as is still the case with *Anomia* and most oysters. *Placunopsis* settled on hard substrates, and it may also be found attached to the shell of *Ceratites*. Good preservation is present in the terebratulid brachiopod *Coenothyris* from Wadi Naur. From the Mukheiris Formation there is a very rich association of palynomorphs of the *Aratrisporites saturnii* zone with high diversity and good preservation. Present are *Alisporites grauvogelii*, *Al. magnus*, *Angustisulcites klausii*, *Aratrisporites fimbriatus*, *Ar. paenulatus*, *Ar. parvispinosus*, *Ar. playfordii*, *Ar. strigosus*, *Ar. saturnii*, *Brachysaccus ovalis*, *Hexasaccites muelleri*, *Triadispora crassa*, *T. plicata*, *T.* spp., *Voltziaceaesporites heteromorphus* and *Stellapollenites thiergartii* (Figs. 2-3). This zone can be dated as late Pelsonian to Illyrian (late Anisian).

The Mukheiris Formation is about 80 m thick at Wadi Mukheiris, which is the most northern deep canyon ending at the shore of the Dead Sea, and is also well exposed in Wadi Dardur just south of Wadi Mukheiris. It can also be recognized in wells in north and northeast Jordan. Three members are distinguished in the Mukheiris Formation, of which the lowest is 30 m thick and consists of fine-grained, cross-bedded sandstone with rippled surfaces and intercalations of marly claystone and siltstone. Channel–fills contain wood and clay beds contain many fragments of gymnosperm leaves still bearing cuticles. The top of the lower member consists of bioturbated calcareous sandstone with glauconite, and many fossils, including bivalves, ceratitid ammonites and bones of an amphibian. The vertebrate remains were found in Wadi Mukheiris and include a 50-cm long skull of a temnospondyl amphibian of the trematosaur group, which lived in marine environments. The Jordanian trematosaur was at least 3 m long and lived in shallow water (Schoch, 2011). The excellent in-situ preservation of the teeth within the mandible indicates a lack of significant transport, suggesting rapid burial. The fossil locality lies about 15 m above the base of the Mukheiris Formation.

The middle member of the formation consists of clay and silty

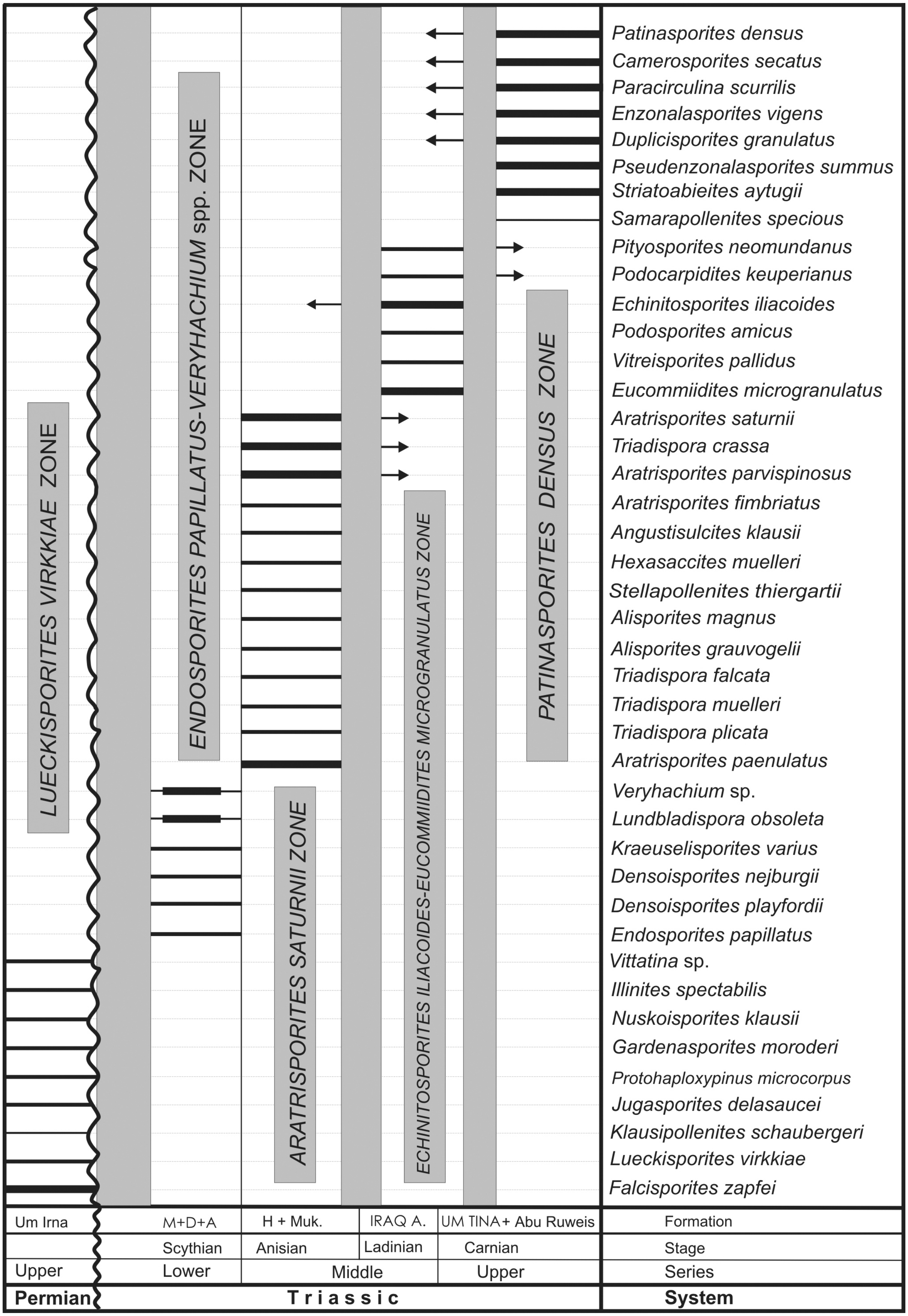

FIGURE 3. Range chart of selected Permo-Triassic palynomorphs from Jordan. **Abbreviations: A**, Ain Musa Formation; **D**, Dardur Formation; **H**, Hisban Formation; **M**, Ma'in Formation; **Muk**, Mukheiris Formation; **UMT**, Um Tina Formation.

shale about 30 m thick and contains *Lingula*. The upper member is approximately 20 m thick and consists of fine to coarsely grained, cross-bedded sandstone and thinly laminated, rippled marlstone and siltstone with plant remains. Sandstone-filled channel scours contain a fine conglomerate of quartz pebbles at their base. The top of the member is dark to black, thinly-laminated claystone, truncated by the unconformity of the Lower Cretaceous Kurnub Sandstone. The upper part of the Mukheiris Formation has been interpreted to be exposed further to the north near Naur, but pollen and spores present no evidence that the deposits here belong to the Mukheiris Formation.

Iraq al Amir Formation

Just north of Naur a roughly 160 m-thick sequence of Triassic rocks exposes the Iraq al Amir and Um Tina formations. Further to the south, this part of the Triassic sequence was eroded prior to deposition of the Lower Cretaceous Kurnub Sandstone. During this time the influx of sediments from the continent decreased, and sandy deposits rarely occur. About 95 m of the Iraq al Amir Formation, consisting of three members, are exposed in Wadi Naur and Wadi Salit.

The exposed part of the basal Bahhath Member of the Iraq al Amir Formation consists of about 26 m of fossil-bearing sandy limestone, marl, calcite-cemented sandstone, fine sandstone, siltstone, and marly, laminated claystone. The macrofossils reported comprise *Placunopsis*, terebratulid brachiopods, crinoid ossicles and ceratitid ammonites. In the limestone beds burrows with an *Ophiomorpha*-type morphology form an interconnected network. Scratch marks on the walls support an interpretation that they were constructed by burrowing crustaceans. Other limestone beds contain reworked, lithified tubes of the type that are characteristic of the Hisban limestone. The depositional environment was a shallow, subtidal, open shelf setting.

The middle Abu Jan Member is about 40 m thick and consists predominantly of limestone and is locally glauconitic. Some beds contain abundant fossils, including various gastropods, bivalves, ceratitid ammonites, terebratulid brachiopods and the bones and teeth of sharks. In some layers bone-beds consist of numerous bones of mixed sizes, usually fragmentary, as well as phosphatic nodules. The upper part of the member is dominated by well-lithified limestone and oolitic limestone containing crinoid ossicles and echinoid spines. The top of the Abu Jan Member consists of about 2 m of sandy dolomite and limestone with irregular hardground surfaces and intraformational limestone conglomerate. It thus appears that following deposition in an open marine environment with an abundant fauna deposition took place in a more restricted setting resulting in more saline deposition and dolomitization. The Abu Jan Member was intruded during the Late Jurassic or Early Cretaceous by a diabase sill up to 5 m thick.

The upper Shita Member is about 25 m thick and consists of fine-grained to marly limestone, thinly-bedded marly claystone, and an upper dolomitic limestone to dolomite. The marl contains *Zoophycus* type traces. Hard-ground surfaces within the limestone were encrusted by oyster-like bivalves and pits contain gastropod steinkerns and the spines of sea urchins. A single layer with pyritic dark limestone and shell debris of *Lingula*-like brachiopods contains many conodonts (Bandel and Waksmundzky, 1985). At Wadi Shita, which discharges into Wadi Naur, this member is exposed with laminated stromatolitic carbonates with dessication cracks and flat-pebble conglomerates at the top grading into the basal beds of the overlying Um Tina Formation. The age of the Shita Member is Ladinian, based on conodonts and holothurian sclerites, and similar beds in Israel have the same conodont age (Saddedin, 1991).

Palynomorphs taxa from the Iraq al Amir Formation include *Angustisulcites klausii*, *Echinitosporites iliacoides*, *Eucommiidites microgranulatus*, *Heliosaccus dimorphus*, *Hexasaccites muelleri*, *Keuperisporites baculatus*, *Alisporites microreticulatus*, *Vitreisporites pallidus*, *Staurosaccites quadrifidus*, *Microcachryidites doubingeri*, *Pityosporites neomundanus*, *Podocarpidites keuperianus*, *Podosporites amicus*, *Triadispora crassa* and *T. sulcata* which define the *Echinitosporites iliacoides-Eucommiidites microgranulatus* zone of Langobardian (late Ladinian) age (Figs. 3-4; Abu Hamad, 2004).

Upper Triassic

Repeated cycles of a shallowing upwards carbonate-sabkha sequence, with a tendency toward more marine conditions towards the northwest may be observed in the Upper Triassic of Jordan. Cycles grade from subtidal oolite shoals, into lime mud of a lagoon, intertidal algal mud with some stromatolites, supratidal laminated mudstone and intraclast conglomerates and nodular anhydrite, and in some cases into halite. The upper 500 m of deposition of Triassic sediments in Jordan is dominated by carbonates and evaporites. Thin clays were deposited from suspension. Most of these beds are not exposed but can be found in the subsurface.

The Upper Triassic of Jordan consists of two formations, the Um Tina and the Abu Ruweis formations. These are assigned a late Cordevolian-Julian (latest early Carnian-middle Carnian) age (Abu Hamad, 2004) based on the palynomorph taxa *Camerosporites secatus*, *Corollina torosa*, *Duplicisporites verrucosus*, *D. granulates*, *Infernopollenites salcatus*, *Lunatisporites acutus*, *Ovalipollis ovalis*, *Patinasporites densus*, *Praecirculina granifer*, *Paracirculina scurrilis*, *Pityosporites neomundanus*, *Samaropollenites speciosus*, *Enzonalasporites vigens*, *Pseudenzonalasporites summus*, *Podocarpites keuperianus* and *Striatoabieites aytugii*. These defined the *Patinasporites densus* Zone, which can be compared with equivalent palynomophs zones from Israel and Europe (Figs. 3-4). Cirilli and Eshet (1991) noted that a similar Carnian palynoflora extended from the Tethyan of Israel to Austalia and Asia.

Um Tina Formation

About 70 m of the Um Tina Formation are exposed in Wadi Um Tina, about 1 km south of Wadi Naur, but it may be up to 200 m thick in the subsurface further to the north in Jordan. Gray fossiliferous limestone and micritic limestone, commonly displaying stromatolitic lamination, and thinly laminated gray marly claystone form the base of the formation. The upper part is dominated by 1 to 2 m-thick beds of gray marly claystone intercalated with yellowish, fractured limestone, and dolomitic limestone. This upper sequence is intruded by a diabase sill. Bioturbation, typically from burrowing crustaceans, is present throughout the formation, but decreasingly common towards the top. Large cushion-shaped stromatolites are exposed in the valley below Naur just below the truncated top of the formation. Conodonts indicate a Carnian age. The formation is truncated in the valley below Naur by the basal Kurnub Sandstone of Early Cretaceous age. In the subsurface the top of this formation is defined by an increase of gypsiferous beds noted in well logs.

Abu Ruweis Formation

The Abu Ruweis Formation is exposed in the canyon formed by the lower Zarqa River. Most of this formation is preserved in the subsurface of Jordan, and only the uppermost deposits are exposed at the surface. About 42 m of layered gypsum interbedded with silt, black clay and dolomite is exposed in several quarries. The gypsum-dominated unit is overlain by about 13 m of intercalated clay, marl and dolomitic limestone. Plant fossils are represented by large leaves of the fern *Phlebopteris*. The fern *Phlebopteris* is also found in the Upper Triassic of the Germanic Basin, particularly in the Rhaetian sandstones (Kelber, 1998). Palynomorphs (pollen and spores) of the Abu Ruweis Formation provide a Carnian age.

In addition to ferns, the uppermost member of the Abu Ruweis Formation contains *Lingula*. Some beds are rich in black organic matter and thin coal layers. The Triassic top is marked by a dolomitic bed which is dissected by channels that cut down as far as uppermost Triassic coaly marl beds with fern fossils. The formation is overlain by about 3 m

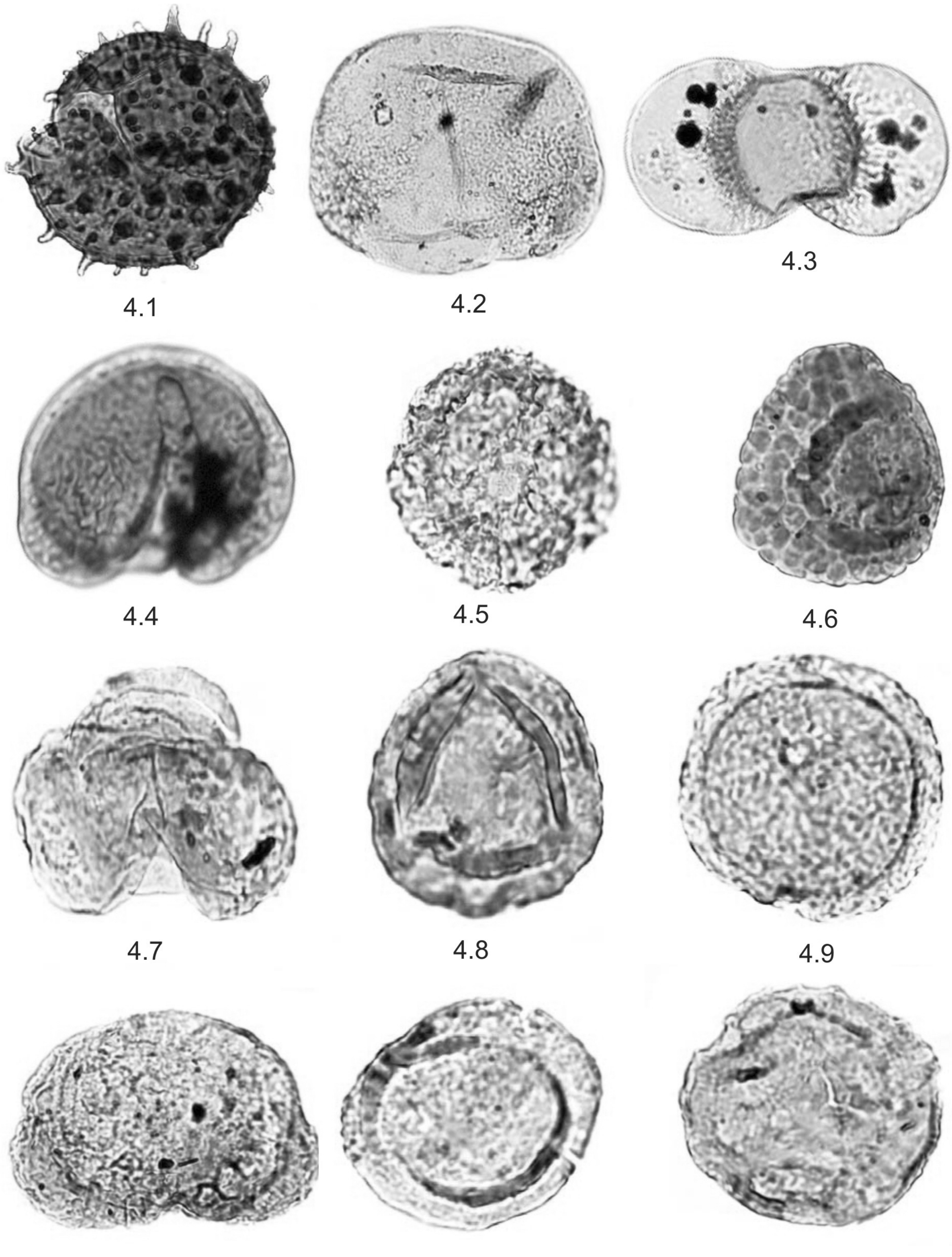

FIGURE 4. Palynomorphs of the Middle through Upper Triassic of Jordan. **4.1-4.4**, from Iraq Al-Amir Formation, Middle Triassic (Ladinian); **4.5-4.6**, from Um Tina Formation, late Triassic (Carnian); **4.7-4.12**, from Abu Ruweis Formation, Late Triassic (Carnian). **4.1**, *Echinitosporites iliacoides* Schulz and Krutzsch 1961, X 400. **4.2**, *Eucommiidites microgranulatus* Scheuring 1970, X 1000. **4.3**, *Vitreisporites pallidus* (Reissinger 1938) emend. Nilsson 1958, X 1000. **4.4**, *Podosporites amicus* Scheuring 1970, X 1000. **4.5**, *Patinasporites densus* Leschik 1956a, X 1000. **4.6**, *Camerosporites secatus* Leschik 1955, X 1000. **4.7**, *Striatoabieites aytugii* Visscher 1966, X 1000. **4.8**, *Duplicisporites granulatus* Leschik 1956a, X 1000. **4.9**, *Enzonalasporites vigens* Leschik 1956a, X 1000. **4.10**, *Samaropollenites specious* Goubin 1965, X 1000. **4.11**, *Paracirculina scurrilis* Scheuring 1970, X 1000. **4.12**, *Pseudenzonalasporites summus* Scheuring 1970, X 1000.

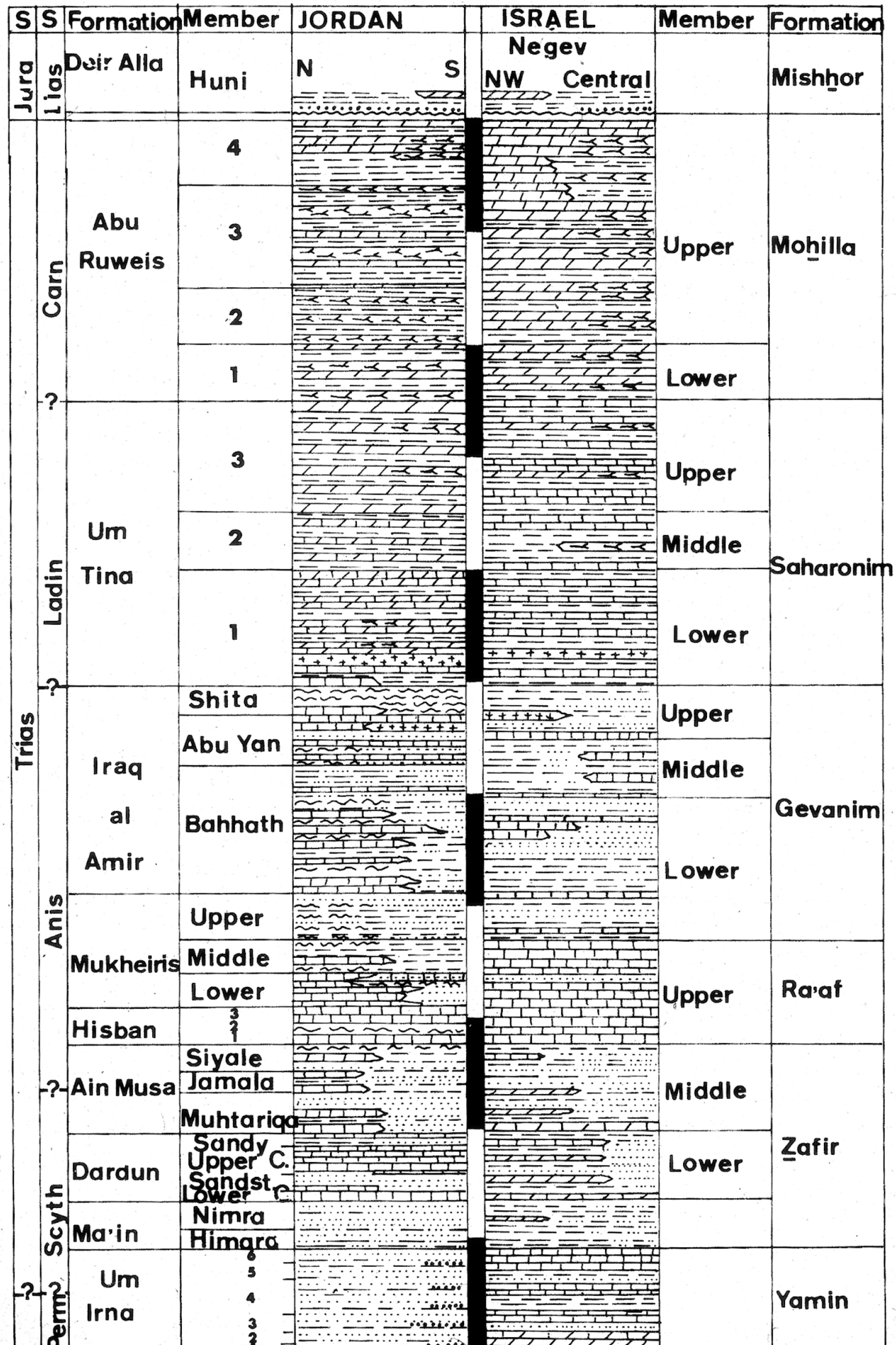

FIGURE 5. Comparison of Jordanian Triassic as described by Bandel and Khoury (1981) and Israel by Druckman (1974). The boundary between the Um Irna and Ma'in formations has since been confirmed as the Permian-Triassic boundary (Abu Hamad, 2004). (Each vertical bar represents 100 m stratigraphic thickness).

of colorful claystone with pisolitic paleosols, which formed sometime in the transition between Late Triassic and Early Jurassic time (Bender, 1968; Bandel, 1981). The transgression of the Jurassic sea occurred after a prolonged period of subaerial exposure.

Dill et al. (2012) found that the inorganic, organic and isotope-based chemofacies analysis of the Abu Ruweis Formation as well as its content of minerals and composition of the coal allows the definition of a special "Arabian Keuper Facies." It contains an evaporite – coal facies of Carnian age that is characteristically found in northwestern Jordan. Its paleogeographic setting was characterized as consisting of two cyclic units with salt pan deposits at the base and mudflats on the top which reflect a gradual deepening of the basin. The salina cycle faded out in a marine incursion and reworking of sulfate. The transition from a transgressive to a regressive facies is marked by a restricted marine depositional environment when the maximum depth was reached. River mud reached this standing water body and was dumped here until sands arrived and came to rest within a delta front and delta plain depositional environment. In the shallow basin, poorly aerated swamps later turned into well aerated delta plains with soil (paleosol) and coal seams.

Top of the Triassic

Deposits from the Norian have not been recognized in Jordan. During the early Norian, continental sandstones are reported to have been deposited in the Sinai area (Bandel et al., 1987; Bandel and Kuss, 1987). The top of the Jordanian Triassic exposures, with the exception of that in the Wadi Zarqa area, is represented by erosional surfaces overlain by sandstones of the Early Cretaceous Kurnub Formation (Bandel, 1981). Erosion occurred between the Late Jurassic and the Early Cretaceous and resulted in a total absence of Triassic rocks south of Wadi Mujib in Jordan. To the north of Wadi Zarqa, Triassic rocks are no longer exposed, but are present in the subsurface (Bandel and Khoury, 1981; Ahmed and Daher, 1988; Andrews, 1992; Makhlouf et al., 1996). In Wadi Ain Musa, the Hisban limestone forms the top of the Triassic section, which is overlain by a basal conglomerate and the sands of the Kurnub Formation. In Wadi Dardun, the unconformity truncates the Mukheiris Formation about 24 m higher in the Triassic section. In Wadi Mukheiris about 80 m of Triassic strata above the Hisban limestone are preserved below the Cretaceous unconformity.

COMPARISONS TO ISRAEL

The Jordanian Triassic, totalling about 1000 m in thickness, can be compared with sections that have been described in southern Israel (Fig. 5; Benjamini et al., 2005). Here the Permian-Triassic succession has been described as about 1500 m thick. In the Lower Triassic, the Yamin Formation consists of about 130 m of sandstone succeeded by carbonates capped with sandstone. About 240 m of alternating shale, fossil-bearing limestone and sandstone compose the Scythian Zafir Formation. The Anisian Ra'af Formation is equivalent to the Hisban limestone in Jordan and the Gevanim Formation correlates in part to Mukheiris Formation. The latter has a thickness of about 270 m and is interpreted to have been deposited in nearshore to tidal-flat environments. In Israel the change to predominantly carbonate and evaporite deposition occurred in Ladinian time during deposition of the Saharonim Formation. The uppermost Triassic formation in Israel is the Mohilla Formation, which consists of up to 200 m of anhydrite and dolomite with some shale, limestone and marl deposited in an environment of hyper-saline supratidal flats during Carnian to Norian time.

ACKNOWLEDGMENTS

We want to thank Dr. Steffen Kiel and Prof Dr. Olaf Elicki for reviewing the manuscript and improving it. Klaus Bandel also expresses his thanks to his Jordanian friends Prof. Dr. Elias Salameh and Prof. Dr. Rafie Shinaq for their hospitality and help whenever visiting Jordan.

REFERENCES

Abu Hamad, A.M.B., 1994, Stratigraphy and microfacies of the Triassic in Wadi Abu Onei area (West Naur) [Master thesis]: Yarmouk University, Jordan, 76 p.

Abu Hamad, A.M.B., 2004, Palaeobotany and palynostratigraphy of the Permo-Triassic of Jordan [Ph.D. dissertation]: University Hamburg, 330 p.

Abu Hamad, A., Kerp, H., Vörding, B. and Bandel, K., 2008, The later Permian flora with *Dicroidium* from the Dead Sea region, Jordan: Reviews of Paleobotany and Palynology, v. 149, p. 85-130.

Aigner, T. and Bachmann, G.H., 1992, Sequence-stratigraphic framework of the German Triassic: Sedimentary Geology, v. 80, p. 115-135.

Andrews, I.J., 1992, Permian, Triassic and Jurassic lithostratigraphy in the subsurface of Jordan: Subsurface Geology Division Bulletin 4, Geology Directorate NRA, Amman, p. 1-60.

Bandel, K., 1981, New stratigraphical and structural evidence for lateral dislocation in the Jordan Rift Valley connected with a description of the Jurassic rock column in Jordan: Neues Jahrbuch Geologie und Paläontologie, Abhandlungen 161, p. 271-308

Bandel, K. and Khoury, H., 1981, Lithostratigraphy of the Triassic in Jordan: Facies, v. 4, p. 1–26.

Bandel, K. and Kuss, J., 1987, Depositional environments of the prerift sediments - Galala hights (Gulf of Suez; Egypt): Berliner Geowissenschaftliche, Abhandlungen A78, p. 1-48.

Bandel, K. and Waksmundzki, B., 1985, Triassic conodonts from Jordan: Acta Geologica Polonica, v. 35, p. 289-404.

Bandel, K., Kuss, J. and Malchus, N., 1987, The sediments of Wadi Qena (Eastern Desert, Egypt): Journal of African Earth Science, v. 6, p. 427-455.

Bender, F., 1968, Geologie von Jordanien: Beiträge zur Regionalen Geologie der Erde, Band 7. Gebrüder Bornträger, Berlin.

Benjamini, C., Druckman, Y. and Zak, I., 1993, Depositional cycles in the Ramon Group (Triassic), Makhtesh Ramon: Israel Journal of Earth Science, v. 41, p. 115-124.

Benjamini, C., Hirsch, F. and Eshet, Y., 2005, The Triassic of Israel; *in* Hall, J.K., Krasherninnikov, V.A. Hirsch; H., Benjamini, C. and Flexer, A., eds., Geological framework of the Levant, Volume 2: The Levantine Basin and Israel: Historical Productions Hall, Jerusalem, p. 331-360.

Blake, G.S., 1936, The stratigrapy of Palestine and its building stones: Jerusalem Printing and Stationary Office, 133 p.

Blankenhorn, M., 1912, Naturwissenschaftliche Studien am Toten Meer und im Jordantal: Berlin (Friedländer), 478 p., 106 fig.

Cirilli, S. and Eshet, Y., 1991, First discovery of *Samaropollenites* and the Onslow micoflora in the Upper Triassic of Israel and its phytogeographic implications: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 85, p. 207-212.

Cox, L.R., 1924, A Triassic fauna from the Jordan Valley: Annual Magazine Natural History, v. 14, p. 52-96.

Cox, L.R., 1932, Further notes on the Transjordan Triassic: Annual Magazine Natural History, v. 10, p. 93-113.

Dill, H.G., Bechtel, A. Kus, J., Gratzer R. and Abu Hamad, A.M.., 2010, Deposition and alteration of carbonaceous series within a Neotethyan rift at the western boundary of the Arabian late: The Late Permian Um Irna Formation, NW Jordan, a petroleum system: International Journal of Coal Geology, v. 81, p. 1-21.

Dill, H.G., Bechtel, A., Berner, Z., Botz, R., Kus, J., Heunisch, C. and Abu Hamad, A.M.B., 2012, The evaporite–coal transition: Chemical, mineralogical and organic composition of the Late Triassic Abu Ruweis Formation, NW Jordan - Reference type of the "Arabian Keuper":

Chemical Geology, v. 298-299, p. 20-40.

Druckman, Y., 1974, The stratigraphy of the Triassic sequence in South Israel: Geological Survey of Israel Bulletin, v. 64, 92 p.

Druckman, Y., Hirsch, F. and Weissbrod, T., 1982, The Triassic of the southern margin of the Tethys in the Levant and it's correlation across the Jordan Rift Valley: Geologische Rundschau, v. 72, p. 919-936.

Eicher, D.B. and Mosher, L.C., 1974, Triassic conodonts from Sinai and Palestine: Journal of Paleontology, v. 48, p. 727-739.

Eshet, Y., 1990, Paleozoic-Mesozoic palynology of Israel. I. Palynological aspects of the Permian -Triassic succession in the subsurface of Israel: Geological Survey of Israel Bulletin, v. 81, p. 1-57.

Eshet, Y. and Cousminer, H.L., 1986, Palynozonation and correlation of the Permo-Triassic succession in the Negev, Israel: Micropaleontolgy, v. 32, p. 193-214.

Eshet, Y., Rampino, M.R. and Visscher, H., 1995, Fungal event and palynological record of ecological crisis and recovery across the Permian-Triassic boundary: Geology, v. 23, p. 967-970.

Hirsch, F., 1973, Middle Triassic conodonts from Israel, Southern France and Spain: Mitteilung der Gesellschaft der Bergbaustudierenden, v. 21, p. 811-828.

Hirsch, F., 1990, Aercu de l'histoire phanérozoique d'Israel: Journal of African Earth Science, v. 11, p. 177-196.

Huckriede, R., 1955, Conodonten in der Mediterranen Trias: Verh Geol. B-A. Wien, S., p. 260-264.

Keegan, J., Majed, H. and Shaheen, Y., 1987, Palynology analysis of well Er-Ramtha 1A. Interval 1340–2754.9 m, North Jordan: Report of biostratigraphic and petroleum geochemistry section, National Resource Authority, Amman.

Kelber, K.-P., 1998, Phytostratigraphische Aspekte der Makrofloren des süddeutschen Keupers: Documenta Naturae, v. 117, p. 89-115.

Kerp, H., Abu Hamad, A., Vörding, B. and Bandel, K., 2006, Typical Triassic Gondwanan floral elements in the upper Permian of the paleotropics: Geology, v. 34, p. 265-268.

Lerman, A., 1960, Triassic pelecypods from southern Israel and Sinai: Bulletin Resarch Council Israel, 9G, P. 1-51.

Makhlouf, I.M., 2003, Fluvial/tidal interaction at the southern Tethyan strandline during Triassic Mukheiris times in central Jordan: Journal of Asian Earth Sciences, v. 21, p. 377–385.

Makhlouf, I.M., Al- Hiayri, A, Al-Bashish, M. and Abu Azzam, H., 1996, Sedimentology and lithostratigraphy of the Triassic strata of Jordan at outcrop and in the subsurface: Subsurface Geology, Bulletin 7, p. 1-95.

Makhlouf, I.M., Turner, B.R. and Abed, A.M., 1990, Depositional facies and environment in the lower Triassic Ma'in Formation, Dead Sea area, Jordan: J. Dirasat, series B, v. 17, p. 7-26.

Mustafa, H., 2003, A Late Permian Cathaysia flora from the Dead Sea area, Jordan: Neues Jahrbuch fur Geologie und Palaontologie, Monatshefte, p. 35-39.

Orlova, O. and Hirsch, F., 2005, The Permian fusulinids in Israel; *in* Hall, J.K., Krasherninnikov, V.A. Hirsch, H., Benjamini, C. and Flexer, A., eds., Geological framework of the Levant, Volume 2: The Levantine Basin and Israel: Historical Productions Hall, Jerusalem, p. 317-329.

Parnes, A., 1975, Middle Triassic ammonite biostratigraphy in Israel: Israel Geological Survey Bulletin, v. 66, p. 1-35.

Parnes, A., 1986, Middle Triassic cephalopods from the Negev (Israel) and Sinai (Egypt): Israel Geological Survey, Bulletin 79, p. 9-59.

Parnes, A., Benjamini, C. and Hirsch, F., 1985, Some aspects of Triassic ammonite biostratigraphy, paleoenvironments and paleogeography in southern Israel: Journal Paleontology, v. 59, p. 656-666.

Quennell, A.M., 1951, Geology and mineral resources of (former) Trans Jordan: Colonial Geology and Mineral Resources, v. 2, p. 85-115.

Rüffer, T. and Zühlke, R., 1995, Sequence stratigraphy and sea level changes in the Early to Middle Triassic of the Alps: A global comparison; *in* Haq, B.U., ed., Sequence stratigraphy and depositional response to eustatic, tectonic and climatic forcing: Amsterdam, Kluwer, p. 161-207.

Saddedin, W., 1990, *Pseudofurnishius priscus* n. sp. (Conodonta) and its stratigraphical significance for the Ladinian (Middle Triassic) in Jordan: Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, v. 178, p. 369-332.

Saddedin, W., 1991, *Acanthotheelia jordanica* n. sp., a new holothurian sclerite species from the Pelsonian (Middle Ansian) of Jordan: Revista Espanola de Micropaleontologia, v. 23, p. 83-88.

Saddedin, W., 1998, Conodont- biostratigraphy, and paleogeography of the Triassic in Jordan: Palaeontographica Abteilung A, Bd. 248, p. 119-144.

Saddedin, W. and Kozur, H., 1992, *Pseudofurnishius siyalaensis* n.sp. (Conodonta) from the Lower Ladinian of Wadi Siyala (Jordan): Neues Jahrbuch für Paleontologie, Monatshefte, v. 6, p. 359-368.

Schandelmeier, H., Reynolds, P.-O. and Semtner K., 1997, Chapers 7 and 8: The Late Permian (Capitanian/Longtanian, ca. 250 Ma), The Late Triassic (Norian, ca. 220 Ma); *in* Schandelmeier, H. and Reynolds, P.-O., eds., Palaeogeographic- Palaeotectonic Atlas of North-Eastern Africa, Arabia, and adjacent areas: Balkema, Rotterdam, p. 39-50.

Shawabekeh, K., 1998, The Geology of Ma'in Area–Map Sheet No. (3155 III), Hashemite Kingdom of Jordan, National Resources Authority: Geological Directorate, Geological Mapping Division, Bulletin 40, 74 p.

Schoch, R.R., 2011, A trematosauroid temnospondyl from the Middle Triassic of Jordan: Fossil Record, v. 14, p. 119-127.

Shinaq, R., 1990, Mikrofazielle Untersuchungen kambrischer triassischer und jurassischer Karbonatgesteine Jordaniens [Ph.D. dissertation]: University Hamburg.

Uhl, D., Abu Hamad, A., Kerp, H. and Bandel, K., 2007, Evidence for palaeo-wild-fire in the Late Permian palaeotropics — charcoalified wood from the Um Irna Formation of Jordan: Reviews in Palaeobotany and Palynology, v. 144, p. 221-230.

Wagner, G., 1934a, Deutscher Muschelkalk am Toten Meer: Natur. u. Volk., v. 64, p. 449-454.

Wagner, G., 1934b, Vom Jordangraben: Aus der Heimat, Naturwissenschaftliche, Monatsschrift, v. 47, p. 193-204.

Wetzel, R. and Morton, D.M., 1959, Contribution à la Géologie de la Transjordanie: Notes Mémoires Moyen-orient: Contributions à la Géologie de la Péninsule Arabique, v. 7, p. 95-188.

Zak, I., 1963, Remarks on the stratigraphy and tectonics of the Triassic of Makhtesh Ramon: Israel Journal Earth Science, v. 12, p. 87-89.

Zaslavskaya, N., Eshet, Y., Hirsch, F., Weissbrod, T. and Gvirtzman, G., 1995, Recycled lower Paleozoic microfossils (Chitinozoa) in the Carboniferous of Sinai (Egypt) and the Permo-Triassic of the Negev (Israel); Paleogeographc considerations: Newsletter Stratigraphy, v. 32, p. 57-72.