Paläobotanik und Palynostratigraphie

der Permo-Trias Jordaniens

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Palaeobotany and Palynostratigraphy

of the Permo-Triassic in Jordan

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DEDICATION

To my wife
Mai.

ABSTRACT

Plant megafossils and microfossils are reported from the Permo-Triassic exposures in Jordan. Two new species of Dicroidium, *D. irnensis* and *D. jordanensis*, are described from the Um Irna Formation (Upper Permian) of the Dead Sea region, Jordan. The plant remains are preserved as compressions with excellent cuticles. These are the earliest unequivocal records of *Dicroidium*, a genus that is typical for the Triassic of Gondwana. It is also the northernmost occurrence of this genus that apparently originated during the Late Permian in the palaeotropics. Middle and Late Permian floras from the Arabian Peninsula and adjacent reigons show a remarkable mixture of elements from different floral provinces. The climatic amelioration in the Gondwana region during the Early Triassic probably enabled *Dicroidium* to migrate southwards and finally colonise the entire Gondwana region. Dicroidium is one of the very few megaplants genera that was not affected by the biotic crisis at the Permian-Triassic transition, the largest Phanerozoic extinction event.

Charcoalified wood from the lower part of the Late Permian Um Irna Formation of Jordan is described. This charcoal represents the first evidence of palaeo-wildfire during the Late Permian in Northern Gondwana. The source locality at the northeastern rim of the Dead Sea has yielded abundant gymnosperm charcoal. Taxonomically most remains are identified as *Dadoxylon*-type gymnosperm wood. However, one woody specimen exhibits features that suggest a taxonomic relationship to the Corystospermales, a group otherwise represented at this locality by compressed fronds assigned to the genus *Dicroidium*. The occurrence of charcoal in the Um Irna Formation is appropriate to palaeoclimatic interpretations of this formation that suggest a tropical climate with alternating wet and dry seasons.

The Permian-Triassic succession is not continuously exposed. Therefore, the results of the palynological analysis will be compared with other Permian-Triassic zonations elsewhere.
Based on the analysis of 98 palynological samples, five assemblage zones were recognized.
These zones are in ascending stratigraphic order:

- *Lueckisporites virkkiae* Zone (Late Permian)
- *Endosporites papillatus-Veryhachium* spp. Zone (Smithian/early Olenekian; Scythian)
- *Aratrisporites saturnii* Zone (late Pelsonian-Illyrian ; late Anisian)
- *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone (Langobardian; late Ladinian)
- *Patinasporites densus* Zone (late Cordevolian-Julian; late early Carnian-middle Carnian)

CHAPTER ONE: INTRODUCTION.

1.a. General geological position of the Permian-Triassic in Jordan

Jordan is located on the northwestern part of the Arabian plate, with the Precambrian plutonic and metamorphic rocks of the Nubo-Arabian shield exposed in the South-West of the country. Since the Cambrian the paleogeography of Jordan has been influenced by the position of an ocean in the west and northwest and by the continent of the Nubian–Arabian Shield in the southeast and south. The later provided the source area of sediments which were transported towards the sea and, in part, were deposited in the north and north west of Jordan which represented continental shelf reached by transgressions coming from the Tethys Ocean since Late Permian time. The Permian-Triassic sedimentary sequence on which this study is based is exposed predominantly to the east of the Dead Sea. In the subsurface the Permian–Triassic succession has been explored in regard to its stratigraphy during exploration for hydrocarbons by the Natural Resources Authority (NRA) Amman

1.b. Aims of the study

The Permian-Triassic succession exposed in Jordan is still quite incompletely known in regard to its biostratigraphy. In respect to the age determination of its deposits floral remains have played almost no role. The Permian age of the basal units as documented by Bandel and Khoury (1981) and supported by the flora described by Mustafa (2003) can, due to the discovery of a well preserved flora, be determined in much more detail. And, consequently, the Permian–Triassic boundary could be recognized and its position in the exposures determined. The lithostratigraphic classification of the succession so far had only been placed in a biostratigraphic frame with the aid of a few limestone beds with conodonts and not so very reliable data based on holothurian remains (Sadeddin, 1998). A survey of the rock column documented that plant remains are found not only in the basal units but also higher up and even at the very top of the Triassic section. A stratigraphy based on pollen and spores is available from Israel (Eshet, 1983, 1990) and it became evident during the work presented here, that such a study can be carried out quite successfully within the even better exposed sections exposed on the Jordanian side of the Jordan-Dead Sea- Rift. A very special aim in this study came about, when we (Prof. Dr. Kerp, Prof. Dr.Bandel and I) discovered an extremely well preserved flora, that amazed Prof. Dr. Kerp, resulting in a joint further visit of the locality and the collection of additional material.

This study also intended to rectify some of the confusion surrounding the different nomenclatures that had arisen since the first description of a complete section of the exposed Permian-Triassic sequence in Jordan by Bandel and Khoury (1981) by later authors dealing with this sequence or parts of it. A paleobotanical study connected to a regional correlation for these Permian– Triassic exposures in Jordan was thus carried out, and the results are documented here.

1.c. Previous work

The Permian-Triassic sequence is exposed in central Jordan, particularly along the eastern shore of the Dead Sea from Wadi Mujib in the south to Wadi Hisban in the northeastern corner of Dead Sea and to the valleys west of the town of Naur and in the lower valley of Zarqa River as most northerly outcrop. Cox (1924,1932) described fossils that had been collected by Wyllie ***et al.*** (1923) from the area of the northeastern shore of the Dead Sea and Wadi Hisban, among them cephalopods, gastropods and bivalves. Their age was determined as indicating Anisian (Middle Triassic). Wagner (1934) found fossils in Wadi Siyala about 3 km SW of Wadi Hisban and confirmed the determinations of Cox (1924). He noted a great similarity of the Hisban Limestone with the German Middle Triassic “Muschelkalk”. Blake (1936), Blake and Ionides (1939) discovered the Triassic rocks exposed in the lower portion of the Zarqa River valley near the confluence of Wadi Huni with Zarqa River in the north. They also noted its presence in Wadi Zarqa Ma’in in the south. Wetzel and Morton (1959) reported the occurrence of ***Paraceratites binodosus*** from the Hisban Formation suggesting a Late Anisian to Early Ladinain age of the Triassic rocks exposed in Wadi Hisban area.

A lithostratigraphic frame for the Permian-Triassic rocks as exposed in Jordan was first presented by Bandel and Khoury (1981) and they also provided an introduction to the history of the discovery of these, closely connected to the work of Blake, (1936), Blake and Ionides (1939), Cox (1924, 1932) and Wagner (1934).

Conodonts were first discovered by (Huckriede and Stoppel, in Bender, 1968) in Wadi Zarqa Ma’in. They are identical to those that had been described from the Early Triassic of Israel (Hirsch and Gerry, 1974). Parnes (1975) proposed an Early Anisian age to similar exposures in the Negev as had been originally described from Wadi Hisban based on the ammonite *Beneckeia levantina*. In Jordan Basha (1981) suggested three units to describe the Triassic of Jordan, the Ma’in Group as is exposed in Wadi Zarqa Ma’in with the Hummrat Sandy Shale Formation. The Hisban

Group as it is exposed in Wadi Hisban area with the three formations: Hisban Shale, Hisban Limestone, Hisban Sandy Formation, and the Zarqa Group as it is exposed in Zarqa River area with the Zarqa Gypsum Formation, and the Pisolitic Sandstone Formation. Basha (1981) did not define neither the top nor the base of any of these formations.

Bandel and Waksmundzki (1985) described conodonts from west of Naur assigning a Ladinian age to these rocks, which had been placed in the Iraq Al–Amir Formation according to the formations suggested by Bandel and Khoury (1981). From the same exposure Sadeddin (1990) found *Pseudofurnishius murcianus* van den Bogaard 1966, *Budurovignathus* cf. *mungoensis* Diebel 1956, and *Pseudofurnishius priscus* Sadeddin 1990. According to Sadeddin and Kozur (1992) the new conodont species *Pseudofurnishius siyalaensis* Sadeddin et Kozur 1992 occurs in the Early Ladinian exposures in Wadi Siyala 2 km south of the village Jalda NE of the Dead Sea. Holothurian sclerites determined as *Acanthotheelia jordanica* Sadeddin 1991 placed into the middle Anisian (Pelsonian) of the exposure in Wadi Abu Oneiz near the village of Adasieh (Sadeddin, 1991) near Naur. Kozur and Sadeddin (1992) discovered additional holothurian sclerites from the Lower Ladinian exposures west of Naur. Sadeddin (1996) suggested a biostratigraphic scheme for the middle Triassic exposures in Jordan based on holothurian sclerites, and subsequently Sadeddin (1998) also proposed one scheme based on conodonts. Mustafa (2003) described some plant remains from the Permian Um Irna Formation exposed at the Dead Sea south of Wadi Zarqa Ma'in.

1.d. General Geology

Carboniferous rocks are not known from outcrops in Jordan. They occur in the subsurface as was stated by Parker (1970). Carboniferous rocks were penetrated in the Safra wells in northern Jordan (Olexon, 1967). Here in the Azraq Trough crystalline basement was encountered at a depth of 2550 m. West of the Wadi Araba, Weissbrod (1967) described the Sa'ad Formation consisting of sandstones with gypsiferous cement and some limestone intercalations, which unconformably overlies the Precambrian Zenefim Formation. Above follows the Arqov Formation with shale and limestone, of 150-217 m of late Carboniferous to Permian age. The Permian in the subsurface of the southern Negev, according to Weissbrod (1967), is represented by the 230 m thick Yamin Formation that predominantly consists of dolomites and limestone as some white sandstone.

Near Makhtesh Qatan 2 well the Permian is represented by Zafir Formation of 240 m of shales and few limestones and sandstones which represents Late Permian and Early Triassic. This so called Negev Group thus consists (in ascending order) of the Sa'ad, Arqov, Yamin and Zafir Formations.

The Permian-Triassic boundary is characterized by a marked palynological break in which almost all the Permian forms become extinct, followed by the first occurrence of Early Triassic taxa (Eshet, 1990, this study). This time is also connected to a terminal Paleozoic fungal event, which according to Visscher *et al.* (1995) and Eshet *et al*. (1995) is connected to the end-Permian extinction event. This event was documented from subsurface section in Israel. In these the Permian-Triassic succession consists of a conformable sequence of shallow marine deposits of the Arqov and overlying Yamin Formations (Druckman *et al*., 1982). According to Eshet (1990, 1992) the uppermost Permian is characterized by *Lueckisporites virkkiae* Potonie et Klaus 1954 and *Klausipollenites schaubergeri* (Potonie et Klaus 1954) Jansonius 1962 throughout the sequence and with rapid end. The change-over occurs in a brownish to reddish clay-stone and only fungal remains are found above it. Early Triassic *Endosporites papillatus* Jansonius 1962 and *Kraeuselisporites* spp. and some bisaccate gymnosperm forms appear right after that bed with fungal remains.

Between the Late Permian and the Late Triassic Gondwana continued to drift northward as an integral part of Pangea. If Schandelmeier *et al*. (1997) are correct, Jordan should have moved from latitude 20° S in the Late Permian across the equator to about 8° N in the Late Triassic. Jordan accordingly lay near the equator during the deposition of the limestones of Hisban Formation.

An early age determination of Scythian rocks had been carried out in the campaign of the German Mission lead by Bender (Huckriede, 1955) while mid-Triassic rocks had been studied by Wagner (1934) who noted great similarity with rocks of similar age in Central Europe (Germanic Basin). Of these Cox (1924, 1932) had determined the Anisian age with *Ceratites*.

Quennell (1951) had created the term Um Sahm Sandstone to include the Jurassic and Triassic Formations of the Zarqa Group. Blake (1939) had noted 75 m of fossiliferous sandstones and shales in Wadi Zarqa Ma'in, which can be confirmed. He noted *Lingula tenuissima* and *Pseudomonotis aurita* Hauer to be present in the lower 20 m. In the upper portion he also found *Anodontophora münsteri* Wiss and *Myophoria transversa* Born. It can be confirmed that bivalves represent the most common fossils in this section. Blake (1936) also notes highly fossiliferous limestone in Wadi Hisban which as determined as of Muschelkalk time equivalent by Cox (1924, 1932). The later noted *Coenothyrtis vulgaris* Schlotheim, *Lingula*, *Nucula*, *Hoernesia hesbanensis* Cox, *Hoernesia* attenuata Cox, *Ostrea montiscaprilis* Lipstein, *Plicatula fissistriata* Winkler, *Daonella* and others.

A detailed microfacies and sedimentological studies were carried out by Makhlouf (1987, 1998, 1999, 2000a, 2003), Makhlouf *et al*. (1990, 1991,1996) and Shinaq (1990). Shawabekeh (1998) produced a geological map 1:50,000 where most of Permian–Triassic cropping out. The Permian–Triassic deposits were intruded by a variety of igneous bodies (sills and dykes), reported by Burdon (1959), Wetzel and Morton (1959), Parker (1970), Bandel and Khoury (1981), Schneider *et. al*. (1984). Jarrar (1991) classified the igneous bodies in Wadi Himara as analcite–bearing alkali gabbros, while the light colored sills in Wadi Hisban are trachytes. The rest of Wadi Hisban and Wadi Naur sills are predominantly trachytic andesites.

The Triassic in Jordan has been grouped in the Ma'in Series by Parker (1970) which can be accepted as general term for the Triassic sequence in Jordan, the Ma'in Group. Bandel and Khoury (1981) discussed the lithostratigraphy of the Triassic in Jordan and presented a frame which has been supplemented by microfacies studies of some carbonate beds by Shinaq (1990). This terminology can be utilized quite well since it is in most part well recognizable in the field.

The Permian-Triassic of Jordan is about 1000 m thick of which about 600 m are exposed between Wadi Mujib in the south and Wadi Zarqa in the north. The nine formations distinguished by Bandel and Khoury (1981) are well recognizable in the field regarding their top and base with only the top of the Um Tina and Mukheiris Formations and the base of Abu Ruweis Formation not exposed. A three part Triassic, as is known from the German Basin with Buntsandstein, Muschelkalk and Keuper is also found in Jordan, even though in detail there are numerous differences. But the lower portions with Um Irna, Ma'in, Dardur, and Ain Musa Formations could be considered equivalent to the Buntsandstein with a predominance of quartz sands and reddish coloration. The Hisban, Mukheiris and Iraq Al-Amir Formations are predominantly marine as is the Muschelkalk, and hold many limestones, even though near terrestrial conditions occur including plant bearing horizons. This sequence may well be compared with the Saharonim Formation in the Negev Desert of Israel. The Um Tina and Abu Ruweis Formations are fine grained beds usually deposited in more or less saline conditions and deviate most from the Keuper which holds many sandy units in the German Basin. But in general these southern Tethyan deposits of a shallow sea possibly wide open to the Ocean are rather similar to the northern deposits of a shallow sea in Central Europe that has quite restricted connection to the Tethys Ocean. They can in southern Israel be seen in the Mohilla Formation. This may perhaps indicate that the accessibility of the open Ocean to this Near Eastern Triassic Basin was also not as open as is thought, and there were lands to the north of it separating it from the Ocean.

1.e. Stratigraphic classification:

Triassic and Jurassic rocks In Jordan had been united within a unit called the “Zarqa Group” by Wetzel (1947), Quennell (1951), and Burdon (1959). Wetzel and Morton (1959) introduced the “Raman Group” for Triassic rocks and subdivided these rocks into three formations. The basal one they called the Humrat Ma’in Deltaic Formation of supposedly Early Triassic age and exposed along the eastern shore of the Dead Sea. The middle one was the Hisban Limestone Formation as had been noted by Wagner (1934) exposed in Wadi Hisban area. The upper formation is the Zarqa Gypsiferous Formation suggested to represent the Late Triassic and exposed in lower Wadi Zarqa area.

Lillich (1964) noticed that the Triassic rock sequences along the eastern rim of the Dead Sea are thinning out from North to South until they wedge out completely in the area of the lower Wadi Mujib and that it rests on the Upper Cambrian Sandstone. According to Bender (1968) the Triassic rocks form a sequence of sandstone and marl of the Early Triassic exposed in Zarqa Ma’in area, above follow the Wadi Hisban limestones and sandy marl sequence of the middle Triassic as exposed in the northeastern corner of the Dead Sea. The top is formed by the gypsiferous sequence (Upper Triassic) exposed in the Wadi Zarqa area. Parker (1970) subdivided the Zarqa Group into Ma’in Formation including all Triassic rocks at the base and the Azab Formation including the Jurassic sequences exposed in Jordan.

Bandel and Khoury (1981) measured the whole exposed section as it is exposed in Jordan from Wadi Zarqa Ma’in to Wadi Zarqa and divided it into nine Formations: The lowest- most formation was found to be of Late Permian age and called Um Irna Formation. The three Early Triassic formations: Ma’in Formation, Dardur Formation, Ain Musa Formation were distinguished according to their characteristic lithofacies. Bandel and Khoury (1981) reported “Durdun” which may be a typographical error. The Middle Triassic limestones of the Hisban Formation was distinguishes from Mukheiris Formation, and Iraq Al-Amir Formation. The later had been discovered in a place that had prior not been expected to expose Triassic rocks at all. Here also the transition to the more saline facies was called Um Tina Formation and suggested to hold the transition from Middle to Late Triassic. The uppermost Abu Ruweis Formation is exposed in the Wadi Zarqa and here the top of the section was made out in the basal unit of the Jurassic (Bandel, 1981). Based on surface and subsurface data the whole thickness of these formations were estimated as around 1000 m.

These subdivisions of the Permian–Triassic rocks were later adopted by Makhlouf *et al*. (1996) and Shawabekeh (1998). Sunna, *et al*. (1988), based on subsurface data, (Internal Report, N.R.A., Amman) introduced the term Hudayb Group to include all the surface and subsurface rocks of Permian age in Jordan, which used by Ahmad (1989). Powell and Khalil (1988), Khalil (1992) and Andrews *et al.* (1992) adopted the name “Um Irna Formation” as the upper part of Hudayb Group. The later authors introduced the unit “Ramtha Group” to include all Triassic rocks and accordingly the Permo–Triassic of Jordan is subdivided into the Hudayb Group and Ramtha Group, Table (1). Hudayb Group has been subdivided from subsurface data from Well NH-2 into the three units: Anjara Formation, Huwayra Frormation, and Buwayda Formation. Only the later Formation can be correlated with the Um Irna Formation at outcrop in the Dead Sea area. Andrews *at al.* (1992) suggested to differentiate the Ramtha Group into the Suwayma Formtion including all Scythian deposits, the Hisban Formation, the Mukheiris Formation as proposed by Bandel and Khoury (1981), a Salit Formation, (including Iraq Al-Amir and Um Tina Formations) and the Abu Ruweis Formation as by Bandel and Khoury (1981).

In his unpublished masters work Abu Hamad (1994) on the Middle Triassic of the Naur area used Hisban Formation, Salit Formation (as proposed by Andrews *at al.*, 1992) and Abu Ruweis Formation. Accordingly in the Wadi Abu Oneiz NW of the village of Adasiah below Naur the Hisban Formation has its most northerly exposure. It consists of a “Sandy Member” that is about 10 m thick and holds *Scolecodonta* sp. and *Dentalina* sp., lies below the “Massive Limestone Member” of the Hisban which has Pelsonian age and has therefore been interpreted to be of Bithynian (Early Anisian) age. Hisban Formation age was based on conodonts and holothurian sclerites. In Wadi Naur, Wadi Salit and Wadi Um Tina the Iraq Al-Amir Formation and Um Tina Formation were united to represent the Salit Formation as proposed by Andrews *et al.* (1992). A lower member exposed in Wadi Salit and Wadi Naur, it is about 38 m thick and according to its fossils belongs to the Fassanian (Early Ladinian). An upper member B is partly exposed in Wadi Salit and the partly in Wadi Um Tina is 92.5 m thick and according to the microfauna of Longobardian (Late Ladinian) age. The transition to the Abu Ruweis Formation was noted. Its 14 basal meters contains the conodont *Mosherrella newpasensis* Mosher from Cordevolian age.

Sadeddin (1998) suggested a subdivision of the Triassic in Jordan into the five formations: Zarqa Ma'in Formation (Scythain – Early Anisian), Hisban Formation (Middle Anisian), Jalada Fromation (Late Anisian – Early Ladinian), Salit Formation (Ladinian), Abu Ruweis Formation (Ladinian to early Carnian). And even a different approach has been suggested by the "Geological Committee of the Natural Resources Authority" also called "Nomenclature Committee for the Jordanian Stratigraphic Column, NCJSC" (Internal Report, N.R.A Amman, 2000). The "NCJSC" adopted the Hudayb Group, as proposed by Sunna, *et al.* (1988) and the Um Irna Formation as the upper formation of this Group. The Triassic rocks all included in the Zarqa Ma'in Group proposed by Shawabekeh (1998). The later Group subdivided into five Formations: Suwayma Sandstone–Limestone–Shale Formation (Scythain–Early Anisian), Hisban Limestone Formation (Middle Anisian), Mukheiris Sandstone-Shale Formation (Upper Anisian), Salit Limestone-Dolomite–Shale Formation (Ladinian) and Abu Ruweis Anhydrite Formation (Carnian).

1.f. General location of the outcrops and the type of the study area.

Jordan as part of Arabia is located between latitudes 29 and 33 north and longitudes 34 and 39 east. Within this country sections were studied in the Dead Sea area, with special emphasis in the area between Wadi Zarqa Ma'in and Wadi Hisban, the deep valleys to the north and west of the town Naur (in Wadi Naur, Wadi Salit, Wadi Um Tina, and Wadi Abu Oneiz) and in the lower part of Wadi Zarqa about 35 km north west of Amman at the location of the side valleys Wadi Huni and Wadi Abu Ruweis (Fig. 1).

System	Triassic								Permian
Stage	Rhathian — Norian — Carnian	Ladinian — Anisian				Scythian			Upper
Wetzel (1947)	Zarqa Group								
Quenell (1951) & Burdon (1959)	Triassic Formation								
Wetzel & Morton (1959)	Raman Group								
	Zarqa Gypsiferous Formation	Not Recognizedl	Hisban Limestone	Humrat Ma'in Deltaic Formation					
Bender (1968)	Zarqa Group								
	Gypsiferous Sequence	Not Recognized	Wadi Hisban Sandstone - Muschelkalk	Sandstone - marl Sequence					
Barker (1970)	Za rqa Group	Not Recognized	Hisban Group	Ma'in Group					
Bandel & Khoury (1981,85)	Abu Ruweis Formation	Um Tina Form.	Iraq Al - Amir Formation	Mukheiris Formation	Hisban Formation	Ain Musa Formation	Dardur Formation	Ma'in Formation	Um Irna Formation
Basha (1982)	Zarqa Group	Not Recognized	Hisban Group	Ma'in Group					
	Zarqa Gypsum Formation	Not Recognized	Hisban Sandy Formation	Hisban Limestone Formation	Hisban Shale Formation	Hummrat Sandy - Shale Formation			
(FEJ) (1988,89)	D	C	B1	B2	B3	B4	B5	A	
Khalil & Muneizel (1992), Andrews (1992)	Ramtha Group								Hudyb Group
	Abu Ruweis	Salit Formation	Mukheiris Formation	Hisban Formation	Suwayma Formation	Buwayda Formation	Huwayra Formation	Anjara Formation	
Abu Hamad (1994), Sadeddin (1998)	Abu Ruweis	Salit Formation	Jalda Formation	Hisban Formation	Zerqa Main Formation				
NCJSC 2000	Zarqa Ma'in Group								Hudyb Group
	Abu Ruweis	Salit Formation	Mukheiris Formation	Hisban Formation	Suwayma Formation	Um Ima Formation			

Table (1): Different nomenclatures of lithostratigraphic successions of Permo – Triassic rocks in Jordan.

The topography of Jordan in general and the studied exposures in special is strongly affected by the Dead Sea- Jordan Valley portion of the East African Rift. This structure features the country along its western part for about 360 km and is continuous from Aqaba in the south northwards along Wadi Araba to the Dead Sea and from here the Jordan Valley to its northern boundary next to Yarmouk River and Lake Tiberias. This main topographic feature of Jordan is the Wadi Araba–Dead Sea-Jordan Valley Depression, with its lowest point located at the shore of the Dead Sea, which is a bit more than 400 m below sea-level. From that level the escarpment rises steeply to the Jordanian high-lands which may be up to 1000 m above sea-level. Into this escarpment numerous rather steep valleys have been eroded providing good exposure of the sequence that ranges from the Precambian with exposures south of Ghor Safi, the Cambrian exposed south of Wadi Mukheiris at the NE shore of the Dead Sea to the south, to the Permian-Triassic described here between Wadi Mujib in the south and Wadi Zarqa in the North, the Jurassic from the towns of Es Salt to a little north of Deir Alla and younger deposits from there on to the North. Further to the East of the rift and its escarpment lies the generally a flat area of the central plateau of central and northern Jordan with oldest sediments exposed of Cretaceous age.

The climate of Jordan is that of Eastern Mediterranean where it is hot and dry in summer (May to October) and cool and rainy in the winter season (late October to April). In summer the annual average daily temperature ranges from 31˚ – 33˚ C and may reach 47˚ C in mid summer, while in winter it is from 15˚ – 17˚ C and may go below freezing and in some areas with some snow fall. The main annual rainfall in north and north west of Jordan is about 300 – 400 mm and declines progressively towards the south and south east to less than 100 mm. Most of the study area is located within the Dead Sea region where the main annual temperature is 22˚ C and the rainfall is less than 100 mm .

The Permian-Triassic exposures are exposed at the eastern rim of Jordan-Dead Sea rift that represents a major structural feature that extends from the southern tip of Sinai Peninsula in the south to Turkey in the north. Along that Dead Sea rift horizontal movements of about 110 km and vertical movements of over 10 km have occurred (references and discussion see Bandel and Shinaq, 2003). The subsidence has been strong as well as erosion creating steep valleys, and erosion was increased due to the history of the area since the decline of the Lissan Lake to the Dead Sea within the last 15000 years. Water level has gone down for about 200 m and therefore the valleys cutting into the escarpment are still being eroded.

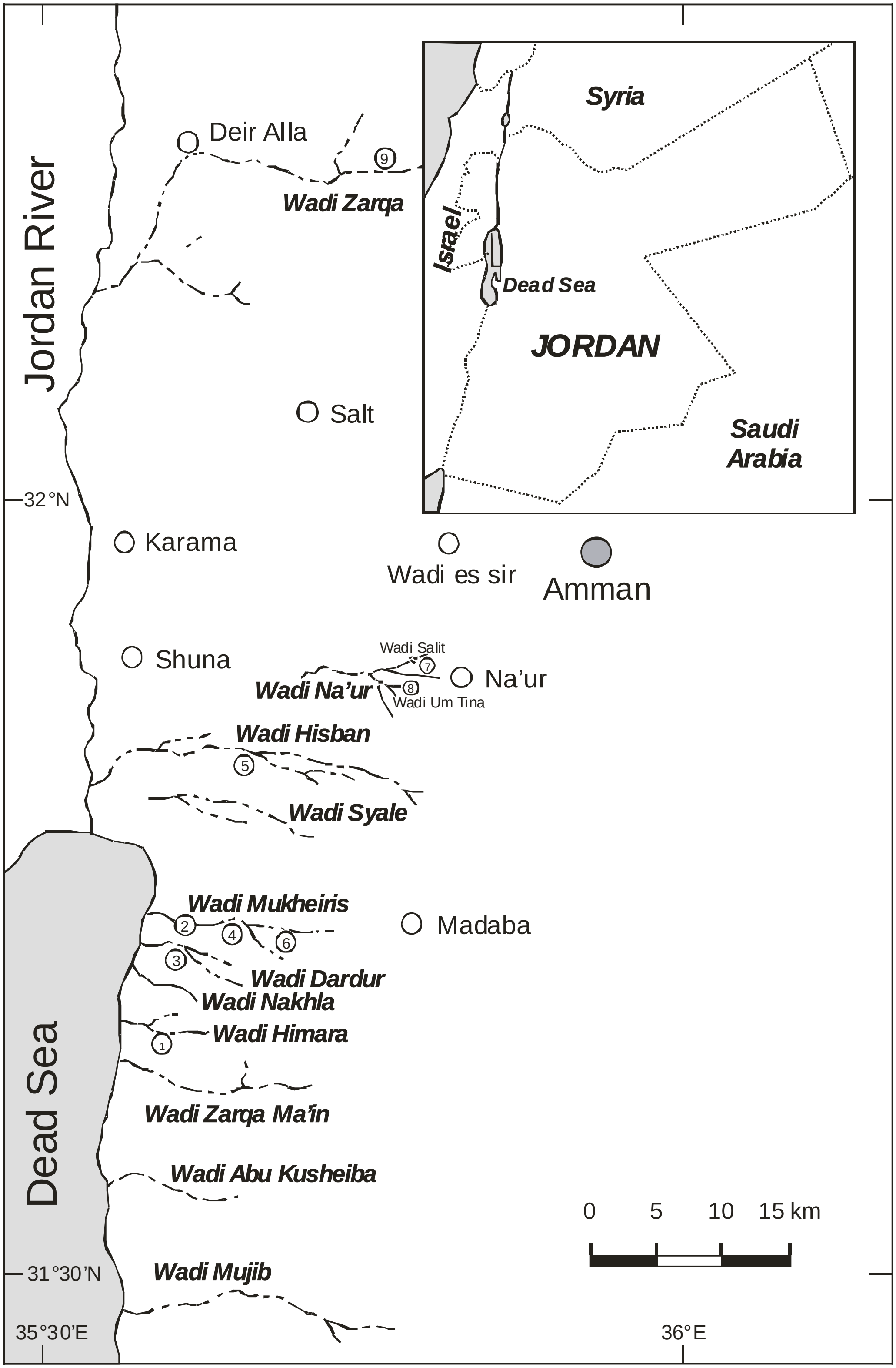

Fig. (1): Locatiom map of the study area. Numbers in circles refers to the geological sections described in chapter two.

1.g. Comparison with the Permian -Triassic sections as they have been described from adjacent countries

According to Schandelmeier *et al.* (1997) Gondwana rotated counter-clockwise and drifted some 10° north-westward, so that NE Africa and the Arabian platform lay between latitude 10-50° S between 315 and 250 Ma years ago. According to their reconstruction Jordan lay at about 20° south. During the late Permian rifting commenced subparallel with the northern margin of Gondwana, initiating the Mesozoic break-up of the super-continent Pangea, in which Gondwana had been its southern portion. The formation of the neo-tethyan passive margin and the initial development of the Gondwana rifts along the present day East African margin are the first tectonic events that indicate the disintegration of the Pangea super-continent.

Subsidence and sedimentation returned to the area of Sinai-Israel-Jordan sometimes during the early Carboniferous (Late Tournaisian) covering the eroded plane with several hundred meters of sandstones and carbonate sediments (Zaslavskaya *et al.,*1995). A second, vertically much smaller uplift of the region took place at the end of the Carboniferous or the Early Permian. Much of the Carboniferous sediments were removed by erosion, as were remaining Lower Paleozoic deposits as was documented by Zaslavskaya *et al.* (1995). Schandelmeier *et al.* (1997) suggested that the combined process of intra-plate compression, uplift of rift shoulders, mantle pluming, and isostatic rebound due to the removal of the late Carboniferous to early Permian ice sheet, caused regional uplift further south of the Middle East on Gondwana.

According to Eshet (1990) during Permian and Triassic times the Afro-Arabian continent was present to the south and the Tethys Ocean to the north. Transgressions invaded from the north and near-shore marine conditions prevailed in the rock column known from southern Israel. **In the south of Israel** the Permian-Triassic succession is composed of 1500 m of near-shore to continental rocks. Most of the Late Permian sediments in Israel were deposited in shallow to near-shore marine environments. Fusulinid limestone was encountered in the subsurface of the coastal plain (Garfunkel and Derin, 1984). Towards the Dead Sea and Negev areas the increased influence of silico-clastic material as well as a rich palynoflora assemblage indicate the proximity of the coast (Eshet 1990, Hirsch 1990). According to Schandelmeier *et al*. (1997) citing Andrews (1992) it is not certain whether the Late Permian hiatus in adjacent Jordan results from non-deposition or from post-Permian erosion. But it had clearly been demonstrated by Bandel and Khoury (1981) that there is a hiatus present between Cambrian rocks and the soil horizons of the latest Permian seen in the outcrops of the eastern Dead Sea area.

The Jordanian Permian-Triassic sequence can be compared with that of southern Israel where it has been described from Makhtesh Ramon by Zak (1957, 1963) and Druckman (1974, 1976). The later extended the sections into the subsurface. Permian-Triassic ostracods were described by Gerry (1966, 1967), Hirsch and Gerry (1974) and Sohn (1963, 1968). Conodonts have been published on by Eicher (1946), Huddle (1970), Hirsch (1972), Eicher and Mosher (1974) Benjamini and Chepstow-Lusty (1988), Foraminifera by Sohn and Reiss (1964), Derin and Gerry (1981), Benjamini (1984,1988), ammonites by Parnes (1962, 1975, 1986), Parnes *et al.* (1985).

The **Permian-Triassic in Israel** has been well studied and it close to that found in Jordan. The most ancient rocks exposed of the Permo–Triassic succession in Israel is of Late Scythian–Early Anisian age of the Ra'af Formation in Har Arif. The sequence is exposed to the Carnian Mohilla Formation at Makhtesh Ramon (Druckman, 1974; Picard and Flexer, 1974; Eshet, 1983, 1987, 1990; Eshet and Cousminer, 1986). Weissbrod (1969, 1981) established the Permian lithostratigraphy based also on subsurface data, starting with the underlying Precambrian. The basal unit is the Negev Group of Early Permian to Early Anisian age. It is subdivided into four formations, of which the basal Sa'ad Formation is about 80 m thick consisting predominantly of quartz arenite, some coaly shale with plant remains and a few layers of limestone and dolostone. It has been interpreted as deposited in a fluvitile to swamp environment and determined to be of early Permian age. The following Arqov Formation in its type section of Makhtesh Qatan 2 well is 194 m thick and consists of alternating sand, shale and carbonate units interpreted to represent near shore, marine deposits. Further to south in the Negev (Ramon 1 well and Boger 1 well) the formation was deposited under more open marine conditions and is thicker (232 m). A Late Permian age (Thuringian) was suggested by Eshet (1990). The third Yamin Formation is 133 m thick in its type section at Makhtesh Qatan 2 well and composed of sandstone in the lower part succeeded by carbonates caped with sandstone. It is interpreted to represents the deposits formed during a regression – transgression – regression cycle. Hirsch and Gerry (1974) and Hirsch (1975) dated the upper part of this formation with conodonts as Early Triassic. Weissbrod (1981) assigned a Late Permian age for this formation proposing that the sedimentation was continuous since Late Permian up to Early Triassic. Eshet (1990) reported that at least part of the Yamin Formation is Triassic in age. The Permian-Triassic boundary lies in its basal part or it lies in the upper-most part of the Arqov Formation. The last of this group is the Zafir Formation of Early Triassic (Scythian) deposits has a total thickness of a 238 m. It has been subdivided into three members (Druckman, 1974) which could be time equivalent to the three formations Ma'in, Dardur and Ain Musa as exposed in Jordan (Bandel and Khoury, 1981). Zafir Formation is composed of an alternation of shale, fossil bearing limestone and sandstone, and deposition is interpreted to have occurred under shallow marine conditions.

The Ramon Group of Middle–Late Triassic age is subdivided into the Ra'af Formation which is equivalent to the Hisban Formation in Jordan of Early to Middle Anisian age were proposed for this formation (Eshet, 1990). Only the upper 25 m of Ra'af Formation are exposed in the type section area at Har Arif while it is 128 m thick in Makhtesh Qatan well (Druckman, 1974). It consists mainly of fossiliferous limestone, some dolomite, dolomitic limestone, argillaceous limestone, marl and claystone. All are interpreted to have been deposited in a shallow, low energy marine environment. The Gevanim Formation is placed in the Anisian (Parnes ***et al***., 1985; Gerry and Derin, 1981; Eshet and Cousminer, 1986; Eshet, 1990). It is subdivided into three members which consist of sandstone, siltstone and shale with minor amounts of limestone and a total thickness of about 270 m obtained calculated from a composite section. These sediments are interpreted to have been deposited in near shore to tidal flat environment. The overlying Saharonim Formation is, according to Bandel and Waksmundzki (1985), equivalent to Iraq Al-Amir Formation and the lower part of Um Tina Formation in Jordan. Saharonim Formation is subdivided into three members, and only 45 m thick in its exposure at Makhtesh Ramon. It consists of fossiliferous limestone, shale, dolomite and some gypsum and anhydrite. It is interpreted to have been deposited in a shallow marine environment representing a transgressive phase during the Late Anisian to Carnian time with a total thickness of about 174 m recorded from Makhtesh Qatan 2 well. The uppermost formation of the Triassic in Israel is Mohilla Formation, subdivided into two members, and consisting predominantly of anhydrite and dolomite with some shale, limestone and marl. It was deposited in an environment of hyper-saline supra-tidal flats during Carnian to Norian age. Its total thickness is about 200 m.

In **Saudi Arabia** the Unyzah Formation is considered of Early Permian age, and it is well exposed from Wadi ad Dawasir south almost to Najran for a distance of more than 300 km (Steinecke *et al.*, 1958). Its thickness has been described as 300 m to 950 m and it generally consists of sandstone with a conglomeratic base that rest unconformably on Precambrian basement. The following Khuff Formation of Late Permian according to Steinecke *et al.* (1958) crops out from Bani Khatmah (lat. 18

00 N) to the Great Nefud (lat. 28 10 N). It consists of shelf carbonates, commonly oolitic and subordinate shales occasionally intercalated with evaporites. It is present over much of the Gulf area and its thickness was estimated to range from 235 m to 292 m.

Triassic rocks are exposed in the **center of Saudi Arabia** in the Jebal Tuwaga area (Steinecke *et al.*, 1958). In it the Sudair Formation that may be equivalent to the Ma'in Formation in Jordan, is exposed in Khashm Abu Er Rumdha, Kashm Ghudhiay and Kashm es Sudair and consists of shale, siltstone, limestone and sandstone with an average thickness of about 116m. It has supposedly been deposited in a fluviatile environment and is interpreted to be of Late Permian to Early Triassic age. The following Jilh Formation exposed at Jilh el Ishahr area has an average thickness of 326 m. It is divided into the lower about 208 m thick fine to medium quartz sandstone, green shale and limestone, and the upper 118 m of coarse quartz sandstone, siltstone, shale, dolomite and limestone. Its depositional environment may have been alluvial, supratidal flats and shore as well as shallow marine, and it has been dated as Middle Triassic. The uppermost unit is the Minjur Formation consisting of 315 m and of quartz sandstone, shale and sandy shale with deposition under terrestrial to fluvial conditions, exposed in the Marrat area. It is interpreted to represent Late Triassic to Early Jurassic age.

In **the Iraq** Triassic rocks are exposed at the north and the southwest (Saint–Marc, 1978; Al–Sayyab *et al*., 1988). Both exposures differ from each other. In the North Iraq five formations have been subdivided. Of these the lower is the Mirga Mir Formation consisting of shales, argillaceous limestone and oolitic limestone with an average thickness of about 200m. They had been interpreted to be deposited in a shallow marine to lagoonal environment during Early Scythian age. The following Beduh Formation is composed dominantly of marl, marly limestone and shale, and it thought to have been deposited in a shallow marine environment during Late Scythian time with a thickness ranging from 64 -100m. The Geli Khana Shale Formation comprised the Middle Triassic. It subdivided into two members, the lower one consists of limestone, laminated gypsum lenses and shale. The Upper Member composed of massive limestone, dolomite, dolomitic limestone, marly limestone and shale. The formation is between 330-700m thick. It had been interpreted to be deposited in shallow marine environment including saline lagoons environment during Middle Triassic time. The following Kurra China Formation possibly about time equivalent to the Abu Ruweis Formation in Jordan consists of limestones, massive dolomite and laminated shale. It is thought that these sediments were deposited in a coastal shallow marine and lagoonal environment during the Carnian. An uppermost Baluti Formation with 43-60 m in thickness consists of shale and marl intercalated with dolomitic limestone, evaporitic carbonate, anhydrite and oolitic limestone. It was interpreted to have been deposited in a lagoonal to fluvial environment during Rhaetian time.

In the **south western Iraqi** Ga'ara Depression the Triassic sequence was subdivided into three formations (Saint–Marc, 1978; Al–Sayyab *et al.*, 1988). The basal one is Ga'ara Formation with average thickness of about 150 m is interpreted to be equivalent to Mirga Mir, Beduh and Geli Khana Shale Formations in north Iraq. It is dominantly composed of variably colored coarse grained sandstone with quartzite and sandy marl. These sediments are interpreted to have been deposited in a terrestrial-fluviatile environment. The following 160 m thick Malussa Formation had been interpreted to be equivalent to Kurra China Formation in north Iraq. It consists of limestone, dolomite, marl and marly limestone in its lower part, while the upper part is composed of marly limestone and fossiliferous limestone. They have been deposited in near-shore shallow marine environment during Carnian time. The Zor Hauran Formation is interpreted to be equivalent to Baluti Formation in north Iraq. It is about 27-30 m thick, decreasing westwards and composed of shale and gypsiferous marl alternating with limestone , these sediments have been deposited in evaporitic lagoon environment during Rhatian (Late Triassic).

In Syria during the Permian–Early Triassic a sequence of clastic deposits is found in central Syria (Palmyra Basin), while in northern and eastern parts of Syria no sediments are found due to the uplift of Mardin-Dyarbaker High and Khleisia High which contributed clastics to the adjacent depressions in Iraq and central Syria during the Triassic.

The Middle Triassic is calcareous while the Late Triassic is formed by succession of limestones and shales with thin bands of anhydrites. In southern Syria the Triassic sequence consists of sandstone and shales, similar to these of Ga'ara Formation of southwest Iraq (Saint-Marc, 1978). In central Syria, the Triassic is not clearly differentiated from either the Permian or the Jurassic (Bebeshev *et al.*, 1988). According to these authors the Permian-Triassic rocks in Syria can be subdivided it into the Dolaa Formation of late Early Permian to Late Permian, the Amanus Formation of Early Scythian, the Amanus Shale Formation of Late Scythian, the Kurra China Dolomite Formation of Late Scythian to Anisian, the Kurra China Anhydrite Formation of Ladinian, the Carnian Butma Formation, Adayah Formation, Mus Formation, Allan Formation, and finally the Sarrgelu Formation of Norian age.

At the end of the Triassic orogenic movements affected central and southern Arabian plate as well as the area of the Dead Sea rift system, and regional regressive phase led in a regional unconformity between the Jurassic and the older Late Triassic deposits. In general there are many similarities between the Permian–Triassic successions found in Jordan, Syria and Israel since the rocks deposited during Permian to Jurassic time were deposited in a basin that extended from northern Jordan into Syria in the north and westward to Israel (Druckman, 1974; Picard and Flexer, 1974; Hirsch and Picard, 1988; Bebeshev *et al.*, 1988).

System	Stage	Jordan, Bandel & Khoury, (1981, 85)	Syria, Bebeshev, et. al., (1978)	North Iraq Al - Sayyab et. al., (1988)	S. West Iraq Al - Sayyab et. al., (1988)	South Iraq & Kuwait, Al - Sayyab et. Al., (1988)	Saudi Arabia Steinecke et al. (1958)	Israel Druckman, (1974)
Triassic	Rhathian – Norian – Carnian	Abu Ruweis Formation Um Tina Formation	Butma Formation Aduya Formation Mus Formation Allan Formation Sargelu Formation	Baluti Formation Kurra China Formation	Zor Hauran Formation Malussa Formation	Butma Formation Manjur Formation	Manjur Formation	Mohilla Formation
Triassic	Ladinian	Iraq Al-Amir Formation	Kura China Anhydite Formation	Geli Khana Formation	Ga'ara Formation	Jilh Formation	Jilh Formation	Saharonim Formation
Triassic	Anisian	Mukheiris Formation Hisban Formation	Kura China Dolomite Formation					Gevanim Formation Ra'af Formation
Triassic	Scythian	Ain Musa Formation Dardur Formation Main Formation	Amanus Shale Formation Amanus Formation	Beduh Formation		Sudair Formation	Sudair Formation	Zafir Formation Yamin Formation
Permian	Upper	Um Irna Formation	Dolaa Formation	Mirga Mir Formation		Khuff Formation	Khuff Formation	Arqov Formation Sa'ad Formation
Permian	Lower					Pre - Khuff	Unayzah Formation	

Table (2): shows the lithostratigraphic subdivision of the Permo- Triassic rocks in Jordan and adjacent countries .

CHAPTER TWO: LITHOSTRATIGRAPHY

As can be extracted from the introduction, the Permian–Triassic formations have been variably assigned with different names according to different authors. But during the review of literature, it became evident that the litho-stratigraphical subdivision of Bandel and Khoury (1981) had been adopted by many authors with more or less modifications. In the here presented work, the palyno-stratigraphical supplements, geological sections and samples were taken based on the subdivisions presented and defined by Bandel and Khoury (1981). In the study area sedimentary rocks of Cambrian age up to those of the Jurassic and Cretaceous are exposed, but for the aims of this study, only the Permian–Triassic sequence was taken into consideration. Nine detailed geological sections representing nine formations were measured from the outcrops in the area of the original type sections, and from them samples for palynological processing and plant macro-fossils were collected.

2.a. Um Irna Formation

The name Um Irna Formation was introduced by Bandel and Khoury (1981) according to the mountain range separating Wadi Zarqa Ma'in from Wadi Himara. The type section is situated in the Wadi Himara, about 3 km north of Zarqa Ma'in hot springs. According to Bandel and Khoury (1981) Um Irna Formation is about 85 m in thickness, while Makhlouf *et al*. (1991) found the formation to be only 60 m thick, and Shawabekeh (1998) measured 67 m.

Lithology and bedforms:

A columnar section of Um Irna Formation was again measured at Wadi Himara (Appendix 3). As suggested by Bandel and Khoury (1981) Um Irna Formation is divided into six well-defined members with fining upward sediment composition. The lower two members are about 23 m thick. They consist of coarse grained conglomeratic sandstone at the base to medium and fine grained sandstone further up. This sandstone passes gradually upwards into reddish–maroon–gray–light gray rippled siltstone, silty–shale and dark gray–dark green, sometimes sulfur rich claystone which include a very well- preserved flora, remains of single plants as well as coals. These two lower members begin with erosional surfaces with conglomeratic base. Sedimentary structures such as cross bedding, ripples marks, and occasionally bioturbation and mottling are found in the part with finer sand.

The upper four members about 45 thick consist mainly of fining upward coarse-grained, cross-bedded sandstone grading up through thinly lamination (10-15 cm), light gray–gray siltstone and brownish–greenish silty mudstone. Here the upper-most bed of each member is composed of non–laminated clay, which contains iron oxide pisolites, which up to 20 mm in diameter. They formed within place in the soil.

Distribution:

The formation crops out along the north eastern shore of the Dead Sea between Wadi Mukheiris and Wadi Mujib. The lower part of Um Irna Formation is disturbed due to faulting south of Wadi Zarqa Ma'in. It has also been encountered in wells in the north and northwest of Jordan.

Boundaries:

Um Irna Formation rests unconformably on the hard sandstone of the Cambrian (Um Ishrin Sandstone Formation, name was established by Lloyd (1969) after Um Ishrin mountain in the southern desert of Jordan). A finer grain size, darker chocolate color, more thinly bedded layers and the presence of local erosional surface characterizes the Late Permian Um Irna Formation from the Cambrian Um Ishrin sandstone Formation. While its overlain unconformably by the Early Triassic Ma'in Formation. At its top it end with an erosion surface that is up to 20 cm thick.

Age and fauna:

Bandel and Khoury (1981) assigned Late Permian age to Um Irna Formation based on pollen grains that had been determined by W. A. Brugman, (Utrecht). Several authors have repeated this age.

Equivalents of this Um Irna Formation were penetrated in many wells and was assigned to early –mid Permian age, for example in ER–1A well, (Keegan *et al.*, 1987a) as Kungurian to Kazanian (late Early – early Late Permian) age, in well NH-2, RH–2 and RH-11 (SSI, 1989). Early to Late Permian age has assigned to the equivalent Argov Formation and lower part of Yamin Formation in Israel (Eshet, 1990).
Mustafa (2003) described some new plant remains from the Permian Um Irna Formation exposed at the Dead Sea south of Wadi Zarqa Ma'in.

Depositional environment:

Bandel and Khoury (1981) distinguished 6 members which have a similar composition with fluviatile deposits containing erosion products of the crystalline basement in it at the base and above it layers of soil some of them containing pisolites of iron-oxides. The Suweilih-1 well, in contrast, had documented sediments which appear to have been deposited in terrestrial near shore and shallow water marine environments. A distal braided fluvial depositional environment for the lower part and a more proximal fluvial origin for the upper clastic part proposed by Makhlouf (1987) and Makhlouf *et al.* (1991). Andrews *et al.* (1992), based on subsurface data and based on a review of the stratigraphic column of the outcrops, suggested a strongly fluvial-terrestrially–influenced depositional environment.

2.b. Ma’in Formation

Bandel and Khoury (1981) took the name from Hummrat Ma’in near Wadi Zarqa Ma’in. They divided the formation into two members, Himara and Nimra with type sections in Wadi Himara for the lower member and Wadi Zarqa Ma’in for the upper member. Ma’in Formation is the oldest part of Triassic exposures in Jordan. According to the recent review of the NCJSC (2000) Ma’in Formation is the lower clastic member (Ma’in Member) of Suwayma Sandstone–Limestone–Shale Formation; but this member is synonymous with Ma’in Formation as originally proposed by Bandel and Khoury (1981).

Lithology and bedforms:

Ma’in Formation is well exposed in different locations in the study area; a complete detailed section was measured in Wadi Mukheiris, where the two members are accessible (Appendix 4). The Himara and Nimra Member as proposed by Bandel and Khoury (1981) was found well founded and recognizable in the field in general and also in this locality.

Himara Member: The conspicuously dark purplish beds of about 26 m thick Himara Member are found in all the side valleys opening to the shore of the Dead Sea just to the south and north of Wadi Zarqa Ma'in. Rocks consist of an alternation of thinly bedded sandstone, siltstone and clay often with considerable amount of carbonate. Burrows are present throughout, trace fossils can be found on the bedding planes together with ripples and mud cracks. Thin, dolomitic limestone beds are developed, commonly with abundant bivalve shells. Some fine silty layers hold the valves of phyllopods like *Esteria*. Bioturbations can be placed in the type of bivalve burrows and trails, arthropod burrows and trails and also *Rhizocorallium* U-burrows.

Nimra Member: The member is 21 m thick and begins with sandstone and siltstone beds commonly with fine to coarse flaser structure. They are reddish and greenish in their clay-rich portions and carbonate-rich beds are present, some of which show beach rock structure and hold clasts. The upper portion consists of fine white sandstone arranged in cross-bedded units of 50 to 150 cm thickness. Bioturbation is present and may or may not destruct original bedding structures. Some pure limestone units are included in the upper portion of the member.

Distribution and thickness:

van den Boogaard 1966 van den Boogaard 1966 van den Boogaard 1966 van den Boogaard 1966 Diebel 1956van den Boogaard 1966Diebel 1956Ma'in Formation crops out along the northeastern margin of the Dead Sea and the deep canyons between Wadi Mukheiris north to Al Mamaleh area south. Fig (map). It has also been encountered in wells N, NE and NW Jordan .
van den Boogaard 1966Diebel 1956Ma'in Formation in its type area between Zarqa Ma'in and Wadi Mukheiris measures 35 to 45 m in thickness Bandel and Khoury (1981). Makhlouf *et al.* (1990) suggested a thickness of 55 m, Shawabekeh (1998) found 47 m for the whole formation, which is confirmed here.

Boundaries:

Ma'in Formation overlies unconformable the Permian Um Irna Formation. Its base is marked by an erosional surface with local relief up to 20 cm, the first occurrence of bioturbation and the purplished color of the beds. This formation is conformably overlain by Dardur Formation, and its top is sharply defined by the contact between sandstone and the limestone of the Durdur Formation.

Age and fauna:

Cox (1923) assigned Scythian age to the fossiliferous clastic sequence that represents the lower part of Ma'in Formation. Huckriede and Stoppel in Bender (1968) reported Early Triassic conodonts from the lower part of the Triassic succession at Wadi Zarqa Ma'in supporting a Scythian age. These conodonts were never illustrated and also the exact locality from which they had been collected is unknown. These authors did not measure a section nor did they indicate the exact place in Wadi Zarqa Ma'in area, which is rather a large place and in which much of the Triassic sequence may be encountered.

In northern highlands area, and based on a subsurface data from drilling wells, the equivalent of Ma'in Formation is dominated by sandstones, and early? Scythian age was proposed to these deposits by Keegan ***et al.*** (1987) and SSI (1989). From Suweilih-1 well Bandel and Khoury (1981) had noted a more marine influence expressed in the lithology of the beds considered time equivalent, as seen in the exposures at the Dead Sea. In Israel this may be the Yamin and Zafir Formations. Conodonts were described by Hirsch (1975). Accordingly, the lowest zone is of Early Scythian age.

Depositional environment:

Bandel and Khoury (1981) proposed a deposition mostly within the tidal zone or very shallow water and more marine influence in the North indicated in the section of Suweilih well. Such a deposition environment was also accepted by Makhlouf ***et al***. (1990), Andrews ***et al***. (1992) and Shawabekeh (1998).

2.c. Dardur Formation

The name is derived from the second major canyon (Wadi Dardur) to the south of Wadi Mukheiris by Bandel and Khoury (1981), Fig (1). The proposed type locality is Wadi Dardur where it measures 60 m in thickness and here it was differentiated into four members, a lower carbonate, a central sandstone, an upper carbonate, and a sandy member.

Lithology and bedforms:

The outcrop in Wadi Dardur was measured with total thickness of 59 m. (Appendix 5). The four members of the Dardur Formation as proposed by Bandel and Khoury (1981) were confirmed. The base of Dardur Formation conformably overlies the sandy facies of the Ma'in Formation. Dardur Formation starts with the Lower Carbonate Member which is about 10 m thick. It consists of alternating beds of gray–greenish, nodular bituminous, marlstone with differently colored, thinly bedded silty shales and creamy to yellowish colored, thinly bedded fine grained sandstone, as well as sandy dolomite and pure dolomite. The Lower Sandstone Member is about

15 m thick. It consists of brownish, white, thin- to thick-bedded, cross–bedded sandstone, carbonate cemented sandstone with thinly bedded dolomitic and marly layers in the upper portion. The Upper Carbonate Member is 24 m thick and composed of pre-dominantly greenish to yellowish marlstone and dolomitic limestone intercalated with thinly bedded shale, limestone, siltstone and very fine sandstone. The Upper Sandstone Member is about 10 m thick and consists of creamy–brown, fine – to coarse-grained, thin and thick beds of lime-cemented sandstone. Intercalated are purplish and greenish, thinly laminated, 10-20 cm thick siltstone and claystone. They hold intra-formational conglomerate layers with pebbles consisting of limestone and shale. In both Sandy Members the sandstone beds represent lenses pinching out or swelling laterally. Load casts, ripple marks, trace fossils, crinoids and bivalves are common. Sand–filled mud cracks and bioturbation without destroying the original stratification where observed where beds bear carbonate. Cross bedding, surfaces with ripple mark, as well as some stromatolitic beds were observed in the upper sandy member.

Distribution:

Dardur 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. It also has been encountered in wells, N, NE and NW of Jordan.

Boundaries:

The base of Dardur Formation is formed by the first appearance of limestone beds (silty shale, dolomite and marlstone) which overlies the sandstone of the Ma'in Formation. The top is the bioturbated silty layers below the sandstone of the Ain Musa Formation.

Age and fauna:

Cox (1932) assigned a Scythian age to the fossiliferous clastic sequence that he found to crop out at Zarqa Ma'in, which may well have come from beds included in the Dardur Formation according the bivalve fauna. Bandel and Khoury (1981) suggested Scythian to early Anisian age for Dardur Formation according to lithological correlation with the equivalent formation in Israel.

Depositional environment:

According to the interpretation of Bandel and Khoury (1981) the sediments of the Dardur Formation were deposited near the coast (shallow marine), on intertidal mud flats environment in the basal member, near the shore in the middle one, and due to crinoid remains in the shallow sea in the upper layers. This reconstruction was accepted by Amireh (1987), Andrews *et al.* (1992), Makhlouf *et al.* (1996) and Makhlouf (1999).

2.d. Ain Musa Formation

Ain Musa Formation according to Bandel and Khoury (1981) is named after the Wadi Ain Musa, where most of the formation is well exposed. It was split into three members (Muhtariqa, Jamala and Siyale) each of which have their type section in the localities with the same name. The National Jordanian geological Mapping project (1:50,000) has followed Bandel and Khoury (1981) as did Shawabekeh (1998), Makhlouf *et al.* (1996) and Makhlouf (1998) but they preferred to introduce a new subdivision as lower, middle and upper member rather than geographical names. Andrews *et al.* (1992) and NCJSC (2000) used Ain Musa Formation of Bandel and Khoury (1981) to name their upper member of a Suwayma Sandstone–Limestone–Shale Formation, a procedure which is not followed here, also due to the rules of priority. It is also noted, that the lithological units (formations) proposed by Bandel and Khoury (1981) can be traced in the field without problems, so that the system is rather useful and needs not to be replaced by another, less well defined one.

Lithology and bedforms:

Own observations while measuring the sections confirmed the usefulness of the nomenclature proposed by Bandel and Khoury (1981). A detailed section was measured in Wadi Mukheiris with the Ain Musa Formation here about 100 m thick, about 20 m thicker than further to the south in the type section. (Appendix 6 A, 6 B).

The Ain Musa Formation conformably overlies Dardur Formation. Its basal Muhtariqa Member is about 45 m thick The Rujm el Muhtariqa hill, situated at the end of the Wadi Ain Musa is the type locality of this member. It consists of predominantly limestone, also marly claystone, siltstone, dolomitic limestone, dolomite and sandstone intercalations. Mary clay-stones and silt-stones are green to yellowish in color, have a horizontal and wavy lamination, and locally show rippled surfaces.

Cross-lamination, flaser-bedding, borrow structures, clay–clasts are found. Within siltstone beds locally glauconitic strikes occur. Tabular beds of hard brown–yellow-creamy limestone, dolomitic limestone, sandy limestone and dolomite form the second component of this member. It forms prominent cliffs above the soft marly claystone–siltstone layers. One bed of stromatolites occurs in the lower part of this member.

Jamala Member: The unit has its type locality below the confluence of Wadi Jamala with Wadi Ain Musa at the spring of Ain el Jamala.In Wadi Mukheiris it attains a thickness of 28 m and forms well-exposed prominent cliffs that can be traced laterally in the field. Lithologically it consists of intercalated sandstone and siltstone. The sandstone beds are composed of thin to thick cross-beds, the color is brownish, and rippled surfaces are common. Many channel fills are observed. In the basal parts of these beds, pebbles of well-rounded quartz, sandstone and siltstone clasts are found. In the type locality of Jamala Member Bandel and Khoury (1981) noted tree trunks in the sandstones Trace fossils like crab burrows and *Chondrites* burrow systems are present throughout and demonstrate that the whole 15 m of the member have been deposited under marine conditions

Siyale Member: The type locality for the Siyale Member is Wadi Siyale just south of Wadi Ain Musa. In Wadi Mukheiris it attains a thickness of 27 m. It is composed mainly of the greenish to gray intercalated marly claystone and siltstone. Fining upward sandstone and calcareous limestone was recorded. In its type locality Siyale Member is 30 m thick and composed mainly of clay and marl holding fossiliferous, calcareous beds. In some layers glauconite and the brachiopod *Lingula* are common. The limestone above comes very abruptly so perhaps there is a hiatus (Bandel and Khoury, 1981).
Only about 4 km to the north the same formation was measured in its type locality (Bandel & Khoury 1981). It attains a thickness of 80 m. The 45 m thick Muhtariqa Member is represented by a sequence consisting of sandstones, limestone layers, dolomitic limestone and siltstone. This indicates the increased influence of marine conditions only a little to the north during the deposition of these sediments.

Distribution:

The formation crops out between Wadi Manshala to the south and Wadi Ain Musa in the north. (Fig. 1). It also has been encountered in wells in the N, NE and NW of Jordan. Makhlouf (1998) measured two slightly more than 100 m of Ain Musa

Formation in Wadi Mukheiris and in Wadi Nakhla. In the present study Ain Musa Formation was studied in Wadi Mukheiris confirming the subdivisions proposed by Bandel and Khoury (1981).

Boundaries:

Ain Musa Formation rests conformably on the underlying Dardur Formation. The base is characterized by the first massive ripple marked sandstone bed, which comprised the base of Muhtariqa Member, while the top is located at the base of the massive limestone beds of the base of Hisban Formation.

Age and fauna:

The regional correlation with the equivalent in Israel induced Bandel and Khoury (1981) to assign an Anisian age to this formation. Based on conodonts Sadeddin (1990) and Kozur and Sadeddin (1992) confirmed the Anisian age.

Depositional environment:

Bandel and Khoury (1981) suggested intertidal with fluviatile influence depositional environment to Muhtariqa Member as indicated by the common occurrence of drift wood, clay balls and quartz pebbles layer in addition to alternation of thin–very thin beds of sandstone, siltstone and marlstone. Northwards this member is represented by a sequence consisting of sandstone, limestone layers, dolomitic limestone and siltstone, indicating the increased influence of marine conditions during the deposition of the sediments. A marine environment with fluviatile influence was also proposed to the Jamala Member as it is indicated by the presence of trace fossils (crab burrows, *Chondrites*) throughout this member. More marine depositional environment was suggested to Siyale Member based on the presence of bioturbation, presence of glauconite grains and the brachiopod ***Lingula.***

Makhlouf ***et al.*** (1996) and Makhlouf (1998) proposed a shallow marine deposition probably within the intertidal zone to both Muhtariqa and Siyale members. Based on the presence of granular quartz, a continental conditions was suggested to have established in the middle part of Muhtariqa and Siyale members. An alternation of both fluvial and intertidal facies during the deposition of Jamala Member indicated fluviatile–intertidal depositional environment according to Makhlouf (1998). Thus they confirmed the interpretation of Bandel and Khoury (1981).

2.e. Hisban Formation

The name of this formation was derived from Wadi Hisban (Fig. 1) where Triassic rocks were found to crop out by Wetzel (1947), noted in an unpublished report. The Hisban Formation is the Hisban Limestone of Wetzel and Morton (1959), the Lower Wadi Hisban Sandstone "Muschelkalk" Sandy Marl of Bender (1968), Hisban Limestone Formation of Basha (1981) and it was included in the fully measures section as Hisban Formation with 35 m of thickness at Wadi Dardur by Bandel and Khoury (1981). This has been confirmed by Andrews ***et al.*** (1992), Makhlouf ***et al.*** (1996), Shawabekeh (1998), Makhlouf (1999), and later also in the study of NCJSC (2000).

Lithology and bedforms:

A section measured in Wadi Hisban attains 30 m in thickness (Appendix 7). The rock consists predominantly of gray, burrowed, fossiliferous, stylolitic, limestone with wavy bedding. It is hard, gray, thinly bedded, nodular, and has a spotty appearance due to the dense and characteristic bioturbation as described by Bandel and Khoury (1981). Gray, hard wavy- bedded dolomitic limestone up to 20 cm is recorded in the lower part of the section.

At Wadi Dardur the Formation measures 35 m in thickness and consists of bedded limestones with marly intercalations. The bulk of the limestone is characterized by calcareous, lithified burrow systems, all of the same undulating type. They cause a characteristic mottling of the rock as well as typical weathered surfaces.

Distribution, thickness and type section:

Hisban Formation is exposed along the northeastern shore of the Dead Sea from Wadi Nakhla south to Wadi Hisban north (NE corner of Dead Sea) further north in Wadi Abu Oneiz (12 km west of the town Naur). It has also been encountered in wells, NW and NE of Jordan.

As long as most authors located the type section of Hisban Formation in Wadi Hisban with 30 m average thickness Makhlouf (1998) reported that the section in Wadi Hisban is incomplete; therefore, he proposed a new type section with 35 m thickness in Wadi Nakhla. Sadeddin, (1998), Shawabekeh (1998) and NSJC (2000) considered the Wadi Hisban section as the type section of their "Hisban Limestone Formation".

Boundaries:

The base of Hisban Formation in Wadi Hisban is not exposed and the top is truncated by the Cretaceous unconformity. Further south (about 20 km) in Wadi Nakhla a complete section is well -exposed, which conformably overlies the Ain Musa Formation and underlies the Mukheiris Formation. The base and top of Hisban Formation can be seen in Wadi Mukheiris and Wadi Dardur where the base is marked by a sharp contact between the green–gray marlstone–siltstone of Ain Musa Formation and the massive limestone of the basal unit of Hisban Formation. The top is represented by the sharp transition from the limestone to marl and sandy marl intercalation of Hisban Formation the cross-bedded sandstone of the base of Mukheiris Formation. This boundary is well developed in Wadi Mukheiris.

Age and fauna:

Cox (1924, 1932) and Wagner (1934) assigned a middle Late Triassic age to Hisban Formation based on bivalves, gastropods and ammonites. An Anisian to Early Ladinian age was suggested by Wetzel and Morton (1959), Parnes (1975) assigned an early Anisian age. Bandel and Khoury (1981) proposed Anisian age based on lithostratigraphical correlation with the equivalent Ra'af Formation that is exposed in the Negev of Israel. Based on conodonts and holothurian sclerites Sadeddin (1992, 1998) assigned an Early –Late Anisian age to what he called Hisban limestone Formation. Hisban Formation as exposed in Wadi Abu Oneiz was assigned by Abu Hamad (1994) to Middle Anisian (Pelsonian) based on conodonts.

Depositional environment:

Bandel and Khoury (1981) proposed a shallow marine depositional environment relatively far from shore for the Hisban Formation as exposed in Wadi Hisban and Wadi Dardur. This had been also suggested by Sadeddin (1998) and Shawabekeh (1998) and was also reported from the drilling wells in northern Jordan (e.g., the NH-2 well).

2.f. Mukheiris Formation

Mukheiris Formation has been named by Bandel and Khoury (1981) after the Wadi Mukheiris (Fig. 1) which represents the last most northern deep canyon ending directly at the shore of the Dead Sea at the Möwenpick Hotel about 8 km southeast

Suwayma village. This formation represents all the sediments preserved above the Hisban Formation up to the Lower Cretaceous unconformity surface in the Dead Sea area. Khalil and Muneizel (1992), Andrews *et al.*. (1992), Makhluof *et al*. (1996), Shawabekeh (1998) and Makhlouf (2003) utilized that formation as proposed by Bandel and Khoury (1981), while NCJSC, (2000) confirmed the name Mukheiris Formation but changed it to Mukheiris Sandstone-Shale Formation. This unit or parts of it have been called Hisban Sandy Formation by Basha (1981), and Jalda Formation by Sadeddin (1992) and these terms are fully or in part synonymous of Mukheiris Formation.

Lithology and bedforms:

A section for Mukheiris Formation is represented as it is exposed in the upper part of Wadi Mukheiris (Appendix 8 A, 8 B). It comprised three well-defined members, the Lower and Upper Members consisting of fine components indicating deposition under rather quiet conditions. The Middle Member consists of hard limestone and sandstone forming a prominent cliffs which can be laterally traced. At the base, a sharp conformable contact between Hisban Formation and Mukheiris Formation is well developed in Wadi Mukheiris.

Lower Member: It measures about 30 m in thickness, and consists of fine-grained, cross-bedded, brown to reddish sandstone interbedded with thinly bedded (10-50) cm soft, gray-greenish, rippled, marly claystone and siltstone. There are channel–fillings, lenticular, bedded siltstone and marly clay-stone. Driftwood and many fragments of leaves still bearing the cuticles are common on the bedding plane of the siltstone and the marly clay-stone beds.

Middle Member: It attains about 28 m thickness. The lower part consist predominantly of yellowish, hard, fossiliferous (mainly *Lingula*) limestone intercalated with gray to green, thinly bedded marly clay-stone, clay, and siltstone. This unit is followed by intercalated yellowish marly limestone and marly clay-stone. A 2.3 m thick sandstone bed is recorded in the lower part. The member terminates with 2.2 m gray, yellowish, thinly laminated, fractured sandy limestone. The upper part of this member was unexposed.

Upper Member: It is about 18 m thick and consists of inter-bedded, fine to coarsely grained, yellowish, brown, cross bedded sandstone and gray to greenish, thinly laminated, rippled marlstone and siltstone. Plant remains are abundant in the upper most marl- and claystone. Common are leaves on the bedding planes of the laminated marly clay-stone. The member ends with dark to black, thinly laminated, clay-stone which is truncated by the unconformity of the Kurnub Sandstone of the Early Cretaceous.

Subdivision:

Bandel and Khoury (1981) subdivided the Mukheiris Formation into three members, lower, middle and upper, each member has about 30 m thickness. Makhlouf *et al.* (1996) divided Mukheiris Formation into two members, a Lower 30 m thick one and an Upper measuring 78 m, since they reported that the middle and upper member of Bandel and Khoury (1981) are very similar to each other and difficult to differentiate. My own observations in the field indicate that the three members as differentiated by Bandel and Khoury (1981) are quite well recognizable and can be separated from each other. The section was measured in Wadi Mukheiris with 30m of thickness to each Lower and Middle, 17 m for the Upper Member.

Distribution, thickness and type section:

Mukheiris Formation crops out in Wadi el Udeimi, Wadi Mukheiris and Wadi Dardur along the northeastern side of the Dead Sea. It is also encountered in wells in north (Suweilih well–1) and northeast Jordan, both in the North Highland (NH–1 and NH–2) and western Risha wells (RH–1, 2, 14, 17 and 19) (Andrews *et al.* 1992). The type section of Mukheiris Formation is described in Wadi Mukheiris by Bandel and Khoury (1981). The later authors measured about 90 m, and 108 m were found to be present by Makhlouf *et al.* (1996), 62 m by Shawabekeh (1998), 40 m by Sadeddin (1998). Later the NCJSC (2000) confirmed the thickness of about 90 – 100 m to Mukheiris Formation in its type outcrop locality. In subsurface data, the section in well NH–2 is illustrated as a complete reference section for the Mukheiris Formation (Andrews *et al.* 1992). I measured 76 m of thickness in the upper Wadi Mukheiris.

Boundaries:

The base of Mukheiris Formation is defined where thick massive limestone beds of Hisban Formation are conformably overlain by argillaceous gray, red brown and gray-green marly claystone of Mukheiris Formation, which is well exposed in Wadi Mukheiris and Wadi Dardur. The transition of beds of the Mukheiris Formation to the following Iraq Al Amir Formation is here not exposed since the upper part of

Mukheiris Formation is truncated by an unconformity and overlain by the Early Cretaceous Sandstone of the Kurnub Group. Based on subsurface data from the well NH–2, (Andrews *et al.* 1992) defined the upper boundary where the predominantly argillaceous beds of Mukheiris Formation are overlain by the limestone of the Salit Formation. This Salit Formation is about equivalent to the Iraq Al- Amir Formation and Um Tina Formation of Bandel and Khoury (1981).

Age and fauna:

Bandel and Khoury (1981) correlated the Mukheiris Formation with the upper part of Ra'af Formation and the lower part of Gevanim Formation as exposed in Israel. They assigned a Middle–Late Anisian age to Mukheiris Formation. Sadeddin (1990,1992,1995,1998) and Sadeddin and Kozur (1992) assigned Late Anisian to Early Ladinian age for what they called Jalade Formation, which is an equivalent to the same rocks that had before received the name Mukheiris Formation. Age determination was carried out with the help of conodonts, holothuraian sclerites, ammonites (*Benekeia* sp.), brachiopods (*Coenothyris vulgaris*) and bivalves (*Placunopsis* sp.). More recent NCJSC (2000) adopted a Ladinian age for Mukheiris Formation based on palynological data from wells, eg. QA-1 well (Stratigraphic Services LTD (ECL 1990)).

Depositional environment:

Bandel and Khoury (1981) indicated a marine depositional environment for the lower member based on the presence of strong bioturbation, glauconitic sandstone, shells of bivalves, cephalopods and even the bones of reptiles, including one well-preserved head. Accordingly the depositional environment was interpreted to be coastal to shallow marine. For the Middle and Upper Member bioturbation, plant fossils and *Lingula* indicate deposition close to the shore as well. Makhlouf *et al.* (1996) proposed a shallow water marine environment for the lower 30 m (Lower Member) of Mukheiris Formation exposed in Wadi Mukheiris, while a fluvial environment suggested to the rest of the formation (78 m) based on the low content of fine material (clay and silt) compared to the high coarse sand content. A hyper-saline near–shore depositional environment was indicated by Sadeddin (1998) for the equivalents Jalada Formation, but this not clearly defined formation probably includes beds that had been placed in the next upper formations by Bandel and Khoury (1981). Makhlouf (2003) proposed a shallow marine tidal environment for the Lower

Member and a fluvial with a low sinuosity braid plain depositional environment for the Upper member.

2.g. Iraq Al-Amir Formation

Iraq Al-Amir Formation was introduced by Bandel and Khoury (1981) after Iraq Al-Amir temple ruin nearby for the Triassic rocks exposed in Wadi Salit and Wadi Naur. Khalil and Muneizel (1992), Andrews *et al.* (1992), Abu Hamad (1994) and Sadeddin (1998) used the term Salit Formation instead after Wadi Salit. But they included here all Triassic exposures in Wadi Salit, Wadi Naur and Wadi Um Tina, which actually had been quite unknown to science before they were discovered by Bandel and Khoury (1981). More recent NCJSC (2000) adopted the term Salit Lime-stone-Dolomite-Shale Formation for the previous rock exposures. Ahmad (1989) and Makhlouf *et al.* (1996), in contrast, were quite satisfied with the definition and they confirmed the Iraq Al-Amir Formation as proposed by Bandel and Khoury (1981).

Lithology and bedforms:

The Triassic rocks in the Naur area were exposed because of a shallow dome-shaped structure that is cut by the Wadi Naur (Bandel and Khoury 1981). The sections taken here confirm the presence of the three members which are well exposed and clearly defined in the field. (Appendix 9 A, 9 B).
Bahhath Member: The name of this member was derived from the spring of Ain Bahhath 1km to the north of the exposure. It consists of about 30 m composed of fossiliferous sandy limestone, lime- cemented sandstone beds in the base which is overlain by yellowish, friable marl, fine sandstone, light green siltstone and thin marly clay-stone with laminations.

Abu Yan Member: It is expressed more in carbonate facies and is about 42 m thick. Here the lower 20 m consist of sandy limestone, dolomitic limestone, fossiliferous limestone and thinly bedded yellowish friable marl- marly clay-stone. The upper part is dominated by hard recrystalized limestone, micritic limestone, oolitic limestone. The member terminates with an about 2 m thick bed of sandy dolomite.

Shita Member: This member is named for Wadi Shita that discharges into Wadi Naur where it is exposed. It is about 23 m thick with its lower part consisting of an intercalation of 7 m of light gray thinly bedded micritic limestone, marly limestone and thinly bedded dark gray clay-stone to marly clay-stone. 4 m of light yellowish dolomitic limestone and dolomite follow overlain by 2.2 m light gray thinly laminated marly clay-stone. The member ends with about 10 m of yellowish, hard, cellular dolomite followed by, yellowish, hard, dolomite, intercalated with thinly laminated marly claystone with fragmented chips of gypsum.

Subdivision:

Iraq Al-Amir Formation has been subdivided into the three members, Bahhath Member, Abu Yan Member and Shita Member (Bandel and Khoury 1981). Also Makhlouf ***et al.*** (1996) subdivided the Iraq Al-Amir Formation into three members, with the Lower Member consisting of about 27 m of predominantly marly shale and dolomitic limestone. The Middle Member is 19 m thick and consists mainly of carbonate rocks with thin shale interbeds, and the Upper Member is more than 16 m thick and consists mainly of greenish–gray marl capped by three meters of thick dolomitic limestone forming the base to the Lower Cretaceous unconformity. Abu Hamad (1994) and Sadeddin (1998) preferred the term Salit Formation for the combined Iraq Al-Amir and Um Tina Formations of Bandel and Khoury (1981) and split this into two members, which are not in phase with the observations of the other authors. The lower of these (Member A) measures about 20 m. It consists of sandy limestone, dolomitic limestone, and marl, and the upper (Member B) is about 90 m thick and composed of limestone, dolomitic limestone, dolomite, marl, shale, hard dolomite, intercalated with thinly laminated marly claystone with fragmented chips of gypsum.

Distribution, thickness and type section:

Iraq Al-Amir Formation is only exposed to the west of Naur town in Wadi Salit and Wadi Naur (Fig. 1). It also has been penetrated in wells, in Northern Highlands, Al –Harra and western Risha. Bandel and Khoury (1981) measured 89 m thickness of Iraq Al-Amir Formation, of which Abu Hamad (1994) confirmed 83 m to be present instead. Makhlouf ***et. al.*** (1996) found 62 m while Sadeddin (1998) measured about 94 from the same Triassic rock exposures. NCJSC (2000) indicated that more than 140 m of Salit Formation were present but this thickness represents the two Formations in Naur area, Iraq Al-Amir Formation and Um Tina Formation together. All these studies considered Wadi Salit, Wadi Naur and Wadi Um Tina as type locality and reference section, which is also the only area in which this formation is exposed.

Boundaries:

According to Bandel and Khoury (1981) the base of Iraq Al-Amir Formation was not exposed, and its base was reconstructed from a lithostratigraphical correlation with Suweileh well. They conclude that only the upper 90 m of Iraq Al-Amir Formation was exposed and that the lower boundary is below the lowermost part of their lower Bahhath Member representing the lower of three members. Andrews *et al.* (1992), Abu Hamad (1994), Makhlouf *et al.* (1996) did also not record the base of Iraq Al-Amir Formation at the outcrop. Sadeddin (1998) indicated that the base of his Salit Formation (about equivalent to Iraq Al-Amir and Um Tina Formations) is exposed about 2 km south of Jalda village. Andrews *et al.* (1992) suggested a base in a thick sequence of limestones with shale interbedded which overlie the red – brown shales of Mukheiris Formation based on the subsurface log of the NH–2 well. This marker beds are not exposed in the outcrops of Wadi Naur, since they probably lie below the surface of the valley.

The upper boundary of Iraq Al-Amir Formation is characterized by the laminated stromatolitic carbonates of the basal Um Tina Formation (Bandel and Khoury, 1981).

Age and fauna:

Bandel and Khoury (1981) assigned Anisian age to Iraq Al-Amir Formatoin based on lithological correlation with Gevanim Formation as exposed in Israel, but later Bandel and Waksmundzki (1985) indicated Ladinian age for the same formation based on the presence of index conodont species such as
Gondolella transita Kozur and Mostler 1971, *Pseudofurnishius murcianus* van den Boogaard 1966, *Metaploygnathus mangoensis* Diebel 1956. Sadeddin and Kozur (1992) confirmed this age based on *Pseudofurnishius priscus* Sadeddin 1990 and *Budrovgnathus truempyi* Hirsch. Abu Hamad (1994) also confirmed this age and recognized the Fasanian - Longobardian boundary based on a microfauna that was reported from the lower part of the Iraq Al-Amir Formation. Here the holothurian sclerites *Tetraverga perforata* Mostler 1965, *Theelia tubercula* Kristan-Tollmann 1963, *Theelia* sp. and the conodonts *Pseudofurnishus murcianus* van den Boogaard 1966, *Budrovignathus mongoesis* Diebel 1956, *Hindeodella* sp., and *Metaprioniodus suevica* Tatge 1956. The macrofossils reported comprise *Placunopsis flabellum* and poorly preserved ammonites.

Depositional environment:

According to Bandel and Khoury (1981), Bandel and Waksmundzki (1985) and Andrews *et al.* (1992) the depositional environment was a shallow sea with open marine conditions. This reconstruction was basically accepted by Makhlouf *et al*. (1996) with a final end within a dolomitic limestone facies in very shallow water. But this may already represent the basal portion of the succeeding formation.

2.h. Um Tina Formation

A Triassic sequence is exposed in Wadi Um Tina 1 km south of Wadi Naur was called Um Tina Formation by Bandel and Khoury (1981). This original name of the formation was utilized by Bandel and Waksmundzki (1985), Ahmad (1989) and Makhlouf *et al.* (1996). Andrews *et al*. (1992), Khalil and Muneizel (1992), Abu Hamad (1994), Sadeddin (1996, 1998) and later NCJSC (2000) used the name Salit Formation for about the combined Iraq Al-Amir Formation and Um Tina Formation.

Lithology and bedforms:

About 62 m of Um Tina Formation are exposed, the lower 12 m of which consist of gray, hard, fossiliferous limestone, micritic limestone and thin lamination of gray marly claystone. The upper part mostly dominated by of 1–2 m thick beds of gray marly claystone intercalated with yellowish, fractured limestone, dolomitic limestone (Appendix 10). All sediments are characterized by laminar bedding usually in wavy stromatolitic structure. Some beds have some bioturbation, but it is more rarely developed further up in the section. The Um Tina Formation may be up to 200 m thick, of which only the lower portion is exposed in the Naur area.

Distribution, thickness and type section:

Um Tina Formation is exposed only in Wadi Um Tina, 1 km south of Wadi Naur (Fig.1) In the locality of its outcrop about 70 m of sequence were measured by Bandel and Khoury (1981), and accepted by Bandel and Waksmundzki (1985). Abu Hamad (1994) found 62 m exposed and 51 m were noted by Makhlouf *et al.* (1996). The Um Tina Formation has been penetrated in many wells, in the Northern Highlands in Al Harra and western Risha areas of north Jordan. In all these wells it appears to be much thicker than in its exposure near Naur.

Boundaries:

The base of Um Tina Formation is exposed at the outcrop according to Bandel and Khoury (1981), Bandel and Waksmundzki (1985) and Makhlouf *et al.* (1996). The top is truncated in the valley below Naur by the basal Kurnub sandstone of Early Cretaceous age. In the subsurface the top of this formation was defined by an increase of gypsiferous beds as note from the well log of Suweilih well. The same characteristic was used to define the upper end of their Salit Formation, which was indicated to be marked by the income of thick beds of anhydrite (Andrews *et. al.* 1992).

Depositional environment:

Bandel and Khoury (1981) suggested upward gradual change from open marine to a lagoonal and saline depositional environment based on the lithology and sedimentary characters such as dolomite and stromatolites. Shinaq and Mustafa (2000) noted the presence of desiccation craks, stylolites and micro-unconformities with concentrations of organic mater and / or iron oxides in Um Tina Formation, thus, they proposed a shalowtidal flats and subtidal to supratidal marine depositional environment to this formation.

Age and fauna:

Based on lithological analogies with Gevanim and Saharonim Formations exposed in Israel, Bandel and Khoury (1981) assumed Ladinian age to Um Tina Formation and Anisan age to the underlying Iraq Al-Amir Formation. Later Bandel and Waksmundzki (1985) based on conodonts obtained from Iraq Al-Amir Formation concluded that the Um Tina Formation was younger than Ladinian age. A Carnian age for Um Tina Formation was also assumed by Sadeddin (1990, 1998) and Abu Hamad (1994).

2.i. Abu Ruweis Formation

Abu Ruweis Formation was first introduced by Bandel and Khoury (1981) after Wadi Abu Ruweis next to the gypsum exposures in the canyon formed by the lower Zarqa River. The succession of this formation comprised the youngest Triassic outcrop in Jordan known since Blake (1936) and Ionides and Blake (1939). It had also been called Zarqa Gypsiferous Formation by Wetzel and Morton (1959), Red-

Spotted Gray Limestone by van den Boom and Lahloub (1962), Gypsiferous Sequence by Bender (1968), and Zarqa Gypsum Formation by Basha (1981). The Abu Ruweis Formation suggested by Bandel and Khoury (1981) was largely accepted by later authors but NCJSC (2000) partially adopted the name with a slight addition to indicate the lithological component of this formation and introduced the name Abu Ruweis Anhydrite Formation

Lithology and bedforms:

An about 42 m thick section comprising the uppermost portion of the formation was measured in the eastern quarry (Appendix 11). Here Abu Ruweis Formation start with an about 4 m bed of grayish massive gypsum followed by about 11 m of intercalation of light gray siltstone, clay-stone, sandy dolomite, marly clay-stone, marly limestone and gypsum. The middle part of this section consist of 11 m massive, thick, gray gypsum with thin lamination of dark black clay-stone occasionally intercalated. The gypsum unit is overlain by about 13 m of intercalated dark gray clay-stone, marly clay-stone and dolomitic limestone. The formation is terminated and overlain by about 3 m of deposits that consist of vary colored clay-stone and pisolitic paleosoil.

Distribution, thickness and type section:

The Abu Ruweis Formation crops out in the lower area of Zarqa River between the confluence of Wadi Huni and Wadi Abu Ruweis which is also considered as the type section. It was penetrated by wells in Northern Highlands, Al Harra and Risha areas. Bandel and Khoury (1981) stated that at the time when they carried out their study the exposure could not be measured exactly since the rocks of the upper Abu Ruweis Formation have been affected by strong slides along the steep slopes of the Zarqa valley. But parts of it have since been well exposed due to being quarried for the cement industry and could be measured.

In any case, the estimated thickness of exposed Abu Ruweis Formation ranges from 150 m measured by Wetzel and Morton (1959) and repeated by Abu Ajamiah ***et al***. (1988), 40 – 60 m by Basha (1981), 80 m by Makhlouf ***et al.*** (1996). Here the about 42 m thick upper portion of the section was measured in outcrops locally present in the gypsum quarry.

Boundaries:

Bandel and Khoury (1981) defined the base of Abu Ruweis Formation from the log of Ramtha Well – 1. They marked the base by the first thick bed of anhydrite and its top by the first Jurassic rocks. This procedure was accepted by Andrews ***et al***. (1992). Abu Hamad (1994), Makhlouf ***et al.*** (1996) and Sadeddin (1998) preferred to find the base of Abu Ruweis Formation in the dolomitic bed of Um Tina Formation exposed in Wadi Um Tina.

Age and fauna:

In spite of inadequate paleontological studies on Abu Ruweis Formation, a Carnian age was confirmed by all authors, since Blake (1936) described ***Myophoria*** sp*.* from the outcrop. Bandel and Khoury (1981) introduced a Carnian age based on lithostratigraphical correlation with Mohilla Formation cropping out in Israel (Druckman *et al.*,1982). Basha (1982) found no microfauna while he reported the shales were barren.

In well RH-1, according to Keegan *et al.* (1987b) palynomorphs of Abu Ruweis Formation provide an Carnian age as had been suggested by Bandel and Khoury (1981).

The uppermost member of Abu Ruweis Formation is now well exposed and has provided a flora of ferns as well as a fauna of ***Lingula***. The fern is a ***Phlebopteris*** according to Kerp (pers. communication). In the German Late Triassic the genus ***Phlebopteris*** is documented from the Rhaetian (Kelbert, 1998). According to this author the genus later on in all Jurassic floras became a cosmopolitan element. It is also known from the Early Keuper of Europe (Konijnenburg-van Cittert, 1993) as well. The Jurassic fern was described by Corsin and Waterlot (1979) and Tidwell and Ash (1994). At the top of the Triassic section in the subsurface of Israel Eshet (1990) found the Triassic Jurassic boundary characterized by an extinction of most Triassic taxa, suggesting an unconformable relationship.

Depositional environment:

Near shore supratidal sabkha environment with saline pools depositional environment had been proposed by Bandel and Khoury (1981). Dalqamouni (1995) described the sediments of Abu Ruweis Formation from subsurface data of the wells Ajlun 1 near Ajlun, Northern Highland near Ramtha and Risha 2 near the Syrian order in the NE panhandle of Jordan. He found that the Formation consists of a cyclic sedimentation of foraminiferal bioclastic limestones, oolitic limestones, parallel laminated limestone and marl, stromatolitic limestones, dolomite and nodular anhydrite, including some more or less extensive rock salt beds. This demonstrates a repeated succession in a shallowing upwards carbonate-sabkha sequence with a tendency toward more marine conditions towards the NW. Cycles show a gradation from subtidal oolite shoals, into lagoonal lime muds, intertidal algal muds with some stromatolites, supratidal laminated mudstone and intraclast layers and nodular anhydrite and in some cases rock salt salinal deposits. Eshet (1990) found in the Carnian deposits of southern Israel a dominance of xerophytic elements indicating arid climate.

CHAPTER THREE: LATE PERMIAN MEGAFLORAS

3.a. Introduction

The Paleozoic floral provicialization began in the Early Carboniferous and reached its maximum in the Permian (DiMichele and Hook, 1992; Wnuk, 1996). Four distinct global floral provinces are recognized. These provinces are the southern Gondwana Province, the northern Angara Province, and the (sub)equatorial Euramerican and Cathaysia provinces. The Permian and Triassic periods represent a time of global climate change from icehouse to greenhouse conditions and atmospheric CO_2 concentrations reaching about five times the present level (Berner and Kothalova, 2001). The extinction event at the Permian-Triassic transition, which affected marine and terrestrial floras and faunas, is often regarded as the most profound biotic crisis of the Phanerozoic (Erwin, 1993). Approximately 85% of the marine species disappeared (Erwin, 1999), and locally, 95% of peat-forming plants became extinct (Retallack, 1995; Michaelsen *et al*., 2002). However, it has recently been argued that in continental environments, the scale and timing of effects varied markedly between different regions (Kozur, 1998; Rees, 2002). Several plant groups became extinct across the Permian-Triassic boundary, whereas others, including most gymnosperms, suffered a marked decline in number of species. Only very few taxa, mainly lower vascular plants, survived the Permian-Triassic biotic crisis. Therefore, the recent discovery of a Late Permian flora from the Dead Sea region in Jordan with abundant, well-preserved foliage assignable to the southern hemisphere pteridosperm genus *Dicroidium*, which is often regarded as typical for the Triassic of Gondwana (e.g., Anderson *et al*., 1999), is of particular interest. This flora, which is here called the Wadi Himara flora, has yielded at least five species of *Dicroidium*. Two species occur abundantly and can be well characterised on the basis of gross morphology and cuticles. These two species appear to be new and are formally described here. A third species with remarkably large pinnules is much rarer; the material is much more fragmentary and less well preserved. This species has abundant stomata on both leaf surfaces, very thin anticlinal walls and very typical stomata with thick stomatal ledges. Another species also has large pinnules and cells are more lessa arranged in longitudinal rows. The cuticles are very well preserved but the pinnule outline remains unclear. The fifth species has small tongue-shaped pinnules and undulating anticlinal walls, unlike any of the other forms from the Um Irna flora. Because these species are still insufficiently known, they will not be described here. A formal description of the latter three species has to await until better material becomes available. However, it is important to note that at least five species of *Dicroidium* have been recorded from the Um Irna Formation at Wadi Himara.

The fossils from the Dead Sea region not only represent the earliest record of *Dicroidium*, but also by far the most northern occurrence of a taxon that became highly successful in the Middle and Late Triassic. These finds shed new light on the early history and distribution of the corystosperms, a group of seed ferns that has long been regarded as a typical Mesozoic group of pteridosperms.

3.b. Locality and source strata

The material was collected from a natural exposure in the lower part of the Um Irna Formation at the northeastern rim of the Dead Sea, Jordan. The locality is situated at ca. 2 km east from the main road that runs along the eastern shore of the Dead Sea, in the incised dry river valley named Wadi Himara. The outcrops of the Um Irna Formation are located ca. 400 m stream upwards along the southern branch after the main bifurcation of Wadi Himara (Fig. 2).

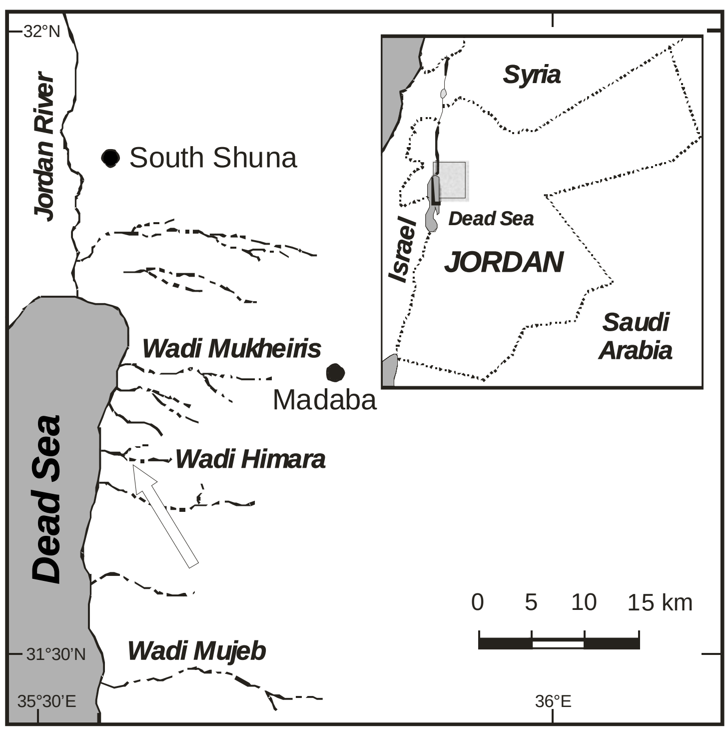

Fig. (2): Location map of the Wadi Himara locality (arrow).

The Um Irna Formation was originally defined by Bandel and Khoury (1981) in Wadi Himara and the here described material has been collected in the type section. The Um Irna Formation locally has a thickness of 67 m and unconformably overlies the Cambrian Um Ishrin Sandstone Formation and is unconformably overlain by the Ma'in Formation. The entire Um Irna Formation is developed in a continental facies. From the bottom to the top six sequences, each beginning with a sandstone layer can be recognised. Makhlouf *et al.* (1991) distinguished two sedimentary facies in the Um Irna Formation. The Lower Member (Facies 1) has a thickness of ca. 10 m and consists of interbedded sandstone and subordinate sandstone and silty shale arranged in fining upward sequences. This facies, which corresponds with the first sequence of Bandel and Khoury (1981), has been interpreted as a distal braided fluvial deposit. The finer units sometimes show desiccation cracks indicating periodic drying out of the depositional surface. The Upper Member of Makhlouf *et al.* (1991) (Facies 2) consists of sandstone, silty sandstone and silty shale and comprises five fining upward sequences. These sediments show characteristics of both meandering and braided stream deposits; the environment is interpreted as a braided river in which deposition was largely controlled by periodic shifts of the active channel tracts (Makhlouf *et al.*, 1991). The silty layers were deposited in abandoned channels. In the entire Um Irna Formation, but especially in the middle and upper part, several palaeosols with ferruginous pisolithes (iron-rich glaebules *sensu* Makhlouf *et al.*, 1991) are developed. These paleosols increase in thickness towards the top of the formation.

Dispersed plant cuticles occasionally occur in the siltstones of the Lower Member. The here described plant remains from the Wadi Himara locality occur in organic-rich, grey to brownish silt and clay layers and lenses between 5.5 and 18 m above the base of the formation. Most of these beds yield numerous small cuticle fragments, but also larger specimens were found. In one layer plants remains are very abundant, and up to 30 cm long frond segments have been found. Apart from cuticles this layer has also yielded abundant charcoalified wood remains. In its type locality in Wadi Himara the uppermost part of the Um Irna Formation mainly consists of sandy deposits. The outcrop section in Wadi Himara with the position of the plant-bearing beds is presented in (Fig. 3).

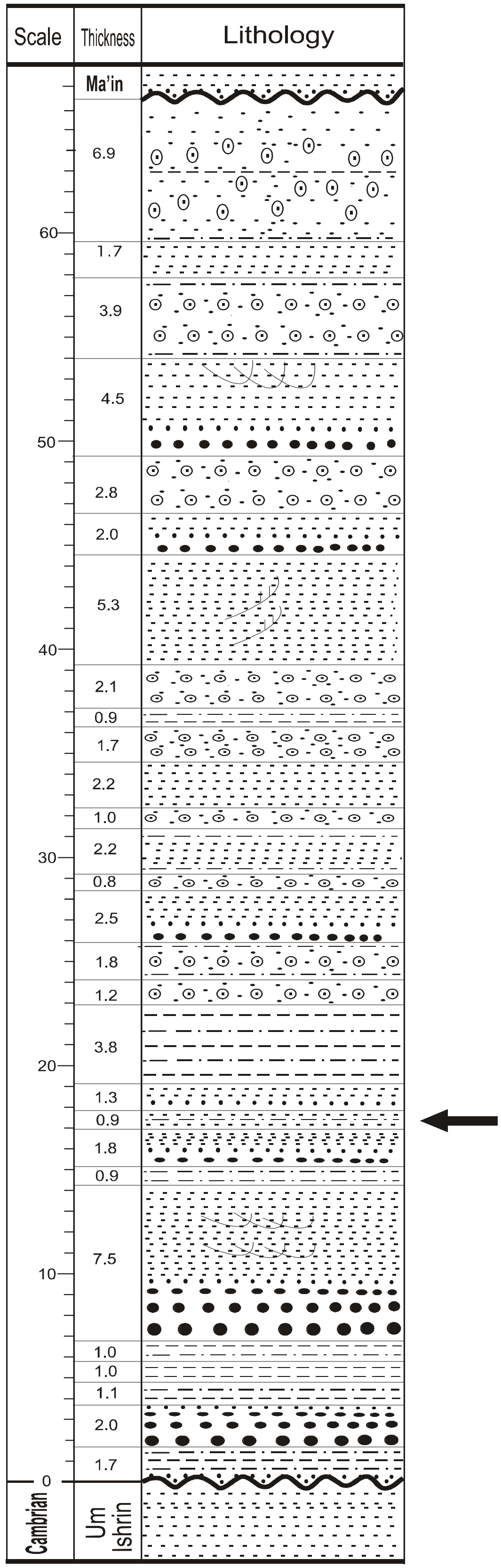

Fig.(3): Stratigraphic log of the Um Irna Formation in the type locality (Wadi Himara) with the position of the plant-bearing bed (arrow).

Although plant megafossils are abundant in the Wadi Himara locality, species diversity is low. The flora consists of at least five species of *Dicroidium*. The material is preserved as compressions with excellently preserved cuticles. Generic assignments of the megafossils are based on the frond and pinnule morphology, i.e. the presence of the characteristic bifurcation in the lower part of the frond and the odontopteroid pinnules, and on the basis of the epidermal anatomy. In addition to *Dicroidium* the flora contains a few poorly preserved, unidentifiable fern remains.

Mustafa (2003) recently described a small flora from an outcrop in the upper part of the Um Irna Formation near the main road along the eastern shore of the Dead Sea, at only a few kilometres from the Wadi Himara locality. This flora is dominated by *Doratophyllum jordanicus* Mustafa, a type of taeniopterid foliage. Another common taxon is *Lobatannularia heianesis* (Kodaira) Kawasaki. Rarer elements are *Gigantonoclea* sp. and *Pecopteris* sp.

Bandel and Khoury (1981) attributed a Late Permian age to the Um Irna Formation on the basis of a preliminary analysis of the microflora. Lithological correlations with drillcore sections further towards the west suggested a Late Permian age (Eshet and Cousminer, 1986). Nevertheless, some authors considered the Um Irna Formation to be Permo-Triassic in age (e.g., Makhlouf *et al*., 1991). New palynological investigations (This study, Chapter 5) have provided new data for the age assessment. The plant-bearing interval has yielded a rich and well-preserved microflora, clearly indicating a Late Permian age, based on the presence of *Lueckisporites virkkiae* Potonié et Klaus, *Klausipollenites schaubergeri* Potonié et Klaus and *Protohaploxypinus limpidus* (Balme et Hennelly) Hart. The palynological assemblages are dominated by bisaccate pollen grains, mainly various species of *Falcisporites* Leschik, including *F. zapfei* (Potonié et Klaus) Leschik and *F. stabilis* (de Jersey) Balme, which together may constitute over 50% of the associations. The high abundance of *Falcisporites* may at first glance seem unusual for the Upper Permian, but can easily be explained by the fact that this pollen type was produced by the pteridosperm *Dicroidium* (Balme, 1995), which is the abundant megafloral element in these beds. The recently described megaflora from the upper part of the Um Irna Formation (Mustafa, 2003) confirms a Late Permian age, because *Lobatannularia* and *Gigantonoclea* are typical Late Permian elements. Both these genera became extinct at the Permian-Triassic boundary (Anderson *et al*., 1999).

The basal part of the unconformably overlying Ma'in Formation (Himara Member) has been dated as (?early) Scythian on the basis of poor palynological assemblages

(This study, Chapter 5), and the second member of the Ma'in Formation has been dated as middle to late Scythian on the basis of bivalves (Cox, 1932) and conodonts (Huckriede and Stoppel, in Bender, 1968).

3.c. Material and methods

The plant material from the Wadi Himara locality consists of compressions with excellent cuticles, occurring in dull brownish to grey-black organic- and sulphur-rich silt- and claystones. Plant megafossils are abundant in the shaley and silty layers in the lower Part of the Um Irna Formation, but only very few species have been recorded. The majority of the specimens belong to two new, here described species of *Dicroidium*, both having rather small pinnules. A number of large (up to 30 cm long) specimens, including several showing the typical frond architecture have been found.

One layer is extremely rich in cuticles. Complete pinnae are not rare. Bulk macerations of this cuticle-rich layer revealed that the vast majority of these cuticles belong to *Dicroidium*; only very few other taxa have been found among the dispersed cuticles, i.e., a few very poorly preserved cuticles, most probably conifers.

The light to medium brown-coloured mummified leaves very easily detach from the slabs. Regarding the richness in sulphur, it seems most probable that the cuticles have been macerated naturally by a reaction with sulphuric acid. A treatment with a 2% potassium hydroxide (KOH) solution usually suffices to clear the cuticles. Only the darkest specimens first have to be bleached a few minutes in a 4% sodiumhypochlorite solution and can then be treated with potassium hydroxide (Kerp, 1990; Kerp and Krings, 1999). After rinsing in water the cleared cuticles are dehydrated in pure glycerine for at least two days before they are mounted in glycerine jelly slides. Some cuticles were stained in Bismarck Brown (Vesuvin) to enhance the cell pattern (Lillie, 1977; Krings, 2000).

Bulk macerations were performed by dissolving the sediment with 43% hydrofluoric acid (HF) in order to isolate the cuticles from the rock. The cuticles were then bleached following the procedure outlined above. Complete pinnae are not uncommon and even up to 8 cm long rachides with several almost complete pinnules still attached (Pl.10, 1) have been obtained by bulk maceration. Upper and lower cuticles can be separated with dissecting needles, thus enabling the study of the upper and lower cuticles of individual pinnules (Plate 4, 5, 11-13, 15, 16, 1-2). Several thousand cuticle slides have been prepared for this study including more than a hundred "opened" pinnules, altogether giving a very good idea about the epidermal morphology and the variation within the two species described in this contribution.

Hand specimens were photographed on low-speed panchromatic film (Agfapan 25), using polarized light to enhance the contrast. Micrographs were made with an Olympus Vanox AH-2 Microscope (2.5 - 40x magnifications) and a Leitz Diaplan microscope with Nomarski interference contrast (100 - 1000x magnifications) on low-speed panchromatic (Agfapan 25) and orthochromatic film (Makrophot Ortho 25), if necessary with green a filter. Some micrographs were made with a Leica DC 480 Digital Camera mounted on a Leitz Diaplan microscope.

3.d. The genus *Dicroidium* Gothan 1912

The genus *Dicroidium* was established by Gothan (1912) for pinnate to bipinnate fronds with odontopteroid pinnules and a characteristic basal bifurcation. The four species recognized by Gothan had originally been accommodated in *Thinnfeldia* Ettingshausen. Apart from differences in the frond architecture and the epidermal anatomy, there appeared to be striking differences in the geographical distribution of *Dicroidium* and *Thinnfeldia*. *Dicroidium* is a typical southern hemisphere plant whereas the occurrence of *Thinnfeldia* is restricted to the northern hemisphere. Although some subsequent authors questioned the criteria on the basis of which Gothan had established *Dicroidium,* or even rejected the genus, it became generally accepted. Based on frond architecture and pinnule morphology Frenguelli (1943) distinguished four genera which were later all regarded as synonyms of *Dicroidium* (Townrow, 1957; Bonetti, 1966; Archangelsky, 1968; Anderson and Anderson, 1983). The genus *Dicroidium* was emended by Townrow (1957), who also described cuticles of several species and transferred some species previously assigned to other genera to *Dicroidium.* More recent systematical studies of *Dicroidium* were published by Retallack (1977), who distinguished a large number of species and varieties, and by Anderson and Anderson (1983) who published a monograph on the genus *Dicroidium* based on material from the Late Triassic Molteno Group, South Africa. The number of taxa recognised by these latter authors is less than by other authors, especially on the infrageneric level. Approximately 30 well-defined species and subspecies are currently recognised (Anderson and Anderson, 1983).

Dicroidium belongs to the family Corystospermaceae. This family was instituted by Thomas (1933), who first described the ovuliferous and pollen organs as *Umkomasia* and *Pteruchus*. Correlations between foliage and reproductive organs were based on repeated associations and similarities in epidermal anatomy. Although these correlations were never questioned, there was some debate on the organization and interpretation of the fertile organs. *Umkomasia* is a cupulate organ with lateral axes which appear to be arranged in a single plane. The entire *Umkomasia* cupulate organ is a branching system, and each cupule represents an individual megasporophyll. Thomas (1933) considered the pollen organs to be organised in a similar way, i.e. the ultimate flattened structures bearing the pollen sacs would be individual microsporophylls borne on a branch. This view was challenged by Townrow (1962), who held the opinion that the entire pollen organ described as *Pteruchus* was a single compound sporophyll. Axsmith *et al.* (2000) described new material from the Antarctic and they could confirm the correctness of Thomas' original interpretation. Moreover, they were the first to demonstrate an organic connection between cupulate organs and foliage-bearing axes. They also concluded that one foliage morphotype might have belonged to two different natural species.

Not only the taxonomy, but also the growth form of the *Dicroidium* plant has been a matter of some debate. Archangelsky (1968) suggested that the *Dicroidium* plant might have had a liana-like growth habit. Later authors (e.g., Meyer-Berthaud *et al*., 1993; Taylor, 1996) could not find proof for a liana-like growth habit. Petriella (1981) reconstructed *Dicroidium* as an unbranched medium-sized tree with an apical crown of closely spaced fronds similar to a tree fern or palm tree. The most complete material currently known, described by Axsmith *et al*. (2000), suggests that the *Umkomasia uniramia-Dicroidium odontopteroides* plant from the Antarctic had an arborescent growth form similar to that of the extant *Ginkgo biloba*.

The systematic position of the corystosperms is still not entirely clear. Most authors accept a close relationship to the peltasperms, another group of Late Palaeozoic-Early Mesozoic seed ferns (e.g., Crane, 1985; Meyen, 1985; Nixon *et al*., 1994; Doyle, 1996). Some authors have suggested that the corystosperms could include angiosperm ancestors (Frohlich and Parker, 2000), whereas this is considered to by to be highly unlikely by others (e.g., Axsmith *et al.*, 2000).

3.e. Descriptve part

Dicroidium irnensis Abu Hamad et Kerp nov. sp. (Plate 1-6)

Holotype: Specimen PbO UmIr 3, illustrated on Pl. 1, 1-3.

Derivatio nominis: The name refers to the Um Irna Formation in which the fossils have been found. Um Irna is the mountain between Wadi Himara and Wadi Zarqa Ma'in.

Type locality: Wadi Himara, in the incised river valley, ca. 400 m upwards along the southern branch after the main bifurcation.

Stratum typicum: Silt and clay layers and lenses, 17 - 18 m above the base of the Um Irna Formation, Upper Permian.

Diagnosis:

Fronds small, bifurcated, bipinnate. Primary axis very robust and smooth, bifurcating with an angle of approximately 25° with at least two pairs of pinnae below the bifurcation; frond portions above the bifurction more or less ovate in outline, tapering towards the apices and with their greatest width in the middle. Pinnae alternating to suboppositely attached, at angles between 45° and 70°, with up to 14 pinnules at each side.

Pinnules densely spaced, sometimes overlapping, in alternating or subopposite position; pinnules obliquely attached with their entire basis, asymmetrical, tongue-shaped to rhomboidal with rounded apices; lateral pinnule margins more or less parallel, distal pinnule margin often more or less parallel to the pinna axis. Basiscopic pinnules more obliquely attached than acroscopic pinnules; basal basiscopic pinnules occasionally continuing along the primary rachis. Pinnae ending in elongated, tongue-shaped pinnules and usually consisting of 3-5 strongly fused pinnules. Intercalary pinnules present, asymmetrically triangular to rhomboidal.

Venation odontopteroid, lacking a clear midvein, with several veins entering the pinnule; veins rather densely spaced, bifurcating one or two times.

Leaves amphistomatic, stomata far more numerous on the lower leaf side. Epidermal cells and stomata of the upper leaf surfaces larger than those of the lower leaf surfaces. Stomata of the upper leaf side mainly restricted to the pinnae rachides and basal parts of the pinnules, particularly over the veins, but very rare to absent on the more distal parts of the pinnules. Stomata very abundant on the lower leaf side, occurring all over the pinnule surface but rare or absent under the pinna axes. Stomata of the pinnules normally completely randomly distributed. Stomata commonly with four subsidiary cells, the lateral ones less strongly cutinised than the polar ones; also stomata with a ring of five or six subsidiary cells occur occasionally. Papillae rare, mainly restricted to the upper pinnule surfaces.

Description:
Fronds small, bifurcated, bipinnate (Pl. 1, 1-2; Pl. 2, 2; Fig. 4). The primary axis is very robust and smooth (Pl. 1, 1-2), bifurcating with an angle of approximately 25°. At least two pairs of pinnae are inserted below the bifurcation; frond portions above the bifurction are more or less ovate in outline, tapering towards the apices and with their greatest width in the middle. Pinnae alternating to suboppositely attached, at angles of between 45° and 70°, bearing up to 14 pinnules at each side.

Pinnules densely spaced or sometimes overlapping, in alternating or subopposite position (Pl. 1, 1-2, Pl. 2, 1, 4); pinnules obliquely attached with their entire basis (Pl. 2, 4, Pl. 3), asymmetrical, tongue-shaped to rhomboidal with rounded apices; lateral pinnule margins more or less parallel, distal pinnule margin often more or less parallel to the pinna axis, pointing towards the pinna apices. Basiscopic pinnules more obliquely attached than acroscopic pinnules; basal basiscopic pinnules occasionally continuing along the primary rachis. Pinnae ending in elongated, broadly tongue-shaped pinnules (Pl. 2, 1, Pl. 3, Pl. 4, 1-2), usually consisting of 3-5 strongly fused pinnules. Intercalary pinnules present, asymmetrically triangular to rhomboidal. The first pinnae in the interior of the bifurcation undifferentiated; individual pinnules not developed. Venation odontopteroid, lacking a clear midvein and with several veins entering the pinnule; veins rather densely spaced, bifurcating one or two times.

Leaves amphistomatic; stomata much more common on the lower leaf side (Pl. 4, Pl. 5). Cuticles of frond and pinna axes thick, having elongated rectangular to isodiametric polygonal cells, arranged in longitudinal rows. Anticlinal walls thick, straight to slightly sinuous. Stomata on the upper pinna axis surface are arranged in longitudinal rows. Multicellular hair bases and papillae are rather common on the frond axis and far less common on the pinna axes. Pinna axes with stomata on both sides but more frequent on the upper surface (Pl. 4). Pinnules are amphistomatic; cuticles of the pinnules are thinner than those of the pinna axes. There is a gradual transition from the pinna axis into the pinnules. The cuticles of the upper pinnule surface are thick. Normal epidermal cells of the upper pinnule surface are isodiametric polygonal to slightly elongated, randomly oriented. Stomata are frequent to very frequent over the pinna axes, rare in the basal one third of the pinnules, where they occur over veins, and virtually absent in the rest of the pinnule. The cuticles of the lower pinnule surface are thinner; stomata are very abundant over the entire surface. The cells over the pinna axes are isodiametric polygonal, usually elongated rectangular, oriented along the pinna axes. The normal epidermal cells of the pinnules are almost isodiametric polygonal to slightly elongated, randomly oriented. The stomata of the lower pinna axes are often oriented more or less longitudinally. The stomata of the pinnules are sometimes more or less positioned in rows parallel to the lateral pinnule margins, or completely randomly distributed. The stomatal pores are oriented randomly. Stomata often with four subsidiary cells, the lateral ones being less strongly cutinised than the polar ones (Pl. 6). Also stomata with a ring of five or six subsidiary cells are occur (Pl. 6, 5-6); stomatal apparatuses occasionally incomplete dicyclic. Stomata randomly oriented (Pl. 6, 1). Papillae rare, restricted to the lower pinnule surfaces.

Additional descriptions:

The frond axis of *Dicroidium irnensis* is sometimes remarkably robust, regarding the relatively small size of the fronds. Five specimens showing the frond bifurcation have been collected. The width of the frond axis varies from 3 to 12 mm below the bifurcation and from 2 to 6 mm above the bifurcation. The maximum pinna length is unknown because virtually all larger attached pinnae are incomplete. Only a single complete attached pinna is known which measures 10 cm in length. The pinnae below the bifurcation are up to 4.5 cm long.

The pinnules are very broad, sometimes wider than long. They are usually 4.5-6 mm long but the smallest ones measure only 2.5 mm, whereas the longest ones reach a length of 9 mm. The average width is 4-6 mm, the smallest being only 2 mm and the largest up to 6.5 mm wide. The terminal pinnules which consist of up to five strongly fused pinnules are 12 to 20 mm long and 6.5 to 9 mm wide. Pinnule size ranges have been determined on the basis of measurements of over 50 hand specimens and are confirmed by many hundreds of larger pinna portions and complete pinnules obtained by bulk maceration. The average sizes are considered to represent pinnules from full-grown fronds. The venation is rather delicate and often obscured by the cuticles and the coalified mesophyll material. Although it is difficult to determine their exact number, at least eight equally strongly developed veins enter the pinnule.

The cells of the lower surfaces of the pinnules and pinna axes are smaller than those of the upper surfaces of the pinnules and pinna axes. The normal cells of the upper side of the pinna axis are 62-120 µm (usually c. 80 µm) long and 20-44 µm (usually c. 30 µm) wide, and those of the lower side are 32-72 µm long and 20-32 µm wide. The normal epidermal cells of the upper pinnule surfaces are 56-100 µm long and 25-50 µm wide, and those of the lower pinnule surfaces are 28-68 µm (usually c. 45 µm) long and 8-40 µm (usually c. 20 µm) wide. The guard cells of the stomata are very narrow, 3-4 µm wide, and 28-44 µm long. The most common type of stomatal apparatus has four subsidiary cells, two lateral ones and two polar ones. The lateral subsidiary cells are relatively wide. These subsidiary cells are 28-64 µm (usually c. 40 µm) long and 16-28 µm (usually 20 µm) wide.

In weakly macerated specimens both the upper and lower pinnule cuticles clearly show the presence of a second cutinised layer below the epidermis. The cells of this layer are much smaller than the cells of the epidermis, about one third to one fourth of the size of the epidermal cells.

Comparisons with other taxa:
In its general appearance *Dicroidium irnensis* is most similar to *D. zuberi* (Szajnocha) Archangelsky, with regard to the general morphology of the frond as well as to the shape of the pinnules. *Dicroidium zuberi* first appears in the lower Olenekian of Australia (Retallack, 1977) and is occurs throughout the rest of the Triassic (Anderson and Anderson, 1983). It is definitely the most widespread *Dicroidium* species and it has been recorded from South America, South Africa, India, Australia, New Zealand and the Antarctic. It is also one of the larger and most variable species. The pinnules of *D. irnensis* are strongly reminiscent of those of *D. zuberi*, except for the terminal pinnules. The main difference is their size. Pinnules of *D. zuberi* can, according to Frenguelli (1944), be 11-14 mm long and some authors have figured even much larger ones, e.g., Townrow (1957, pl. II, b-c: figured under the name *Hoegia papillata)* and Anderson and Anderson (1983, pl. 36, 8-9). This

means that *D. zuberi* pinnules are normally about twice as large as those of *D. irnensis*. The neotype of *D. zuberi,* selected by Archangelsky (1968) and originally figured by Frenguelli (1944, pl. 4), is a juvenile frond. Some of the pinnules of this specimen have about the same size, but most are even larger as those of full-grown *D. irnensis* fronds. The shape of the terminal pinnae in *D. irnensis* and *D. zuberi* is very different. In *D. zuberi* the pinnae gradually taper towards the apex and end in a relatively small and narrow terminal pinnule, whereas the pinnae of *D. irnensis* hardly reduce in width towards the pinna apex and end in a long and broadly rounded terminal pinnule.

Also the cuticles of *Dicroidium irnensis* and *D. zuberi* are differ considerably. *Dicroidium irnensis* has amphistomatic leaves, whereas those of *D. zuberi* are hypostomatic. However, it should be noted that on the upper leaf surface of *D. irnensis* stomata occur only over the pinna axes and in the basal parts of the pinnules. Moreover, Anderson and Anderson (1983, p. 196) mentioned a single specimen from South Africa identified as *D. zuberi* having amphistomatic leaves (Slab 1351), but they did not illustrate cuticles of this specimen. A clear difference is the shape of the anticlinal walls. In *Dicroidium zuberi* the anticlinal walls of the upper and lower pinnule surfaces are straight but possess prominent anticlinal projections (= buttressed cell walls *sensu* Anderson and Anderson, 1983). Sometimes these projections are so well developed that the anticlinal walls may have a strongly sinuous appearance (Anderson and Anderson, 1983, pl. 101, 6, pl. 102,1). Such anticlinal projections are absent in *D. irnensis*, which has perfectly straight anticlinal walls*. Dicroidium zuberi* has stomata four to five very strongly cutinized subisidiary cells forming a ring, whereas in *D. irnensis* stomata usually have two lateral subisidiary cells which are very weakly cutinized and two polar cells which are normally cutinized.

At first glance *Dicroidium irnensis* also shows some superficial similarities with *D. jordanensis.* However, the pinnule morphology and the cuticles are clearly different. These differences will be further discussed under *D. jordanensis* (p. 58, Table 3). Comparisons with other early (Early Triassic) *Dicroidium* species are presented in a separate paragraph and in Table 4.

Discussion

Although no complete fronds of *Dicroidium irnensis* have been found, the specimens at hand give a pretty good idea about the size and shape of the frond (Fig. 4). The frond looked rather similar to the juvenile frond of *D. zuberi* that has been illustrated by Frenguelli (1944, pl. 4), although it must have been slightly smaller, attaining a length of ca. 20-25 cm. The angle of bifurcation is relative small (25°). The lowermost interior pinnae are not well developed but the other pinnae in the interior part of the frond are normally developed and the pinnae from both sides overlapped each other like in many other *Dicroidium* species with bipinnate fronds.

The frond morphology justifies the classification of this species to the genus *Dicroidium.* Although cuticles of the various *Dicroidium* species show a considerable variation, notably in the shape of the stomata, these further substantiate the generic assignment. Stomata usually have two weakly cutinized lateral subsidiary cells and are of the same type as of *D. longifolium* which has been illustrated by Jacob & Jacob (1950). This latter species, however, has a very different pinnule morphology. The distribution of stomata is highly remarkable. The leaves are amphistomatic, but the distribution of stomata on the upper and lower leaf surfaces is very uneven. On the upper leaf surface the stomata are almost completely restricted to the pinna rachises and basal parts of the pinnules; most of the pinnule lamina does not show any stomata. The cuticle of the lower leaf is completely different, lacking stomata on the pinna axes, whereas the cuticles of the lower pinnule surfaces have numerous stomata. Stomata are evenly distributed over the entire pinnule surface.

The fact that stomata on the upper leaf surfaces are restricted to the pinna axes and the basal parts of the veins may either suggest that (1) they might have had a function for evapotranspiration, or, (2) more likely, they were formed when the pinnules were not still fully differentiated and the lamina had not spread; in juvenile fronds pinnules are folded up or rolled in – only the upper surfaces are in contact with the atmosphere and only there stomata can be functional.

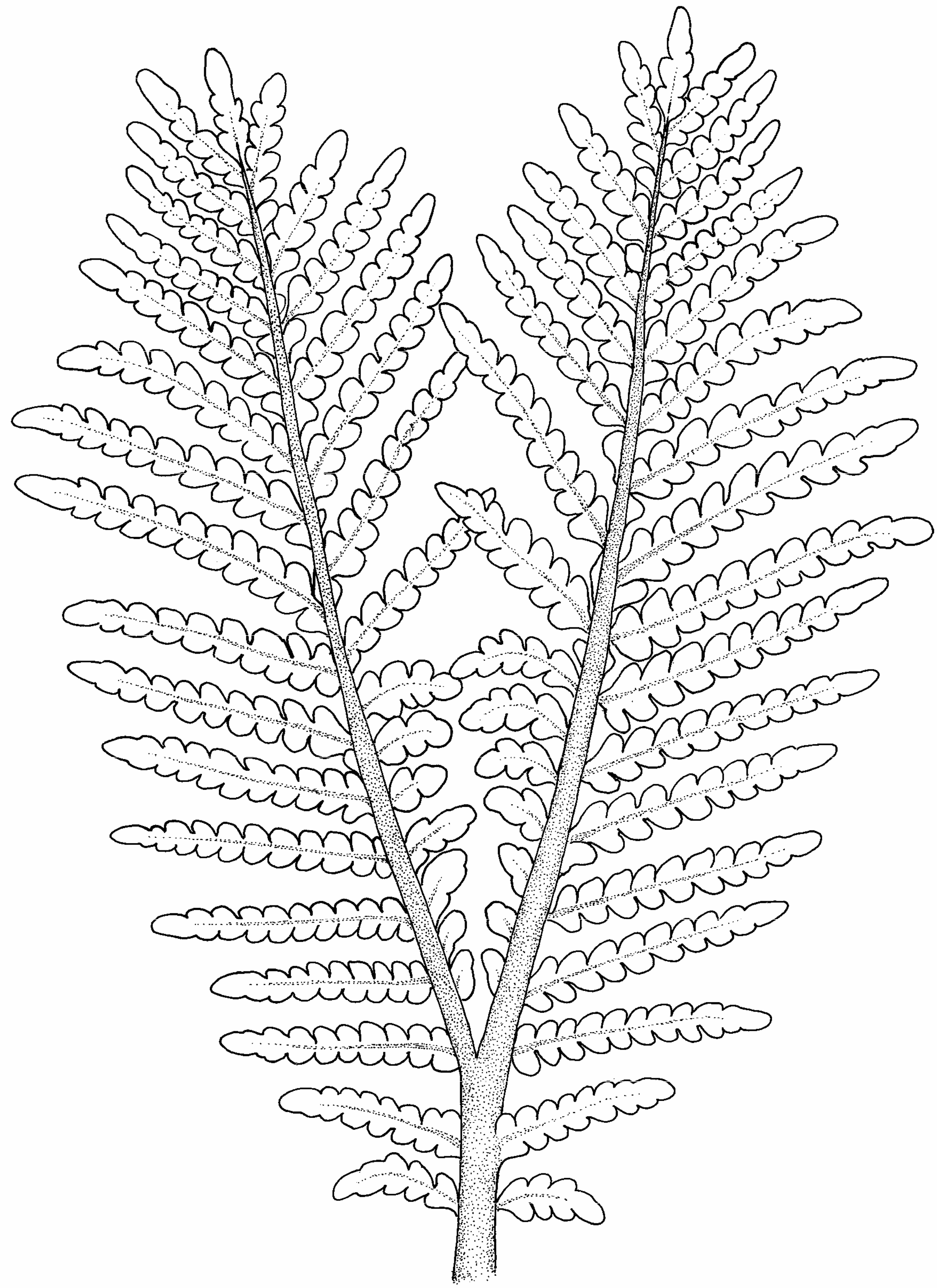

Fig. (4) Tentative reconstruction of a *Dicroidium irnensis* frond

Dicroidium jordanensis Abu Hamad et Kerp nov. sp. (Plate 7-16)

Holotype: Specimen PbO UmIr 66, illustrated on Pl. 7,1, Pl. 8, 1-2.

Derivatio nominis: The name refers to the Jordan Valley, the rift structure of which the Dead Sea is part of.

Type locality: Wadi Himara, in the incised river valley, ca. 400 m stream upwards in the southern branch after the main bifurcation.

Stratum typicum: Silt and clay layers and lenses, 17 - 18 m above the base of the Um Irna Formation, Upper Permian.

Diagnosis:
Fronds small, bifurcated, bipinnate. Primary axis robust and smooth, bifurcating with an angle of approximately 25°. At least six pairs of pinnae are inserted below the bifurcation; frond portions above the bifurcation more or less ovate in outline, tapering towards the apices and with their greatest width in the middle. Pinnae alternating to suboppositely attached, at angles of between 30° and 70°, bearing up to 17 pinnules at each side. Pinnules normally widely spaced but sometimes overlapping, in alternating or subopposite position; pinnules broadly attached, decurrent, asymmetrical, tongue-shaped to triangular in outline with rounded to acute apices pointing towards the pinna apices. Basiscopic pinnules more obliquely attached than acroscopic pinnules; Basal basiscopic pinnule semi-cricular in outline. Pinnae ending in elongated, narrow terminal pinnules usually consising of 2-3 strongly fused pinnules. Intercalary pinnules occasionally present, asymmetrically triangular and smaller than normal pinnules.

Leaves amphistomatic; stomata more abundant on lower than on upper leaf surface. Cells of upper leaf surface larger than those on the lower surface; cells of upper leaf surface up one-and-a-half times as large as those on lower surface. Normal epidermal cells isodiametric to elongated, rectangular. Stomatal complexes with two slightly sunken guard cells, which are partly underlying the adjacent subsidiary cells. Stomatal apparati monocyclic to incomplete dicyclic with a ring of four to six subsidiary cells; subsidiary cells similarly cutinised as normal cells.

Additional descriptions:

The frond axis of *Dicroidium jordanensis* is narrower than that of *D. irnensis*, being 2-8 mm wide below the bifurcation and 4, occasionally up to 6 mm wide above the bifurcation. The pinnae are up to at least 9 cm long.

Pinnules are usually longer than wide, with a length-width ratios from 2:1 to 3:2. Pinnules are normally 4-5 mm long, but pinnules up to 7.5 mm long have occasionally been found. The width varies from 1.7 to 4.5 mm. Basal pinnules are often trapezoid to tongue-shaped and rounded (Pl 10, 1; Pl. 11), those in the middle pinna portions asymmetrical trapezoid to triangular with more or less acute apices (Pl. 9, 4-5, Pl. 12), and those of the apical frond portions are rather narrow, triangular, inserted at a very low angle and pointing towards the pinna apices (Pl. 10, 2-7, Pl. 13). Terminal pinnules are relatively narrow and ca. 7 mm long and 1.5 to 3 mm wide (Pl. 10, 2-7).

The cells of the lower surfaces of the pinnules and pinna axes are smaller than those of the upper surfaces of the pinnules and pinna axes. The normal cells of the upper side of the pinna axis are 36-108 µm (usually c. 67 µm) long and 12-37 µm (usually c. 24 µm) wide, and those of the lower side are 33-70 µm long (usually c. 52 µm) and 10-30 µm wide (usually c. 23 µm). The normal epidermal cells of the upper pinnule surfaces are 40-52 µm long and 26-32 µm wide, and those of the lower pinnule surfaces are 37-40 µm (usually c. 39 µm) long and 24-27 µm (usually c. 26 µm) wide. Small papillae may occasionally be present on the cells of the upper leaf surface; papillae are absent on the lower leaf surface.

Stomata evenly distributed, usually more or less arranged in longitudinal rows, rarely randomly oriented. The most common type of stomatal apparatus has four to seven (usually five) subsidiary cells, encircling the stoma. In internal view the guard cells are wide with faintly developed wood lamellae and each guard cell with a longitudinal ridge along the inner margin. The guard cells of the stomata are narrow in external view, 4-7 µm wide, and 28-45 µm long. The lateral subsidiary cells are relatively wide. These subsidiary cells are 7-18 µm (usually c. 12 µm) long and 8-15 µm (usually 11 µm) wide. Subsidiary cells may bear small thickenings on the periclinal walls. Trichomes are restricted to the frond rachis and the pinna axes.

Discussion:

Dicroidium jordanensis is a much more delicate form than *D. irnensis*. The entire frond was probably c. 30 cm long. The frond morphology justifies the assignment to *Dicroidium*. Several, up to six pinnae may be present below the bifurcation. The lower ones largely consist of strongly fused pinnules, whereas the ones just below the bifurcation show well differentiated pinnules. The lower pinnules in the interior of the frond strongly resemble the lower ones below the bifurcation. A specimen showing a widened frond base suggests that an abscission tissue was present and that entire fronds were thrown off. Fig. (5) Tentative reconstruction of a *Dicroidium irnensis* frond

Although the guard cells are partly underlying the subsidiary cells, they are not strongly sunken. The presence of stomata over the entire upper leaf surface, the relatively thin cuticles and the virtual absence of papillae in most of the specimens studied suggests that *Dicrodium jordanensis* grew in rather humid environments.

Comparisons with other taxa:

As stated before *Dicroidium jordanensis* shows some superficial similarities with *D. irnensis*. The pinna terminals of *D. irnensis* are large, broad, trapezoid and obtuse, whereas those of *D. jordanensis* are asymmetrically triangular and narrower. Also the spacing of the pinnules differs in these two species. Another clear difference is the shape of the pinna terminals which are much larger in *D. irnensis*. Even more striking are the differences in the cuticles. In *D. irnensis* the upper cuticles of the pinnules hardly have any stomata, only a few at the pinnule bases, whereas stomata occur over the entire upper pinnule surface of *D. jordanensis*. Also the shape of the stomata differs considerably. Therefore also dispersed, fragmentary cuticle remains can easily be identified. The main differences between the two species are summarized in Table 3.

	Dicroidium irnensis	*Dicroidium jordanensis*
position of the pinnules	densely spaced, sometimes almost overlapping	densely spaced only in the lower pinnae and towards the pinna apices
shape of the pinnules	broad, trapezoid with rounded apex; broadly attached, not decurrent	asymmetrically triangular, often slightly constricted just above the pinnule base, apex obtuse to acute; decurrent
shape of the pinna terminals	large, broadly tongue-shaped, consisting of 5-6 fused pinnules	smaller, usually rather narrow, sometimes even lanceolate
distribution of stomata	leaves amphistomatic, but stomata mainly on the lower cuticle; stomata on the upper surface are restricted to the pinna axes and the pinnule bases; most of the upper pinnule surface lacks stomata	leaves amphistomatic; although stomata are less frequent on the upper than on the lower pinnule surface, they occur over the entire upper pinnule surface and the pinna axes
orientation of the stomata on the lower pinnule surfaces	randomly oriented	stomatal pores more or less aligned in the same direction
shape of the stomata	mostly with 4 subsidiary cells, the polar ones are more strongly cutinised than the lateral ones; stomata with 5-6 subsidiary cells occur also but are less frequent; incompletely dicyclic stomata occasionally present	stomata usually with a ring of 5-6, occasionally 4 or 7 subsidiary cells; stomata with 4 subsidiary cells often have 2 lateral ones at each side; all epidermal cells equally strongly cutinised
papillae	present but rare and small, randomly distributed	usually absent; only very occasionally weakly developed papillae occur
trichomes	very rare, randomly distributed	present, but restricted to the frond rachis and pinna axes; occasionally on upper pinnule surface

Table (3): A comparison between *Dicroidium irnensis* and *D. jordanens*

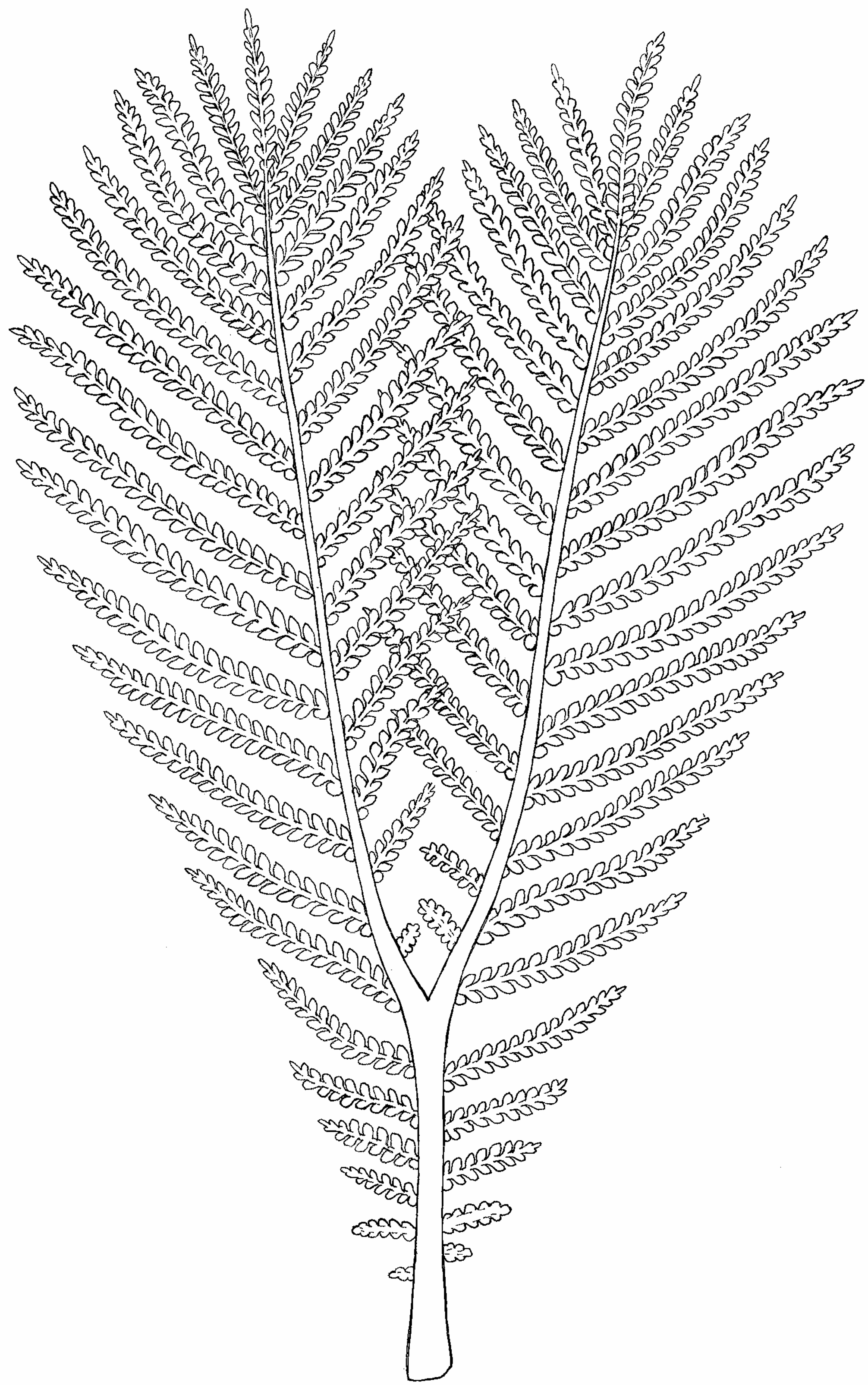

Fig. (5) Tentative reconstruction of a *Dicroidium jordanensis* frond.

In its gross morphology *Dicroidium jordanensis* also shows some superficial resemblances with *D. superbum* f. *townrowii* (Retallack) Anderson and Anderson. This taxon was first described from the Ladinian of Australia and has also been recorded from the Carnian of South Africa. Although both taxa are morphologically quite similar, they differ considerably in their epidermal anatomy. *Dicroidium jordanensis* does not show a differentiation into coastal and intracostal fields that is typical for *D. superbum*. Moreover, the stomata of *D. superbum* are very different from those *D. jordanensis*. In the latter species stomata are not sunken and subsidiary cells are not strongly cutinised like in *D. superbum*. The stomata of *D. jordanensis* are much more similar to those of species like *D. elongatum* (Carruthers) Archangelsky (cf. Anderson and Anderson, 1983, pl. 103, fig. 3-4, 7-8) and *Dicroidium narrabeenense* (Dun in Walkom) Jacob et Jacob (cf. Jacob and Jacob, 1950, fig. 8A, 9). However, *D. elongatum* and *D. narrabeenense* have a very different gross morphology. *Dicroidium elongatum* has pinnate fronds with long, very narrow, lanceolate to sphenopteroid pinnules. *Dicroidium narrabeenense* has pinnate fronds narrow pinnules to bipinnate fronds with narrow, largely fused (pinnatifid) pinnules (= *D. dubium* var. *australe* (Jacob et Jacob) Retallack).

3.f. Comparisons of *Dicroidium irnensis* and *D. jordanensis* with Early Triassic *Dicroidium* species

Regarding the age of the Wadi Himara material, a comparison with early representatives of *Dicroidium* is of particular interest. Apart from *Dicroidium zuberi* and *D. narrabeenense*, which have already been discussed, several other *Dicroidium* species have been reported from the Lower Triassic (Olenekian). These are traditionally considered to be the earliest representatives of the genus. The species are *D. hughesii* (Feistmantel) Lele, *D. nidpurensis* Bose et Srivastava, *D. pinnis-distantibus* (Kurtz) Frenguelli, and *D. voiseyi* Holmes et Ash. Some of these forms show different frond morphology, having usually pinnate instead of bipinnate fronds like in *Dicroidium irnensis* and *D. jordanensis*. *Dicroidium pinnis-distantibus* has very narrow, extremely remarkably widely spaced pinnules. *Dicroidium nidpurensis* has bipinnate fronds. The pinnules are entire-margined to slightly wavy. The lower cuticle shows a very clear differentiation into costal and intercostal fields, unlike the two species from the Um Irna Formation. It should be noted that the typical bifurcation has not been demonstrated for *D. nidpurense*. Also regarding its alethopteroid venation it may be questioned whether this species could not better be accommodated in *Thinnfeldia* or *Pachypteris*. *Dicroidium voiseyi* has very long, narrow pinnules. The main gross morphological differences are summarised in Table 4.

	Frond	Pinnules
*D. irnensis**	Bipinnate	odontopteroid, small
*D. jordanensis**	Bipinnate	odontopteroid, small
D. hughesii	pinnate, occasionally bipinnatifid	alethopteroid, very large
*D. narrabeenense**	pinnate to bipinnatifid	alethopteroid, elongate, narrow with acute apex, bipinnatifid forms with strongly fused pinnules
*D. nidpurensis**	bipinnate (without basal bifurcation?)	alethopteroid, lateral margins crenulate
D. pinnis-distantibus	Pinnate	alethopteroid, very long and narrow, widely spaced
D. voiseyi	Pinnate	alethopteroid, very long and narrow
*D. zuberi**	Bipinnate	odontopteroid; large and broad, rhomboid

Table (4): Morphological comparison between the two species from the Dead Sea region and Early Triassic *Dicrodidium* species. Taxa which can be further differentiated on the basis of epidermal characters are marked with an asterisk. For a detailed comparison of *D, irnensis* and *D. jordanensis* see Table (3).

3.g. Climatic and ecological considerations on *Dicroidium* from Wadi Himara

The palaeogeograpical position of the Dead Sea region at ca. 15°S (see e.g., Baud *et al.*, 1993; Ziegler *et al.*, 1997; Stampfli and Borel, 2001) indicates that the Wadi Himara flora grew in a (sub)tropical lowland area. The lithology of the Um Irna Formation and the cuticles provide further information on the climate and ecology of the Wadi Himara flora. Soils with pisolithes, like they occur in middle and upper part of the Um Irna Formation, are typically formed in hot and humid climates with a high annual rainfall and a short dry season (Driessen *et al*., 2001). Also the epidermal features of the two *Dicroidium* species described here in detail indicate humid conditions. The cuticles are not extraordinarily thick and leaves are amphistomatic. Stomata are very abundant, even when they are in *Dicroidium irnensis* mainly restricted to the lower leaf surface. Moreover, the stomata are not sunken and the guard and subsidiary cells not thickened. Papillae are rare or even completely absent.

The mass occurrence of *Dicroidium* in fluvial sediments, including larger, rather delicate frond segments, excludes long-distance transport. It can therefore be concluded that these plants grew along rivers and streams.

3.h. The stratigraphic and geographic distribution of *Dicroidium*

As has been outlined above, several *Dicroidium* species have been recorded from the Olenekian (Lower Triassic), but the genus is most common in the Middle and Upper Triassic. *Dicroidium callipteroides* has been considered as the earliest representative of the genus. The species is known from the basal part of the Narrabeen Group in the southern coalfield and western margin of the Sydney Basin (New South Wales, Australia) which is Early Triassic in age. The species has lend its name to the *Dicroidium callipteroides* Oppel Zone, the lowermost floral zone of the Triassic (Retallack, 1977, 1995). However, based on cuticular studies and associated fructifications, it was recently demonstrated that *D. callipteroides* does not belong to the corystosperms, but is a member of the peltasperms. Hence, this species could longer be accommodated in *Dicroidium* and was transferred to *Lepidopteris* (Retallack, 2002). The oldest unequivocal representatives of *Dicroidium* (e.g., *D. narrabeenense*, *D. zuberi*) appear higher in the Narrabeen Group, i.e. in the upper Bulgo Sandstone and the Newport Formation, which are of early Olenekian (Smithian) age. The last occurrences of *Dicroidium* have been reported from the Rhaetian (Retallack, 1977). The stratigraphic ranges of the genus *Dicroidium* in the various parts of Gondwana are shown in Fig. 6.

Dicroidium is a typical Gondwana taxon. It has been described from localities found at palaeolatitudes above 35°S in South Africa, Australia, New Zealand, India, Chile, Argentina and Antarctica (Anderson and Anderson, 1983). More recently the genus has also been recorded from other localities in Chile (e.g., Mohr and Schöner, 1985; Gnaedinger and Herbst, 2001), southern Brazil (e.g, Guerra Sommer *et al.*, 1999a,b), and the Antarctic (e.g., Pigg, 1990; Boucher et al., 1993; Meyer-Berthaud et al., 1993; Axsmith, 2000). There are two reports of *Dicroidium* from the Northern Hemisphere. Wagner (1962) illustrated a specimen from the uppermost Permian of Hazro (SE Turkey) as "*?Dicroidium* vel *?Thinnfeldia*". This specimen was later identified as *Botrychiopsis* sp. (Archangelsky and Wagner, 1983). Lejal Nicol and Klitzsch (1975) reported two species of *Dicroidium* from the Jurassic of the Murzuk Basin (Libya). They mentioned the occurrence of *Dicroidium odontopteroides* (Morris) Gothan, but this species was not illustrated. The figured specimen of *D.*

nidpurensis is very fragmentary, showing only a few pinnules with an alethopteroid venation. Neither the specimen from Libya nor the type material from Nidpur (Madhya Pradesh, India; Bose and Srivastava, 1971) shows a bifurcation of the frond which is typical for *Dicroidium*. It can therefore be concluded that the material from the Dead Sea region are the first unequivocal reports from the Northern Hemisphere. The geographical distribution of *Dicroidium* is shown in Fig. 7. This map shows that the Dead Sea occurrence is located at least 25° further north than the northern limit of its distribution area during the Triassic.

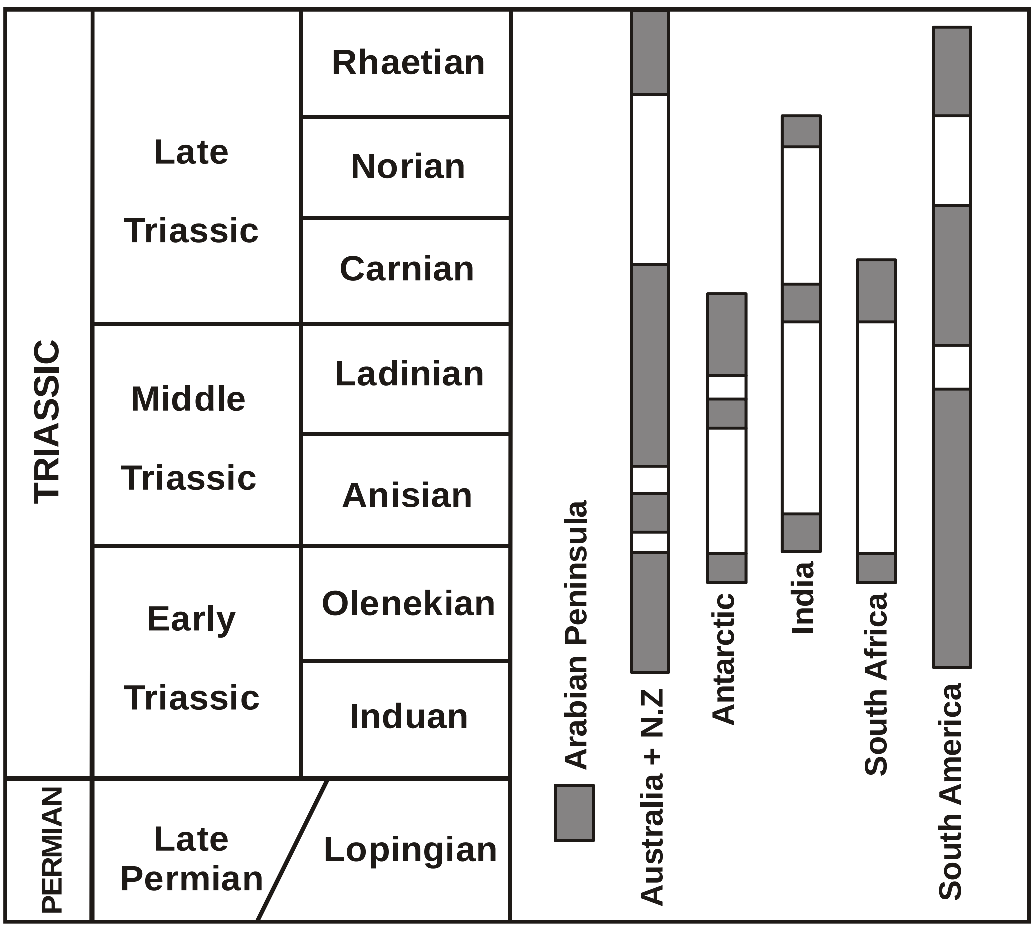

Fig.(6): Straigraphic ranges of Dicroidium in the Middle East and different parts of Gondwana. Ranges according to Anderson and Andeson (1983) and more recent literaturre.

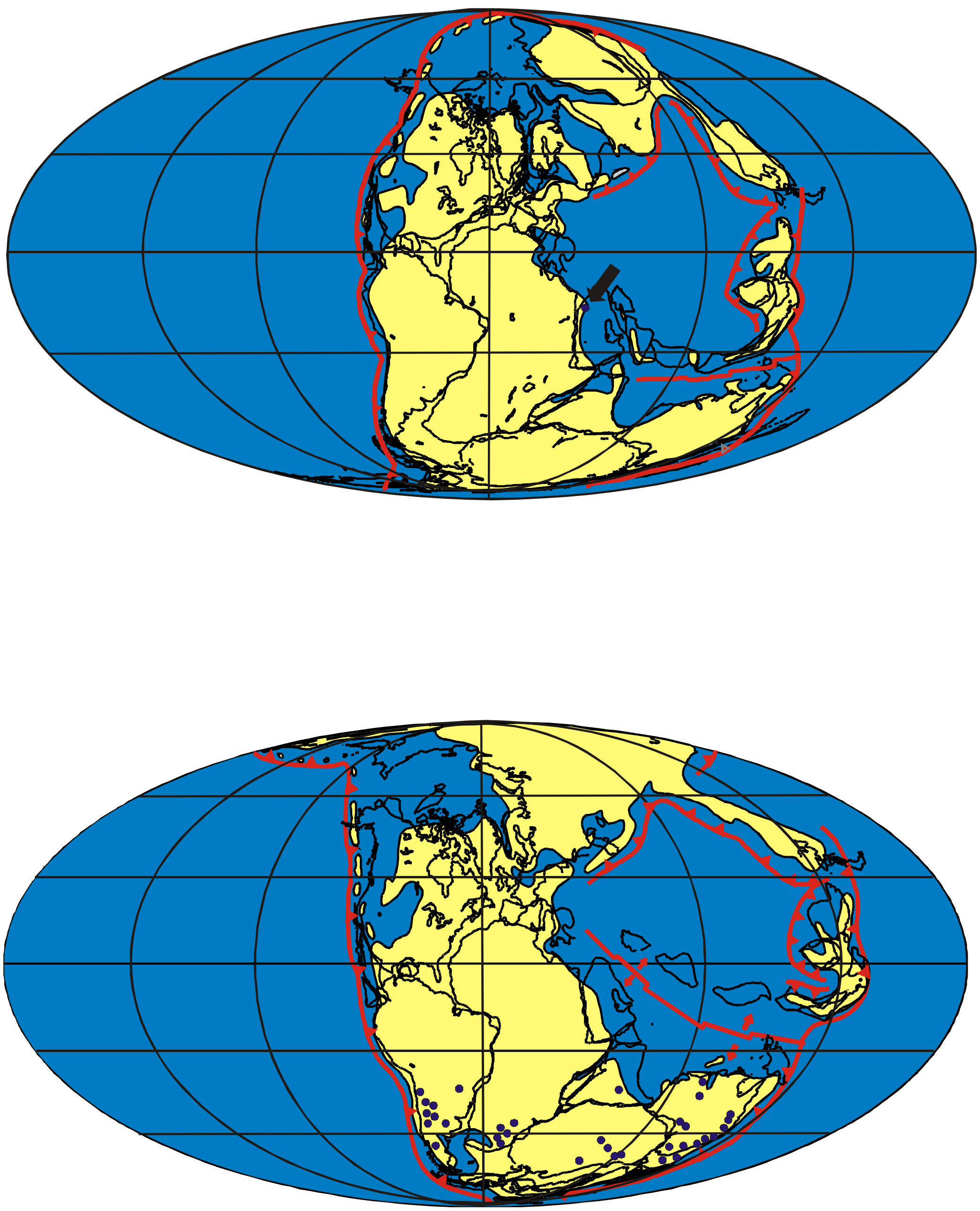

Fig.(7): Palaeogeographic reconstructions according to Scotese and Langford (1995). Late Permian (above) with the position of the Wadi Himara locality (arrow). Triassic (below) with the position of *Dicroidium* localities. Distribution of *Dicroidium* according to Anderson and Anderson (1983) and more recent literature.

3.i. Middle and Late Permian from the Arabian Peninsula and adjacent regions

In the Late Permian, the Arabian Plate was connected to the northeastern part of the African Plate, and the Dead Sea region was a lowland area located at ca. 15°S, well within the equatorial belt (Baud *et al*., 1993; Ziegler *et al*., 1997 (Fig. 9); Golonka and Ford, 2000; Dercourt, 2000; Stampfli and Borel, 2001 (Fig. 8)). Comparisons of the Wadi Himara micro- and macroflora with Middle to Late Permian floras from the Palaeo- and Neotethys regions are of special interest with regard to considerations as to the palaeophytogeographical and palaeoecological significance of the Dead Sea plant fossils. Middle to Late Permian floras from this region include the Southern Alps (northern Italy), the Hazro flora from eastern Turkey, the Ga'ara flora from northwestern Iraq, several floras from Saudi Arabia and the Gharif flora from central Oman (Fig. 8).

The Late Permian floras from the Southern Alps (northern Italy) are generally dominated by conifers; *Ortiseia* Florin, *Majonica* Clement-Westerhof, *Pseudovoltzia* Florin, *Dolomitia* Clement-Westerhof, *Quadrocladus* Mädler, and *Ullmannia* Göppert are the most common genera (Clement-Westerhof, 1984, 1987). Additional floral elements include peltasperms (Poort and Kerp, 1990) and ginkgophytes. Virtually all gymnosperm taxa from the Southern Alps display xeromorphic features, including a thick cuticle, often with prominent papillae, and frequently in combination with strongly sunken stomata and heavily cutinised subsidiary cells. Moreover, most of the plants had thick fleshy leaves, and in some conifers, e.g., *Ortiseia*, the leaves were covered with closely spaced hairs (Clement-Westerhof, 1984). The floras of the Southern Alps probably represent xeric hinterland vegetations. Some genera from the southern Alps are also known from the Germanic Zechstein, i.e., *Pseudovoltzia*, *Quadrocladus*, and *Ullmannia* (see e.g., Schweitzer, 1984). However, the microfloras of the Southern Alps differ from those of the Germanic Zechstein, but these differences are quantitative rather than qualitative (Kerp, 1996, 2000). The conifers, which are abundant in the floras from the Southern Alps, were apparently also present in the Arabian region. This is evidenced by the occurrence in the Wadi Himara microflora of (pre)pollen such as *Lueckisporites virkkiae* Potonié et Klaus, *Jugasporites delasaucei* (Potonié et Klaus) Leschik and *Nuskoisporites dulhuntyi* Potonié et Klaus, which have been attributed to conifers (Looy *et al*., 1999; 2001). In the Um Irna Formation, these forms are relatively rare, suggesting that these plants did not grow in the immediate vicinity of the area of deposition, but further away, probably in drier habitats.

A completely different flora has been described from the uppermost Permian of Hazro, eastern Anatolia, Turkey (Wagner, 1962; Archangelsky and Wagner, 1983). The composition of this flora, which includes numerous sphenopsids and several pecopterids, suggests a warm and humid environment. The flora contains several typical Cathaysia taxa, i.e., ***Lobatannularia heianensis*** (Kodaira) Kawasaki, ***Sphenophyllum*** cf. ***koboense*** Kobatake, ***Bicoemplectopteris hallei*** Asama, ***Fascipteris hallei*** (Kawasaki) Gu et Zhi, ***Cladophlebis tenuicostata*** (Halle) Archangelsky et Wagner, and ***Pseudomariopteris hallei*** (Stockmans et Mathieu) Wagner, but also Gondwana elements such as ***Glossopteris anatolica*** Archangelsky et Wagner and ***Botrychiopsis*** sp. Palaeogeographical reconstructions show that the Hazro flora was more or less equatorial (Dercourt, 2000). Cathaysia elements have also been recorded from Iraq, Saudi Arabia, and Oman.

A small flora, exclusively consisting of Cathaysia elements, has been described from the Ga'ara region, western Iraq (Čtyroký, 1973). The age of this flora is not very well constrained, but it is definitely Middle to Late Permian. This flora contains the typical Cathaysia taxa ***Lobatannularia heiansenis*** and ***Plagiozamites oblongifolius*** Halle, together with ***Pecopteris*** sp., ***Taeniopteris*** sp. and ***Protoblechnum*** sp. The composition of this flora suggests a warm and humid environment.

Floral assemblages have been described from two members of the Middle Permian to Lower Triassic Khuff Formation in Qasim Province, Saudi Arabia (El-Khayal ***et al***., 1980; Lemoigne, 1981a,b; Hill and El-Khayal, 1983; El-Khayal and Wagner, 1985; Hill ***et al***., 1985; Wagner ***et al***., 1985; Berthelin, 2002). According to Le Nindre ***et al.*** (1990) the Khuff Formation can be subdivided into five members. Plant fossils have been described from the Unayzah and Midnab members, which are both Late Permian in age. The flora from the Unayzah Member is dominated by several pecopterids and ***Lobatannularia lingulata*** (Halle) Kawasaki, the latter being a typical Cathaysia form. Other Cathaysia elements are ***Fascipteris hallei*** (Kawasaki) Gu et Zhi and ***Gigantonoclea*** sp. This flora furthermore encompasses ***Cladophlebis***, sphenopterids and a cordaite. An early marattialean fern was described as ***Quasimia schijfsmae*** (Hill ***et a***l., 1985). Based on the abundance of ferns and sphenophytes, the climate has been interpreted as warm and humid. The somewhat younger flora from the Midnab Member contains ***Pseudovoltzia liebeana*** (Geinitz) Florin, ***Culmitzschia*** sp., ***Wattia texana*** Mamay, ***Discinites orientalis*** Gu et Zhi and pecopterids (Hill and El-Khayal, 1983). Berthelin (2002; Broutin ***et al***., work in progress) also mentions ***Ullmannia bronnii*** Göppert, ***Phyllotheca australis*** Brongniart, ***Lobatannularia heianensis***, ***L. multifolia*** Kon'no et Asama, ***Glossopteris formosa*** Feistmantel, ***G.***

decipiens Feistmantel and *Arberia* sp. The flora from the Midnab Member represents a mixture of European-type conifers (*Pseudovoltzia*, *Ullmannia*, *Culmitzschia*), Cathaysia forms (*Lobatannularia*, *Discinites*) and Gondwana elements (*Glossopteris, Arberia, Phyllotheca*). The conifers were adapted to drier habitats, whereas the sphenopsids indicate humid conditions. It may therefore be concluded that this association constitutes a mixture from different environments.

Another mixed flora has been reported from the Gharif Formation (Wordian) of central Oman, where rich macrofloras with a mixture of Euramerican, Cathaysia and Gondwana taxa has been found (Broutin *et al*., 1995; Berthelin, 2002; Berthelin *et al*., 2003). Typically European forms are *Otovicia hypnoides* (Brongniart) Kerp et al., *Sigillaria brardii* Brongniart and *Calamites gigas* Brongniart and its fructification *Metacalamostachys dumasii* (Zeiller) Barthel. Cathaysia elements include *Gigantopteris* sp., *Gigantonoclea lagrellii* (Halle) Koidzumi, *Catahysiopteris whitei* (Halle) Koidzumi, *Tingia* sp., *Tingiostachya* sp., *Lepidodendron acutangulata* (Halle) Stockmans et Mathieu, and *Sphenophyllum sino-coreanum* Yabe. Gondwana taxa include six species of glossopterids, i.e., *Glossopteris occidentalis* White, *G. damudica* Feistmantel, *G. taeniopteroides* Feistmantel, *G. angustifolia* Brongniart, *G. clamarginata* Anderson et Anderson, and *G. browniana* Brongniart. Several types of glossopterid fructifications have been found. *Sphenophyllum speciosum* (Royle) McClelland is another species that is widely distributed in Gondwana but that has also been reported from China and Korea. *Comia* is another remarkable genus from the Gharif flora. It has originally been described from the Petchora Basin (Angara), but is also known from Cathaysia and the eastern United States (pers. comm. W.A. DiMichele, Washington DC, 2000). Also silicified wood remains and the palynoflora also show a mixture of elements from different floral provinces (Broutin *et al*., 1995; Berthelin *et al*., 2003).

Middle and Late Permian floras from the Arabian Plate thus often show a mixture of elements from several floral provinces. These mixed floras are explained as the result of the expansion and migration of taxa from other flora provinces to the Arabian region. A northward expension of Gondwana elements is easily imaginable, because during the Permian the Arabian Plate was still connected to the African Plate. During the Permian this block moved northwards and a number of typical Gondwana elements apparently adapted to gradually changing climatic conditions. The westward migration of Cathaysia elements is more difficult to explain, because Cathaysia consists of a number of isolated blocks in the eastern part of the Tethys. Several palaeogeographical reconstructions have been proposed for the Middle-Late

Permian (Baud *et al.*, 1993; Scotese and Langford, 1995; Ziegler *et al.*, 1997; Golonka and Ford, 2000; Dercourt, 2000; Stampfli and Borel, 2001; Crasquin-Soleau *et al.*, 2001). One of the main differences between these palaeogeographical reconstructions is the position of Cathaysia. The palaeogeographical map of Fig. 9 is based on the map by Ziegler *et al*. (1997). The Ziegler *et al.* map is one of the few palaeogeograpical reconstructions in which the Dead Sea region is not shown as marine but as a land mass.

It has been suggested that the migration of Cathaysian plants into the Arabian region was primarily determined by the evolution of climatic and palaeogeographic conditions (Fluteau *et al.*, 2001a,b). Cathaysian elements first settled in the Arabian region during the Wordian, when the Arabian plate which moved northward had reached a latitude of 20°S. The Cathaysia plants thrived in the warm and humid flood plains, whereas the seasonally dry, slightly elevated areas were apparently inhabited by European type conifers. However, not only Cathaysia elements reached the limits of their geographical distribution in the Arabian plate, but also Gondwana taxa such as the glossopterids. The typical Gondwana Late Permian glossopterid-dominated floras are considered to have been adapted to cool to cold temperate, moist environments (McLoughlin *et al.*, 1997). The glossopterids from the Arabian plate (Broutin *et al.*, 1995), Turkey (Archangelsky and Wagner, 1983) and Morocco (Broutin *et al.*, 1998) were apparently adapted to warmer conditions than the typical Gondwana forms. Thus, the Cathaysia and the Gondwana elements in the floras from the Arabian Plate were immigrants.

Some typical Gondwana taxa migrated northward during the Permian, and *Dicroidium,* which seems to have originated in the palaeotropics, later migrated southward. The palaeogeographic position of the Dead Sea locality with *Dicroidium*, indicates a warm and humid climate. The sedimentological setting (i.e. a flood plain environment) and epidermal features of the two *Dicroidium* species provide additional evidence for humid conditions.

3.j. The Permian-Triassic transition and the subsequent southward migration of *Dicroidium*

The Permian-Triassic biotic crisis, probably the largest mass extinction in Earth history, led to a large-scale extinction of both marine and terrestrial organisms. Among the plant groups that became extinct were some of the typical Cathaysia taxa, such as the gigantopterids, *Tingia* and *Lobatannularia*. Other groups strongly diminished and eventually also perished, e.g., the glossopterids in Gondwana. Only a few Triassic floras with *Dicroidium* and glossopterids have been described (Thomas, 1952, 1958; Anderson and Anderson, 1983, 1985; Bose *et al.*, 1990; Holmes, 1992). The conifers are well represented in the Late Permian and Triassic, but the mega- and the microfossil record suggest that hardly any of the genera known from the Permian persisted into the Triassic (Eshet, 1983; Gall *et al.*, 1998; Looy *et al.*, 1999, 2001). Four discrete successive recovery stages have been recognized after the Permian-Triassic extinction, comprising most of the Early Triassic (Eshet *et al.*, 1995).

The Permian-Triassic transition is characterized by a shift from cold temperate to cool temperate conditions (Retallack and Krull, 1999). In Gondwana, the earliest Triassic is considered to have been significantly warmer and more seasonally dry than the latest Permian based on sedimentological, palaeopedological, and palaeobotanical evidence (McLoughlin *et al.*, 1997; Retallack and Krull, 1999; Ward *et al.*, 2000 Michaelsen, 2002). The Early Triassic vegetation of Gondwana was not diverse and dominated by lycophytes and voltzialean conifers; highly diverse, *Dicroidium*-dominated floras did not appear prior to the Middle Triassic (Retallack, 1995). In the northern hemisphere, Early Triassic floras were dominated by lycophytes; conifers did not appear before the transition form the Early to the Middle Triassic (Gall *et al.*, 1998; Looy *et al.*, 1999). The Early Triassic floras from Cathaysia are characterized by a dominance of lycophytes (e.g., Wang, 1996).

It appears that some pteridosperm groups were not affected by the biotic crisis at the Permian-Triassic transition. Also the peltasperms, a group of rather small, probably shrubby, mesic to xeric plants, which originated during the latest Carboniferous (Kerp, 1988) survived the Permian-Triassic biotic crisis. This small group was widespread during the Permian and apparently not adversely affected by the outspoken provincialization since peltasperms have been reported from various floral provinces, except for Gondwana. *Dicroidium* is one of the very few genera that survived the biotic crisis at the Permian-Triassic transition, although it should be noted that there are no unequivocal records of this genus from the lowermost Triassic. This, however, might be due to the fact that in general only very few floras from the lowermost Triassic are known. During the Early Triassic, as the climate became increasingly favourable, *Dicroidium* apparently migrated southward, whereas the Arabian plate moved further northward. The corystosperms finally fully expanded during the Middle Triassic where they reached their maximum diversity and inhabited large parts of Gondwana. Not only *Dicroidium* migrated southward but also the peltasperms (Retallack, 2002). Suggested migrated pathways for Euramerican, Cathaysian and Gondwana elements during the Middle Permian to Triassic are shown on Fig. 9.

The corystosperms are often considered to be closely related to the peltasperms (e.g., Crane, 1985; Meyen, 1988; Doyle, 1996). *Dicroidium* has often been compared with *Supaia* from the Middle Permian, which has fronds showing a similar bifurcate architecture (e.g., Schopf, 1973). *Supaia*, was originally described from the Hermit Shale of Arizona and was long considered to be endemic to the American Southwest. However, the genus has also been recorded from southern France (Doubinger and Kruseman, 1975) and northern Spain (Gand *et al*., 1998). *Supaia* has recently been interpreted as a peltasperm (Wang, 1997).

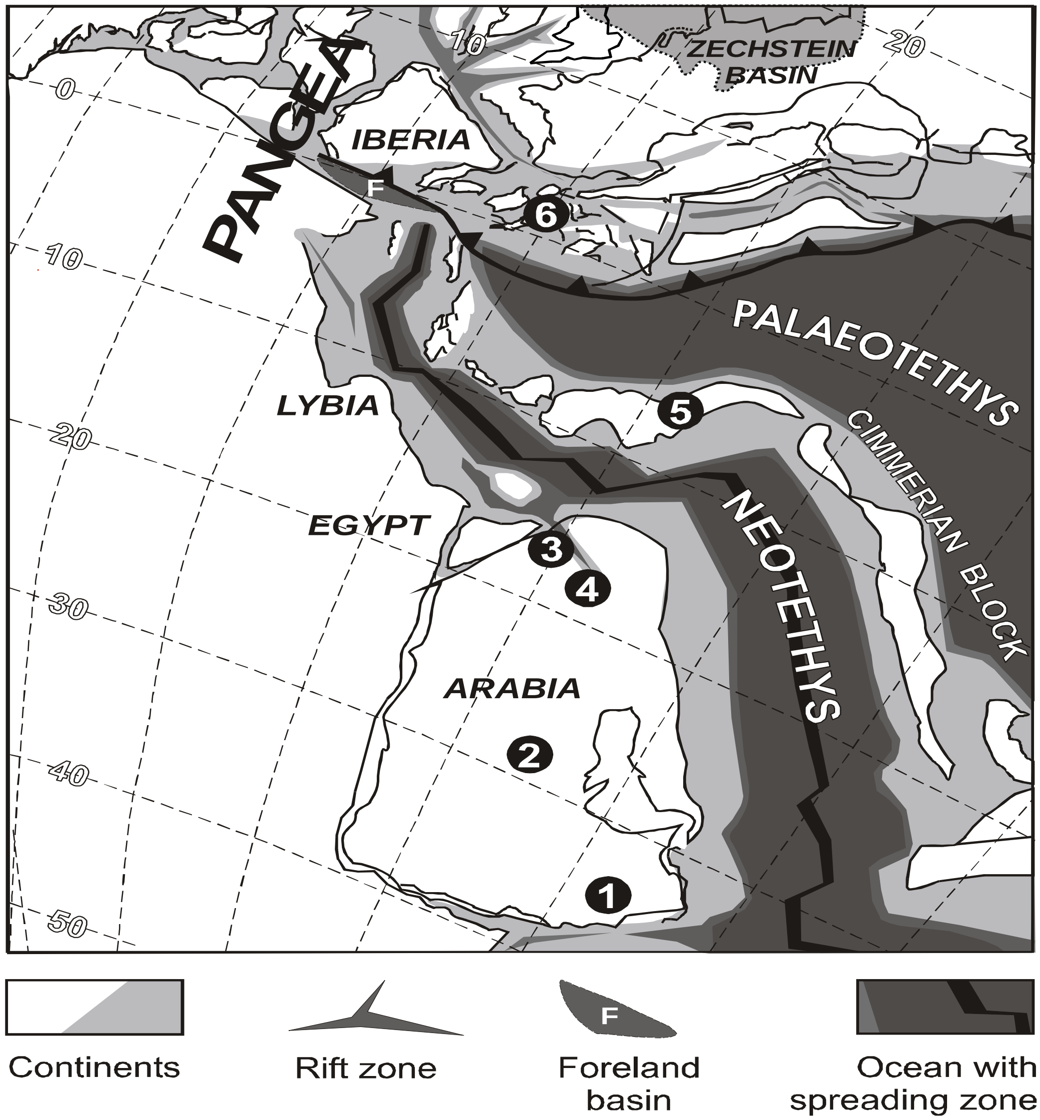

Fig.(8): Localities of Middle and Late Permian in the Tethyan Region.

(1) Oman: Euramerian, Cathaysian and Gondwanan elements (Middle Permian).

(2) Saudi Arabia: Euramerian, Cathaysian and Gondwanan elements (Late Permian).

(3) Um Irna Formation, Jordan: Cathaysian and Gondwanan elements (Late Permian).

(4) Western Iraq: Cathaysian elements (Late Permian).

(5) Eastern Anatolia: Euramerian, Cathaysian and Gondwanan elements (Lte Permian).

(6) Southern Alps: Euremerian (and Gondwanan ?) elements.

Map modified after Stampfli and Borel (2001).

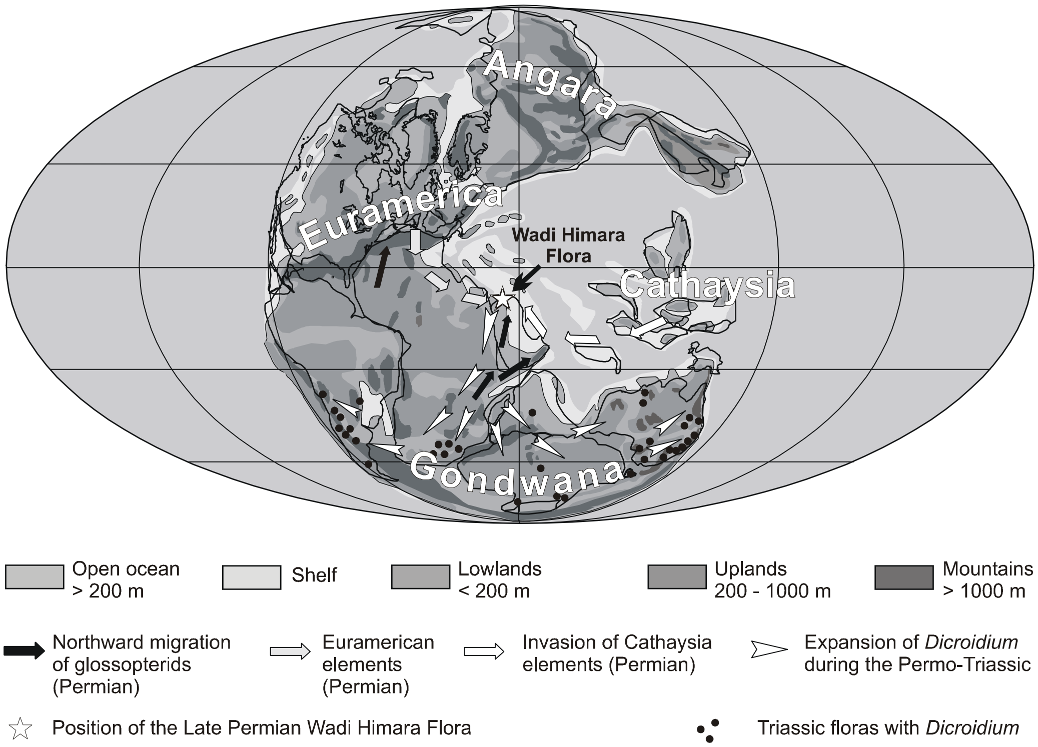

Fig.(9): Suggested migration pathways of Euramerian, Cathaysian and Gondwanan elements during the Middle and Late Permian.
Map modified after Ziegler *et al.* (1997).

CHAPTER FOUR: CHARCOALIFIED WOOD LITHOSTRATIGRAPHY

4.a. Introduction

Plant bearing localities from the Late Permian of Euramerica and adjacent Northern Gondwana are very rare and our knowledge about plants from this period is rather incomplete. However, knowledge about these plants and their ecology is crucial to understand the development of terrestrial ecosystems in this areas prior to the greatest mass-extinction of the past 600 million years, which occurred at the Permian-Triassic boundary (Erwin 1990, Benton and Twitchett 2003).

So far only a few major Middle to Late Permian palaeofloras have been described from Arabia, which represents the easternmost part of Northern Gondwana: i.e. the Late Wordian Unayazah flora (El-Khayal *et al.* 1980, Lemoigne 1981, El-Khayal and Wagner 1985) and the Early Changhsingian Jal Khartam flora (Hill and El-Khayal 1983, Hill *et al.* 1985) from the Saudi Arabian Khuff-Formation, as well as the Early Wordian Gharif flora from Oman (Broutin *et al.* (1995, Berthelin *et al.* 2003). In recent years several new discoveries from the Um Irna Formation of Jordan added additional information about the Late Permian vegetation of this region. A hydrophilic flora, consisiting of *Doratophyllum jordanicus* Mustafa, *Gigantonoclea* sp., *Lobatannularia heianensis* (Kodaira) Kawasaki, and *Pecopteris* sp. has been described by Mustafa (2003). In this study two new species of the Corystosperm *Dicroidium* are described (see chapter 3). Here charcoalified woods from the Late Permian Um Irna Formation of Jordan will describe to provide the first evidence of palaeo-wildfire during this period in Northern Gondwana.

4.b. Material and methods

Locality, source strata and fossil content:

The charcoal remains were collected from a natural exposure in the lower part of the Um Irna Formation at the northeastern rim of the Dead Sea, Jordan. The locality is situated about two km from the main road that runs along the eastern shore of the Dead Sea, in the incised valley with a creek running all year named Wadi Himara. The outcrops of the Um Irna Formation are located ca. 400 m upwards along the southern branch after the main bifurcation of Wadi Himara (Fig. 10).

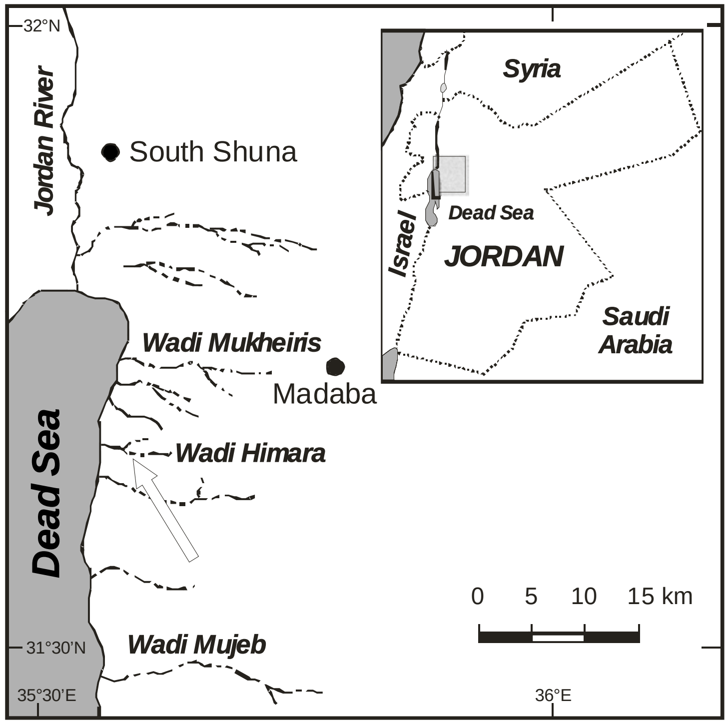

Fig.(10): Map showing the position of the sampling locality at the northeastern rim of the Dead Sea (arrow).

The Um Irna Formation was defined by Bandel and Khoury (1981). The formation locally has a thickness of 67 m and unconformably overlies the Cambrian Um Ishrin Sandstone Formation. The Um Irna Formation is unconformably overlain by the Ma’in Formation. Preliminary palynological investigations assigned a Late Permian age for the lower (W.A. Brugman, in Bandel and Khoury 1981), as well as the upper part (H.A. Armstrong, in Makhlouf 1987) of the Um Irna Formation. Also lithological correlations with drillcore sections further towards the west suggested a Late Permian age (Eshet and Cousminer 1986, Eshet 1990). The plant-bearing layers have yielded rich and well-preserved microfloras clearly indicating a Late Permian age based on the presence of *Lueckisporites virkkiae* Potonié et Klaus, *Klausipollenites schaubergeri* Potonié et Klaus and *Protohaploxypinus limpidus* (Balme et Hennelly) Hart. The palynological assemblages are dominated by bisaccate pollen grains, mainly various species of *Falcisporites* Leschik, including *F. zapfei* (Potonié et Klaus) Leschik and *F. stabilis* (de Jersey) Balme, which together may constitute over 55% of the associations. (see chapter 5)
Indirect stratigraphic control is also provided by the age of the unconformably overlying Ma'in Formation (Himara Member). The basal part of this formation has been dated as (?early) Scythian on the basis of poor palynological assemblages recorded from subsurface samples in North Jordan (cf. Shawabekeh 1998), whereas

the second member of the Ma'in Formation has been dated as middle to late Scythian on the basis of bivalves (Cox 1932) and conodonts (Huckriede and Stoppel in Bender 1975). In this study the palynological analysis indicates Lower Triassic (Smithian) age for the Ma'in Formation. This age was assigned based on index palynomorphs yielded from the above formation, i. e. *Endosporites papillatus, Densoisporites nejburgii, D. playfordii, Kraeuselisporites apiculatus, K. varius, Lundbladispora obsolete* and *Lapposisporites echinatus.*

The lower part of the Um Irna Formation has been interpreted as a distal braided fluvial deposit (Bandel and Khoury 1981, Makhlouf *et al.* 1991). Plant remains occur in organic-rich, grey to brownish silt and clay layers and lenses between 5·5 and 18m above the base of the formation at Wadi Himara. Most of these beds yield numerous small cuticle fragments. In one bed plants remains are very abundant, and also larger, up to 0·3 m long frond segments of the Corystosperm *Dicroidium* have been found. This layer has a thickness of up to 1·2 m, and is ca. 17m above the base of the formation. Apart from cuticles this layer has also yielded the charcoalified wood remains. The plant-bearing clay-and siltstones are here interpreted as abandoned channels. The outcrop section with the position of the plant-bearing beds is presented in Fig. (11).

Although plant megafossils are abundant in the silty and clayey layers in the lower part of the Um Irna Formation at Wadi Himara, species diversity is low. The assemblage comprises several species of *Dicroidium* that are preserved as compressions with fine cuticular detail and a few poorly preserved, unidentifiable fern remains. Those fossils assigned to *Dicroidium* have a frond morphology (presence of characteristic bifurcation in the lower part of the frond) and epidermal anatomy characteristic of the genus. Apart from this interval, the rest of Um Irna Formation at Wadi Himara has not yielded any fossils, neither megafossils nor microfossils. However, from another section of the Um Irna Formation, about 9·5 km north of Wadi Mujeb, a small macroflora has been described by Mustafa (2003).

Methods:

Charcoal fragments were extracted mechanically from the sediment with the aid of preparation needles, lancets and tweezers under a binocular microscope. Due to their very fragile nature they could no be cleaned with water or any acids to remove adhering mineral remains. The fragments were mounted on standard stubs with Leit C (Plano), and subsequently examined with the aid of a LEO 1450 VP GEMINI Scanning Electron Microscope (SEM) at the University of Tübingen.

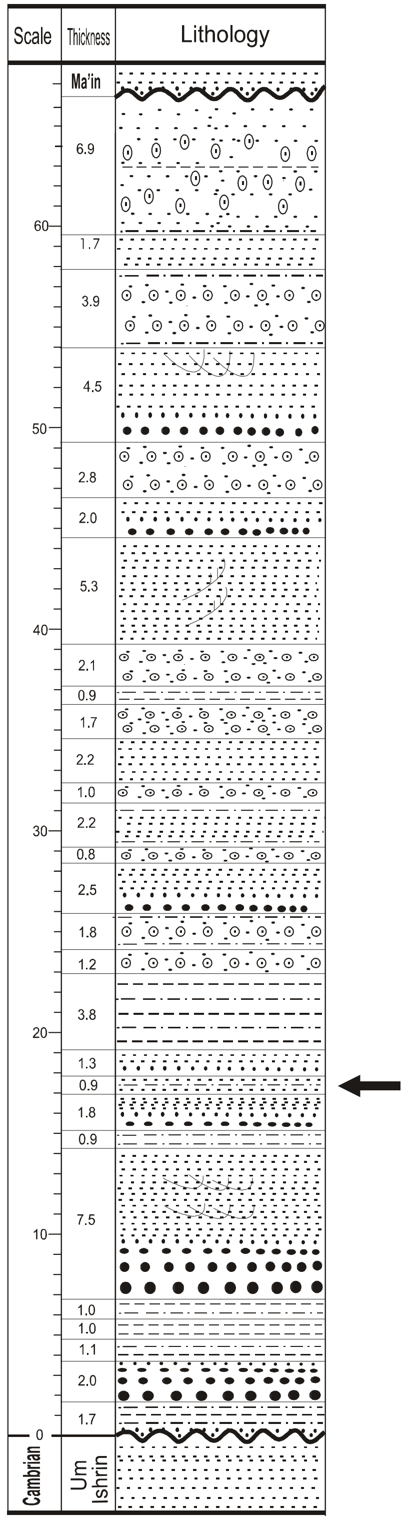

Fig.(11): Lithological profile of the Um Irna Formation at Wadi Himara. The position of the plant bearing layer (compressions and charcoal) is indicated by the arrow.

4.c. Results and discussion

Preservation:

The charcoal remains from Wadi Himara have diameters up to 50 mm and show only slight abrassions at the edges. This indicates that the remains probably have not been transported over a wide distance. Such an interpretation is in agreement with the sedimentological interpretation of the plant-bearing horizon as abandoned channels of a braided fluvial system. However, experimental data and field observations suggest that charcoal may be transported in suspended load over rather long distances (up to hundreds of kilometers) without abrasion (e.g. Blong and Gillespie 1978, Vaughn and Nichols 1995, Nichols *et al.* 2000). The remains have a black color and streak, as well as silky lustre, typical for charcoal (e.g. Scott 1989, 2000). SEM-studies reveal further features, like the typical 'bogen-structures' (Pl. 18, 1), homogenized cell walls (Pl. 17, 2-6), and excellently preserved anatomical details, which are considered as diagnostic for charcoal (e.g. Scott 2000). In some of the charcoal fragments remains of charred fungal hyphae of unknown taxonomic affinity are frequent (Pl. 17, 1–2).

'Bogen-structures' occur in small areas in almost all of the charcoal fragments investigated (Pl. 18, 1). Though charcoal is chemically almost inert, it is highly susceptible to mechanical stresses and cell walls may fracture easily during compaction of the embedding sediment forming these typical structures (e.g. Scott 1989). Areas with 'bogen-structures' usually form weak spots, which may cause the already fragmentary charcoal remains to fragment further, as soon as the stabilizing sediment is chemically or mechanically disintegrated (e.g. during bulk maceration). In the case of the Jordanian charcoal this fact prevented not only the extraction of larger intact specimens from the rock matrix, but also the cleansing of the mechanically isolated small fragments with water and or acids (e.g. HCl or HF) prior to SEM studies.

In the charcoal from the Um Irna Formation of Jordan anatomical details are excellently preserved. Not only the cell walls of the woody tracheids, but also the much more delicate cell walls of the parenchymatous ray cells have been preserved in several specimens (e.g. Pl. 18, 3). Also in some cases the tori within the bordered pits are still present and in place (Pl. 17, 5–6). Another noteworthy detail are the cross-field pits, which can be seen in some specimens not only from the ray side (Pl. 18, 5), but also from the tracheid side (Pl. 17, 3–4). Occasionally it can be observed that the bordered pits break away from the tracheidal walls in areas adjacent to 'bogen-structures' (Pl. 17, 7). Probably this can be related to mechanical stress.

Taxonomic affinities:

As demonstrated above, the charcoal remains investigated here show excellently preserved anatomical details, even compared to many permineralized specimens from this time period. However, in many cases the taxonomic determination of woods does not solely rely on such small scale anatomical characters, but also on the organization of the wood and in many cases on the ontogentic development of the wood (e.g. Jane 1962). Due to the fragmentary nature of the charcoal remains investigated here, nothing can be said about these important taxonomic and systematic characters. Without these characters, however, most of the charcoal remains can only be determined as being of the *Dadoxylon*-type of gymnospermous wood.

However, one specimen from the Um Irna Formation of Jordan exhibits some anatomical details, which may allow a more specific taxonomic delimitation (Pl. 18, 1–8). The anatomy of this particular specimen is therefore decribed in detail:

In transverse view tracheids polygonal to square, 20–40 µm wide (Pl. 18, 1), with uniseriate and biseriate (rarely multiserriate) bordered pitting on radial walls (Pl.18, 4–6). Pits contiguous, with circular or elliptical apertures (3–7 µm in diameter) (Pl. 18, 4–6). Where pits are bi- or multiseriate they are alternately arranged (Pl. 18, 4–6). Rays abundant, uniseriate, 1–9 cells high (Pl. 18, 2–3), composed of parenchymatous cells, 110–150 µm long and 30–50 µm high (Pl. 18, 2–3). No ray tracheids could be observed. Cross-field pitting consists of 6–9, alternately arranged circular to elliptical pits (5–12 µm in diameter) per field (Pl. 18, 5). No growth rings visible. Leaf vascular system organized in (two?) pairs of traces, each strand 270–280 µm in diameter (Pl.18, 7–8).

	Characters typical for the wood of the Corystospermales (sensu Meyer-Berthaud *et al.* 1993)	Wood described here
wood pycnocylic	+	+
rays uniseriate	+	+
Tracheids in secondary wood with araucariod pitting	+	+
cross-field pits simple, tend to be few and wide	+	+
pith with scleroctic nests and lacunae or secretory structures	+	?
leaf vascular sytem complex, originating from several axial bundles	+	+ (?)

Table (5): Comparison of wood anatomical characters typical for the Corystospermales (sensu Meyer-Berthaud *et al.* 1993) and the here described wood from the Late Permian Um Irna Formation of Jordan.

Remarks. Like all other charcoalified specimens from Wadi Himara this specimen can not be determined to a generic or even specific level, except as being of the *Dadoxylon*-type of gymnospermous wood. However, by a closer look on the paired leaf trace (Pl. 18, 7), a gap in the tracheids directly adjacent to this pair is clear. The course of the tracheids at the margins of this gap is not linear, as in normal areas of the wood, but curved. This observation leeds to the impression that a second pair of leaf traces may be missing at the position of the gap. A comparable configuration with a complex leaf vascular system has been considered by Meyer-Berthaud *et al*. (1993) as typical for the Mesozoic seed fern order Corystospermales. Additionally to the configuration of the leaf traces Meyer-Berthaud *et al*. (1993) defined other characteristics for the wood of this order. Comparing these proposed corystospermalean characteristics with the anatomy of the here described specimen (Table 5), show that most characters are in agreement with each other. However, some of the details proposed to be characteristic for the Corystosperms can not be observed in this specimen. Though it can not be proved on the base of anatomical data the possibility remains that the here described specimen may belong to the Corystospermales. Especially when seen in the light of the fact that fronds of the Corystosperm *Dicroidium* are the major component of the compression/impression taphoflora at Wadi Himara.

Palaeoenvironmental significance:

From the occurrence of charcoal in the Late Permian sediments at Wadi Himara, it can be stated that the source-vegetation must have experienced fires, though at the moment very little can be said about the frequency or intensity of these wildfire activity. Today wildfires occur frequently in vegetation types which are characterized by a well marked dry season and many ecosystems show a tendency towards higher fire frequencies with increasing aridity of the environment (e.g. Martin 1996, Brown 2000, Paysen *et al.* 2000). One of the reasons for higher fire frequencies in such environments, apart from the general dry conditions, is the slow decomposition of leaf litter and wood, leading to an increased accumulation of potential fuels (e.g. Harrington and Sackett 1992). Even in tropical rain forests occasional droughts can promote the spread of wildfires, leading to catastrophic burns over large areas (e.g. Johnson 1984). From this, it could be assume, that the Late Permian palaeoflora growing during the deposition of the Um Irna Formation may have experienced more or less dry conditions at least during some time of the year. However, up to now there is no direct palaeobotanical evidence, like growth rings, for such a seasonallity (see below). On the other hand such an interpretation is in full agreement with sedimentological data for the Um Irna Formation, which indicate a low latitude tropical savannah climate, with alternating wet and dry seasons (Bandel and Khoury 1981, Makhlouf *et al.* 1991). These interpretations are corroborated by the results of climate modelling, which predicted a monsoonal climate in Arabia during the Late Permian, with summer precipitation. Such a climate would favour the establishment of a warm and seasonally humid savannah climate with a more or less marked dry-season (Fluteau *et al.* 2001).

The excellent preservation of anatomical features relatively susceptible to decay, like the parenchymatous cell walls of the ray cells, may indicate that the plants were burnt while they were still alive or shortly after their death. Also no evidence of 'checking' of cell walls could be observed so far, which would indicate desiccation of dead wood prior to charring (Jones 1993). It is not clear whether the observed charred fungal hyphae were growing before the wood died or not. However, the occurrence of fungal hyphae in (decaying?) wood is not very surprising and has also been reported from other occurrences of fossil charcoals (e.g. Scott 2000).

The charcoal fragments investigated so far show no signs of true or even false growth rings (e.g. Pl. 17, 8), which would indicate seasonally changing environmental conditions, for example changing water availability, light regime (day light) or temperature. Such non-seasonal environments are common in the tropics, in areas where there is little change in climatic and environmental conditions during the year, except some minor variation in rainfall. Under such conditions growth is more or less uniform and growth rings are weekly developed or totally absent; (Creber 1977). However, the lack of growth rings in the specimens investigated from Wadi Himara, does not indicate that there were no such seasonal changes. It is known from other Late Palaeozoic wood remains that even under seasonally changing climatic and/or environmental conditions not all taxa did produce growth rings (e.g. conifers from the Upper Permian Zechstein deposits of Central Europe; Schweitzer 1962, 1986). Nevertheless, the lack of growth rings in all specimens investigated, may point to the fact that the source plants grew under favourable conditions, well within the limits of their climatic and environmental tolerance. This may reflect very local conditions with enough moisture near the abandoned channels during all the year, in contrast to the regional climate which has been reconstructed as a low latitude tropical savannah climate, with alternating wet and dry seasons (Bandel and Khoury 1981, Makhlouf *et al.* 1991, Fluteau *et al.* 2001).

Fossil charcoal, as direct evidence of palaeo-wildfires, has so far been reported from the Late Permian of Cathaysia (e.g. Wang and Chen 2001), Central Europe (Uhl and Kerp 2002; 2003) and the high latitudes of Southern Gondwana (e.g. Glasspool 2000). The here described charcoalified wood from the Late Permian of Jordan testifies for the first time to the occurrence of palaeo-wildfires in the low latitudes of Northern Gondwana during this period. The evidence of wildfires represents an important addition to our knowledge of terrestrial ecosystems in this region at the eve of the end-Permian crisis.

CHAPTER FIVE: PALYNOLOGY

5.a. Introduction

Biostratigraphical studies have been carried out on the outcrops of the Permian-Triassic in the Dead Sea region, but no systematic palynological investigations have been yet been performed. The only palynological information available is from the subsurface and has been acquired by petroleum palynologists, (e.g. Fina Exploration Jordan B.V. (FEJ) 1988-1990, Ahmad 1989, Stratigraphic Services International (SSI) 1989). However, all these studies are published as confidential bulletins and technical reports for the N.R.A. (Amman).

In this study, the present author provides new information on the biostratigraphy of the Permian-Triassic of Jordan, in addition to the previous work (e.g. Bandel and Waksmundiski 1985, Abu Hamad 1994, Sadeddin (1998). This is the first systematic palynological study of the Permian-Triassic of Jordan. The Jordanian Permotriassic is compared and correlated with important time-equivalent sequences from other regions. Most attention is given to the Um Irna Formation, the age of which has been the subject of a long debate. The current age assessment is based on both palynological data and plant macrofossil record.

5.b. Material and Methods

Sampling:
During the intensive fieldwork, columnar sections were described from the basis of the Um Irna Formation up to the Abu Ruweis Formation. The stratigraphy is based on Bandel nad Khoury (1981). A total of approximately 600 m of exposed Permian-Triassic sections is described. Samples were taken from fresh surfaces, or from 20-30 cm deep, freshly cut trenches. Each sample consists of c. 500 g; samples were immediately stored in new and clean plastic bags which were marked with field numbers. The numbers assigned generally start with a serial number, starting with 1 followed by the first letters from the formation name, e.g., 10 UIR. The sample locations are plotted in the columnar sections figures (12-15, 17).

Samples were generally taken from black, grey or brown clay, siltstone and shale. Sandstones, dolomites, limestones were mostly ignored because these sediments are usually completely barren; the few samples that have been processed all appeared to be unproductive. The same is true for reddish, violet and greenish sediments and for gypsum.

Chemical processing of the samples:

Palynological processing methods depend on the aim of the study, on the type of sediment and the maturation of the organic matter. Therefore, Wood *et al.*(1996) stated, "good palynological processing is individualistic art requiring astute skill, knowledge and hands-on involvement". Several publications outline different techniques for palynological processing (e.g., Doher 1980, Traverse 1988, Wood *et al.* 1996, Batten 1999). They differ in some steps by the different aims, equipment used, and specific needs of the study. The most useful and most detailed outline have been published by Wood *et al.* (1996), which has been basically followed in this study.

All samples used in this study are of clastic sediments- for the recovery of spores and pollen from the Permian-Triassic of Jordan the following steps were applied:

- Breaking down the samples to fragments less than 2 mm across in porcelain mortar.
- Wash and dry mortar before using a second time to prevent contamination.
- 20–30 gr.-crushed sample is transferred into a poly-ethylene acid resistant plastic container.
- The samples were tested with 10 % hydrochloric acid in order to check whether it contains carbonate.
- The samples are placed in a special HF fume hood and 40% hydrofluoric acid was carefully added. Working with hydrofluoric acid of course requires special safety procedures.
- After 2-4 days the sediment is dissolved and/or disintegrated. Then the acid is diluted with water and decanted after all particles have settled.
- The sample is then repeatedly washed with water in order to neutralize the remaining acid.
- When the sample is neutral the organic matter is separated from the remaining sediment particles (mostly clay minerals) by heavy liquid separation. Two types of heavy liquid separation were applied, both liquids having a density 2.0. g/cm^3. The first sample sets were treated in a solution of zinc chloride in 10% hydrochloric acid. Because this heavy liquid can be used only once, sodium polywolframate for the later samples. Although this sodium polywolframate is much more expensive than zinc chloride, this method is much better because the sodium polywolframate can be regenerated and is less harmful for the environment than zinc chloride.

The heavy liquid was added to the residue in a small polyethylene tube and thoroughly mixed with the sediment. The tubes were centrifuged for 20-40 minutes at 600-1000 rpm.

- After centrifuging the organic matter floats on the heavy liquid, whereas the sediment has settle at the bottom of the tube. When zinc chloride separation is used a few drops of distilled water are added and then the concentrated organic matter can be sucked up with a plastic pipette and transferred to a small porcelain beaker. In case sodium polytungstate separation is used the upper part of the liquid containing the organic particles is carefully decanted-
- The residue can then be sieved over a 10 or 15 µm mesh sieve in order to get rid of all the very fine particles. Of samples treated with sodium polytungstate, the heavy liquid used is filtered and regenerated. Samples are sieved with hand-warm water; in order to speed up the process of very rich samples a few drops of soap may be added to reduce the surface tension. Sieving may sometimes take over an hour, depending on the nature of the material; the residues should be regularly checked under the microscope in order to see whether they are good or not.

  Sieving is done in simple self-constructed Perspex beakers with a 10-15-µm mesh mounted in the bottom. The use of vacuum sieve equipment as is advocated by some palynologists is not recommended because (1) material may be too easily lost and/or damaged, and (2) in very rich samples the sieve mesh is easily torn apart because the vacuum is too strong.
- If palynomorphs are still too dark they can be bleached in sodium hypochlorite or Schulze's reagent (40-65% nitric acid with potassium chlorate) and a 10% potassium hydroxide solution.
- After sieving the organic matter is concentrated by centrifuging it in a small glass tube and finally in a small well sealable plastic container (Eppendorf tube). Finally a few drops of pure glycerine are added to avoid that the sample dries out. In order to avoid contamination with recent fungi the glycerine contains a few drops of thymol per litter.

Slide Preparation:

- Palynological residues are mounted on clean 76x26 mm glass slides using 22x22 mm cover slips.
- Glycerine jelly used as embedding medium. A small drop of glycerine jelly is put on the slide and carefully mixed with a small drop of the organic residue. Glycerine jelly becomes fluid at ca. 70°C. Therefore a precision heating plate is used to make the slides. Air bubbles can be removed with a needle. The

cover slip is mounted, carefully avoiding air bubbles. Excessive amounts of glycerine jelly around the margins of the cover slip can then be removed with a razor blade after a few days. The slides should lie flat during the first weeks, because the glycerine jelly is still not completely solid and palynomorphs might still "wander" within the slide. When the glycerine jelly is completely solid, the slide is cleaned with alcohol and the cover slip is carefully sealed with colourless nail polish in order to avoid the formation of air bubbles and desiccation.

- Sample and slide numbers are marked on the slide with a permanent maker. Six slides were prepared for each positive sample. Slides are stored in boxes in a dark cabinet at room temperature. All slides, residues and unprocessed samples are permanently stored in the Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

Relocation of specimens:
In order to be able to find the same spores and pollen grains under different microscopes with different stages and coordinate systems, the positions of all illustrated specimens are indicated by England Finder™ coordinates.

Microscopy and Photography:
The micrographs were taken with a Leitz Diaplan microscope using Nomarski interference contrast, if necessary in combination with a green filter, using 40x and 100x oil immersion lenses. Photographs were made on low-speed, high resolution Agfapan 25 and Agfaortho 25 film. After Agfa stopped the production of these two film types, Macophot 25 film was used. Negatives and documentation are stored in the Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

5.c. Palynostratigraphy

The Permian-Triassic succession is not continuously exposed in Jordan as is discussed in the chapter of the fieldwork. Therefore, the results of the palynological analysis will be compared with other Permian-Triassic zonations elsewhere.

Palynological Zonation of the Permo-Triassic of Jordan:
Based on the analysis of 98 palynological samples, five assemblage zones were recognized.
These zones are in ascending stratigraphic order:

- *Lueckisporites virkkiae* Zone (Late Permian)
  (Plate **19 - 26**), (Appendix **12**).
- *Endosporites papillatus-Veryhachium* spp. Zone (Smithian/early Olenekian; Scythian).
  (Plate **27 - 31**), (Appendix 13-14).
- *Aratrisporites saturnii* Zone (late Pelsonian-Illyrian ; late Anisian).
  (Plate **32 - 49**, **50**,1-7), (Appendix 15-16A and 16B).
- *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone (Langobardian; late Ladinian).
  (Plate **50**, 8 **- 58**,11), (Appendix 17 and 17B).
- *Patinasporites densus* Zone (late Cordevolian-Julian; late early Carnian-middle Carnian).
  (Plate **58**,12 **- 66**), (Appendix 18-19).

These zones will be introduced and discussed in this chapter with brief reference to the lithostratigraphy. All taxa idetified in this study are listed in alphabatic list (appendix 1).The index taxa are listed with some comments on the composition of assemblages. It should be noted that many taxa have long ranges, and may occur in more than one zone. Therefore, the zones defined in this study are characterized by a combination of index taxa, rather than by a single taxon. Age assessments are given and comparisons with other parts of the Middle East and other relevant regions where good zonations have been established are made
For the Anisian, Ladinian and particularly for the Carnian good zonations are available and the microfloras from Jordan are well comparable to those from the Alpine / Tethyan region. For the Permian and Early Triassic comparsions are more difficult, due to the lack of a uniform standard zonation. Moreover, the record is more scanty, especially in the Lower Triassic, and continuous sequences hardly

exist. Furthermore, the composition of the microfloras differs in the sense that the assemblages from Jordan consist of a mixture of elements from different floral provinces. Therefore comparisons with Late Permian and Early Triassic microfloras from other regions are more extensive than for the Middle and Upper Triassic.

5.d. The Upper Permian

The Lueckisporites virkkiae Zone

This zone is restricted to the Um Irna Formation, which in its type locality Wadi Himara consists of a 67 m thick sequence, uncomfortably overlying the Cambrian Um Ishrin Formation and unconformably overlain by the Lower Triassic Ma'in Formation.

Samples: Twelve samples of Um Irna Formation were processed, but only three appeared to be productive while the others were barren. Fig. 12 shows a stratigraphical log of the Um Irna Formation in its type locality with the position of the samples.

Index taxa: *Lueckisporites virkkiae*, *Klausipollenites schaubergeri*, *Falcisporites zapfei*, *Protohaploxypinus microcorpus*, *P. varius*, *Striatopodocarpites fusus*, *Hamiapollenites insolitus*, *Nuskoisporites klausii*, and *Potonieisporites novicus*.

Composition: Pollens grains constitute c. 80% of the assemblages from this zone. Striate bisaccate taxa are abundant, including *Protohaploxypinus microcorpus*, *P. varius*, *Lunatisporites pellucidus*, *L. fuscus*, *Hamiapollenites insolitus*, *Striatopodocarpites fusus, S.* sp. and *Guttulapollenites hannonicus*. Bisaccate non-taeniates are also abundant, i.e., *Lueckisporites virkkiae*, *Klausipollenites schaubergeri*, *Pinuspollenites thoraceus*, *Falcisporites nuthiales, F. stabilis, F. zapfii*, *Platysaccus fimbriatus* and *Cedripites* sp. as well as bisaccate trilete spores, i.e. *Illenites parvus, I, tectus, I. spectabilis* and *Jugasporites delasaucei*, the bisaccate monolete *Gardenasporites moroderi*, the polyplicate grain *Vittatina* sp. the monocolpate *Cycadopites* sp. and the monosaccate prepollen *Nuskoisporites klausii*, *Plicatipollenites indicus*, *Potoniei-sporites novicus, P.* sp. and *Cordaitina* sp. Bisaccate palynomorphs are dominant in this zone and comprise c. 55% of the total assemblages.

In addition to the pollen mentioned above, this zone is characterized by a diverse assemblage of azonotrilete spores, e.g., *Leiotriletes* sp. *Camptotriletes warchianus*, *Acanthotriletes tereteangulatus*, *Verrucosisporites* sp., *Punctatisporites minutus, Calamospora* sp., and *Triquitrites proratus*, by azono-monolete spores, e.g. *Polypodiites* sp. and *Laevigatosporites vulgaris,* and by perinotrilete spores e.g. *Kraeuselisporites echinatus, K.* sp. and *Guthoerlisporites cancellosus*. All these latter taxa are rare.

The presumed fungal remain *Tympanicysta stoschiana* can also be common.

Age: A Late Permian Age has been inferred on the basis of comparisons with other microfloras. *Gardenasporites moroderi, Hamiapollenites insolitus, Jugasporites dela-saucei, Klausipollenites schaubergeri, Kraeuselisporites rallus, Lueckisporites virk-kiae, Nuskoisporites klausii, Protohaploxypinus amplus, P. limpidus, P. varius and Vittatina* sp. are generally considered to indicate a Late Permian Age. However, it should be noted that in some regions (e.g. China, Pakistan and the Arctic) some of these forms (i.e., *Jugasporites delasaucei, Klausipollenites schaubergeri, Luecki-sporites virkkiae*) have occasionally been reported from the lowermost Triassic, indicating that some taxa did not become completely extinct at the Permian-Triassic Boundary and could locally persist into the earliest Triassic.

Comparisons and correlations

The microfloral assemblages from the *Lueckisporites virkkiae* Zone can be compared with associations from the the Upper Permian of Israel, Saudi Arabia, Iraq, North Africa, the Alpine region and southern Europe, northwest and central Europe, Pakistan, India and Australia. The assemblages from the Um Irna Formation have also been compared with Late Permian microfloras from South America and the Antarctic. However, microfloras from these latter regions will not further be discussed here, because the material is not well preserved and/or no detailed zonations have been established.

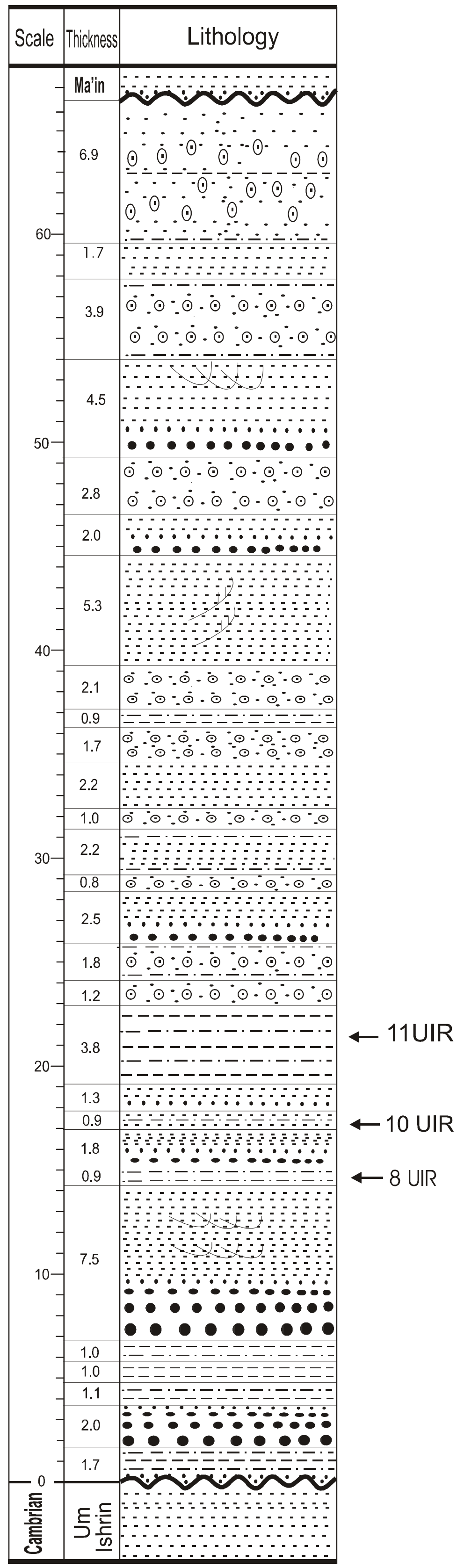

Fig.(12): Sample location of the *Lueckisporites virkkiae* Zone, Um Irna Formation.

Israel

The microflora of the *Lueckisporites virkkiae* Zone is very similar to that described from the Upper Permian of Israel, qualitatively as well as quantitatively. The associations from the Upper Permian of Israel were all recovered from boreholes, e.g., Zohar 8 and Avdat 1 (Horowitz 1974), Maktesh Qatan 2, Negev (Eshet 1983, 1990; Eshet and Cousminer 1986). The most recent account was published by Eshet (1990) who studied eleven boreholes. The *Lueckisporites virkkiae* Zone corresponds to Palynozone II of Eshet (1990), which is dated as Late Permian.

A striking difference between the associations from Israel and Jordan is that the material from Israel is often very poorly preserved; palynomorphs are very dark and partly oxidized, whereas the material from the Um Irna Formation is excellently preserved. Organic geochemical analyses revealed that the material from the Um Irna Formation was not subjected to any thermal alteration (pers. com. Prof. Dr. J.W. De Leeuw, Texel 2004).

The following taxa encountered in the assemblages assigend to the *Lueckisporites virkkiae* Zone have also been recorded from the Upper Permian of Israel: *Falcisporites stabilis*, *F. zapfei*, *F. nuthallensis, Gardenasporites* sp., *Guthoerlisporites cancellosus*, *Klausipollenites schaubergeri*, *Lueckisporites virkkiae, Plicatipollenites indicus, Protohaploxypinus microcorpus, P. limpidus, P. varius, Striatopodocarpites* cf. *rarus, Striatopodocarpites* sp. and *Vittatina* sp.

Saudi Arabia and Oman

In recent years extensive palynological studies have been carried out in Saudi Arabia and Oman (Stephenson and Filatoff 2000, Stephenson *et al.* 2003) on the basis of well data. Stephenson *et al.* (2003) established eight biozones for the uppermost Carboniferous to Permian in Oman and Saudi Arabia on the basis of subsurface samples: OSZP 1-6; OSZP 3 is subdivided into OSZP3a-c. However, it should be noted that the boundaries between the uppermost three zones (OSZP4-6) couldn't be defined very clearly. The basal Khuff Formation, encountered in wells Dilam-1, Haradh-51 and Nuayyim-2 (central Saudi Arabia) has been dated as Late Permian (Tatarian or younger). The associations are very similar to those from the Um Irna Formation, except for the complete absence of *Falcisporites*, which is the most common taxon in the Um Irna Formation. Moreover, *Klausipollenites schaubergeri* and *Lueckisporites virkkiae* are very rare. The assemblages from the basal Khuff Formation are dominated by non-taeniate bisaccate pollen (50-70%); taeniate bisaccate pollen are less abundant are (30-40%). The assemblages from the Khuff Formation were compared to those from the European Zechstein and the Russian Platform and Gondwana. Correlations were also made to the lower part of Chhiddru Formation of Pakistan (Balme 1970) and "Assemblage Zone A" from Iraq (Nader *et al*. 1993).

The following taxa encountered in the samples from the Um Irna Formation have also been reported from OSPZ 6 Saudi Arabia: *Camptotriletes warchianus*, *Cedripites* sp.,
Triplexisporites sp., *Klausipollenites schaubergeri*, *Lueckisporites virkkiae*, *Protohaploxypinus microcorpus* and *Lunatisporites pellucidus*.

Based on the quantitative difference between Late Permian assemblages from Saudi Arabia and (southern) Gondwana - particularly with regard to the abundance of multitaeniate bisaccate pollen, Stephenson and Filatoff (2000) concluded that *Glossopteris* was absent in the Arabian Peninsula. This was attributed to climatic differences. Because of the presence of *Lueckisporites virkkiae*, *Striatopodocarpites richteri* and *Jugasporites leschikii* they correlated these assemblages with the Euramerian flora province and they stated that the Saudi Arabian Late Permian assemblages had no affinities with Gondwana. However, it should be noted that glossopterids have been found in the Gharif Formation (Wordian, Middle Permian) in Oman (Broutin *et al.* 1995, Berthelin *et al*. 2003) and in the uppermost Permian of Hazro, eastern Anatolia (Wagner 1958, Archangelsky and Wagner 1983). The Gharif Flora (Wordian) is a mixed flora with Euramerian, Cathaysian and Gondwana elements. As has already been shown in the chapter on the macroflora, Gondwana and Cathaysia elements occur throughout the Arabian Peninsula. Even within the Um Irna Formation two different megafloras have been found: the *Dicroidium* flora described in this study (Chapter three) and a flora dominated Cathaysia elements (Mustafa 2003).

Iraq

The microflora of the Um Irna Formation is relatively well comparable to the microflora from the Chia Zairi Formation, Atshan Well near Mosul, northern Iraq, which was dated as Late Permian, although spores are much more common in this flora (Singh 1964).

India and Pakistan

The *Lueckisporites virkkiae* Zone can be correlated with Assemblage zones II and III from the Raniganj Coalfield (Bharadwaj and Tiwari, 1977), based on the occurrence of *Klausipollenites schaubergeri*, *Striatopodocarpites rarus* and *Lunatisporites fuscus*. However, some taxa from the Um Irna Formation have not been reported by Bharadwaj and Tiwari: *Lueckisporites virkkiae*, *Falcisporites* and *Protohaploxypinus.*

The *Lueckisporites virkkiae* Zone can also be correlated with Palynozone III from Iria Nala, Tatapani-Ramkola Coalfield, (Srivastava *et al.*, 1997), with Assemblage Zone II from the Sohagpur Coalfield (Ram-Awatar, 1997), with the Almod Bed, Satpura Basin (Kumar, 1997), and with Assemblage I from the Talchir Coalfield, Orissa (Tripathi, 2001). However, it should be noted that comparisons with India are strongly hampered by the fact that many Indian palynologists use a different nomenclature and often also use different species concepts. Taxa described and/or illustrated from the above mentioned Upper Permian sequences in India that have also been found in the *Lueckisporites virkkiae* Zone include: *Cycadopites* sp., *Falcisporites stabilis*, *Falcisporites* sp., *Guthoerlisporites cancellosus*, *Guttulapollenites hannonicus*, *Klausipollenites schaubergeri*, *Leiotriletes* sp., *Lunatisporites pellucidus*, *Laevigato-sporites vulgaris (*= *Navalesporites spinosus*), *Platysaccus queenslandi*, *Plicati-pollenites indicus*, *Podocarpites* sp., *Protohaploxypinus microcorpus* and *Striato-podocarpidites* sp.,

The assemblages from the *Lueckisporites virkkiae* Zone from Jordan are very similar to those from the lower part of the Chhiddru Formation, Salt Range, Western Pakistan (Balme, 1970), except for the fact that these marine beds also contain acritarchs. These beds are well dated with conodonts (Wardlaw and Pogue, 1995) and are according to the subdivisions of Jin *et al.* (1997) Changhsingian (Late Permian) in Age. The following taxa have been recorded from the *Lueckisporites virkkiae* Zone and from the Salt Range: *Falcisporites stabilis, F. zapfei, F. nuthallensis, Klausipollenites schaubergeri*, *Hamiapollenites* sp., *Lueckisporites virkkiae*, *Lunatisporites* sp., *Potonieisporites novicus*, *Protohaploxypinus microcorpus*, *P. limpidus, P. varius*, *P.* spp., *Striatopodocarpites rarus* and *Vittatina* spp.

Australia

The Permian and Triassic of Australia have been studied extensively, particularly in Queensland by Evans (1966, 1969), Filatoff (1971) Helby (1973), Foster (1979, 1982), and by De Jersey (1979). Foster (1982) recognized five palynofloral zones from the Middle Permian to the Lower Triassic of the Bowen Basin, Queensland. The *Lueckisporites virkkiae* Zone can be correlated with Foster's Upper Stage 5: the *Playfordiaspora crenulata* and *Protohaploxypinus* zones. Taxa present in both zones are: *Camptotriletes warchianus*, *Falcisporites* sp., *Lueckisporites* sp., *Protohaploxy-*

pinus amplus, P. limpidus, P. microcorpus, Striatopodocarpites fusus, Klausipollenites sp., *Triquitrites proratus* and *Triplexisporites* spp.

North Africa

Palynological associations similar to those from the Um Irna Formation have also been reported from the El-Uotia Unit, Tripolis Basin Libya (Adloff et *al.*, 1986) and southern Tunisia (Kilani-Mazraoui *et al.*, 1990) who reported the following taxa which have also been recovered from the Um Irna Formation: *Acanthotriletes* sp., *Calamospora* sp., *Cycadopites rarus*, *Cycadopites* sp., *Falcisporites zapfei, Klausipollenites schaubergeri*, *Leiotriletes* sp., *Lueckisporites virkkiae*, *Lunati-sporites noviaulensis, Nuskoisporites* sp., *Protohaploxypinus* spp. *Punctatisporites* sp., *Platysaccus* spp. and *Tympanicysta stoschiana*.

Africa

Assemblage Zone 3 from the "Série de l'Agoula", Côtier Basin (Karroo), Gabon was dated as Late Permian (Jardiné, 1974). Associations from this zone include many taxa that have also been found in the Um Irna Formation: *Falcisporites nuthallensis, F. zapfei, Hamiapollenites* sp., *Klausipollenites schaubergeri*, *Lueckisporites virkkiae*, *Lunatisporites noviaulensis, Nuskoisporites* spp., *Protohaploxypinus limpidus, P. varius, P.* sp., *Striatopodocarpites* sp. and *Potonieisporites* spp.

The upper part of the Tarat Formation, northern Nigeria, has yielded a microflora in which bisaccates comprise 75.8% of the total assemblage (Broutin *et al.*, 1990). This microflora has been dated as Late Permian and contains many species which are also known from the Upper Permian of Jordan: *Calamospora* sp., *Cedripites* sp., *Cycadopites* sp., *Falcisporites zapfei, Hamiapollenites* sp., *Illinites tectus, Laevigatosporites vulgaris*, *Lueckisporites virkkiae*, *Nuskoisporites klausii*, *Plicatipollenites densus, P.* sp., *Potonieisporites novicus, Protohaploxypinus microcorpus*, *Punctatisporites* sp., *Striatopodocarpites* sp., *Vittatina* spp.,

The older assemblage described by Hankel (1992) from the Maji ya Chumvi Formation, Mombasa Basin, Kenya, which was dated as Late Permian shows some similarities to the assemblages from the *Lueckisporites virkkiae* Zone. The following taxa occur in both: *Cycadopites* sp., *Falcisporites* sp., *Lueckisporites virkkiae, Platysaccus* sp., *Plicatipollenites* sp., *Protohaploxypinus microcorpus*, *Striato-podocarpites* spp., *Triplexisporites* sp. and *Tympanicysta stoschiana*.

The European Zechstein Basin

Many palynological studies have been carried out in the European Zechstein Basin and adjacent regions, e.g. Niederrhein, Germany (Grebe, 1957, Grebe and Schweitzer, 1964), Hesse, Germany (Leschik, 1956, Schaarschmidt, 1963), northern England (Clarke, 1965), southern England (Warrington and Scrivener, 1990), Ireland (Visscher, 1971), Poland (Dybova-Jachowicz, 1974, Fijałkowska, 1994). Although the Zechstein can reach a considerable thickness, only a single palynological zone can be recognized, indicating that the the Zechstein covers only a relatively short time-span (Visscher, 1971). The relatively short duration of the Zechstein has been confirmed by other studies (e.g. Menning, 1986). Visscher (1971) and Fijałkowska (1994) have been able to recognize subzones on the basis of different morphotypes of *Lueckisporites virkkiae*.

The microfloras from the regions listed above are all very similar; differences are quantitatively rather than qualitatively. The following taxa have been recorded for most these regions: *Falcisporites zapfei*, *Gardenasporites* spp., *Illinites* spp., *Jugasporites delasaucei*, *Klausipollenites schaubergeri*, *Laevigatosporites* sp., *Lunatisporites* spp., *Limitisporites moersensis, Lueckisporites virkkiae, Nuskoi-sporites dulhuntyi, N. klausii, Platysaccus* spp, *Potonieisporites* sp., *Protohaploxy-pinus microcorpus, P.* spp., *Striatopodocarpites* spp., *Tympanicysta stoschiana, Vittatina* spp. All these forms have been found in the assemblages from the Um Irna Formation.

Protohaploxypinus, *Potonieisporites, Vittatina*, *Cycadopites*, and *Tympanicysta stoschiana* have not been reported from the basal Zechstein in the Niederrhein; the latter three taxa are also absent in the associations from the Zechsteinkalk from Büdingen (Hesse, Schaarschmidt, 1963). *Protohaploxypinus* and *Falcisporites* have not been recorded from Ireland. The occurrence of latter taxon, which was originally described from the Zechstein of Neuhof near Fulda (Leschik, 1956), appears to be very variable. It is the dominant constituent of the Um Irna microflora but rare elsewhere (e.g. Büdingen: Schaarschmidt, 1963), or even completely absent (Ireland: Visscher, 1971).

The Upper Permian from the Alps and the northern Mediterranean

The Val Gardena Formation (= Grödner Sandstein) and the overlying Bellerophon Formation form the Southern Alps have yielded very rich and well preserved microfloras (Klaus, 1963, Massari *et al.*, 1994). These associations are very similar to the assemblages from the Um Irna Formation and dominated by mono- and bisaccate pollen, e.g., *Falcisporites zapfei, Illinites* sp., *Jugasporites delasaucei, Klausi-*

pollenites schaubergeri, *Lueckisporites virkkiae*, *Lunatisporites* spp., *Nuskoisporites klausii*, *Protohaploxypinus* spp. while *Vittatina* is also common. The Permian-Triassic boundary is characterized by a high abundance of the presumed fungal spore *Tympanicysta stoschiana* (Visscher and Brugman, 1988). This latter form has recently also been interpreted as an alga (Stephenson *et al.*, 2003).

The Upper Permian of the Dôme de Barrot, southern France, has yielded a microflora similar to that from the Um Irna Formation with taxa like *Cordaitina* sp., *Falcis-porites zapfei*, *Jugasporites* sp., *Klausipollenites schaubergeri* and *Luecki-sporites virkkiae* (Visscher *et al.*, 1974)

Microfloras from the Upper Permian of the Iberian Range, Central Spain, are dominated *Klausipollenites schaubergeri, Lueckisporites virkkiae* and *Nuskoisporites* sp. (Doubinger *et al*., 1990). These taxa are present in the assemblages from the Um Irna Formation but rare. Other taxa reported by Doubinger *et al.* which are also known from Jordan are *Cedripites* sp., *Guthoerlisporites cancellosus*, *Illinites* sp., *Jugasporites delasaucei*, *Leiotriletes* sp., *Platysaccus* sp., *Potonieisporites* sp. *Protohaploxypinus* sp. and *Vittatina* sp.

The Upper Permian of Menorca, Spain, has yielded a microflora dominated by pollen such as *Falcisporites stabilis*, *Illinites tectus, Jugasporites* sp., *Klausipollenites schaubergeri*, *Lueckisporites virkkiae*, *Lueckisporites* spp, *Protohaploxypinus microcorpus* (Broutin *et al*., 1992).

The Arctic

The *Lueckisporites virkkiae* Zone can be correlated with the *Scutasporites* sp. cf. S*cutasporites unicus-Lunatisporites* sp. Concurrent Range Zone from the Finnmark Platform, Barents Shelf, (Mangerud, 1994). This zone was dated as Kazanian-Tatarian. Many taxa which are common in this zone are also common in the assemblages from the Um Irna Formation, e.g. *Hamiapollenites* sp., *Jugasporites* sp., *Lueckisporites virkkiae*, *Nuskoisporites* sp. *Protohaploxypinus varius*, *P. sp.*, *Striatopodocarpites* sp., and *Vittatina* sp. It was should be noted that some of these taxa have been recorded in the lowermost Triassic, i.e. *Vittatina* spp. and *Lueckisporites virkkiae*. *Vittatina* is considered to be reworked from the Upper Permian, as is evidenced by the poor preservation. However, the well preserved *Lueckisporites virkkiae* grains, which can even be common, are considered to be earliest Triassic. *Klausipollenites schaubergeri*, *Protohaploxypinus microcorpus* and

Triquitrites proratus have also been reported from the lowermost Triassic. In most regions the occurrence of these forms is restricted to the Upper Permian.

North America

A typical Late Permian microflora was described from the Flowerpot Formation, Green County, Oklahoma, U.S.A. (Wilson, 1962). *Lueckisporites virkkiae* constitutes up to 68.1% of the total assemblage. Other taxa include *Calamospora* spp., *Hamiapollenites* sp., *Nuskoisporites* spp., *Potonieisporites* spp. and *Vittatina* spp. *Klausipollenites schaubergeri*, which is generally considered as an important index fossil for the Upper Permian is absent. Although quantitative differences are considerable, this microflora can well be compared with that from the Um Irna Formation.

China

The Late Permian *Lueckisporites-Jugasporites* assemblage Zone (Qu, 1980, Ouyang and Wang, 1983, Ouyang, 1986) comprises most of the Sunjiagou Formation, North China. A number of taxa from this zone have also been found in the samples of the Um Irna Formation, i.e., *Anapiculatisporites* sp., *Acanthotriletes* sp., *Cordaitina* sp., *Gardenasporites* sp., *Illinites* sp., *Lueckisporites virkkiae*, *Protohaploxypinus* sp., *Punctatisporites* sp., and *Vittatina* sp.

The Upper Permian-Lower Triassic sequence in Meishan, Changxing County, Zhejiang Province, has been chosen as reference (GSSP) for the Permian-Triassic Boundary. The *Leiosphaeridia changxingensis-Micrhystridium stellatum* Assemblage Zone is based on marine acritarchs which complety dominate the associations (82-99%) (Ouyang and Utting, 1990). The Um Irna Formation is developed in a terrestrial facies. Therefore the associations differ considerably, qualitatively as well as quantitatively. Only few miospore taxa have been reported (e.g. *Apiculatasporites* sp., *Cyclogranisporites* sp., *Hamiapollenites* sp., *Klausipollenites* sp. and *Platysaccus* sp.). However, it should be noted that the associations described from the lowermost Triassic consist of a mixture of typical Early Triassic taxa and taxa which are normally restricted to the Permian (*Gardenasporites* sp., *Klausipollenites schaubergeri*, *Lueckisporites virkkiae*, *Protohaploxypinus* sp., *Vittatina* sp.). Because these latter grains can be rather common and are well preserved, it is unlikely that they have been reworked from older sediments. Some “typical Permian” taxa apparently persisited into the earliest Triassic, at least locally.

A similar situation has been described for the Permian-Triassic boundary interval in the Junggar Basin, NW China, where well-preserved grains of *Hamiapollenites* sp., *Klausipollenites schaubergeri*, *Lueckisporites virkkiae*, *Protohaploxypinus* sp. *and Vittatina* sp. have been described from the earliest Triassic ***Lundbladispora-Lunatisporites-Aratrisporites*** Assemblage Zone (Ouyang and Norris, 1999).

5.e. The Lower Triassic

The *Endosporites papillatus-Veryhachium* spp. Zone

This zone is named after its markers, the common spore *Endosporites papillatus* and the common acritarch *Veryhachium.* The base of this zone cannot be defined; the Lower Triassic unconformably overlies the Upper Permian. The top of this zone is cannot be defined either because the Lower Triassic Ain Musa Formation is conformably overlain by the predominantly carbonatic Hisban Formation, which appeared to be barren. However, the conformably overlying Hisban Formation has been dated as Anisian which implies that the top of the *Endosporites papillatus-Veryhachium* spp. Zone coincides with the lithological boundary between the Ain Musa Formation and the Hisban Formation

Samples: This zone comprises the entire nearly 206 m thick Lower Triassic sequence underlying the Hisban Formation (Anisian). It includes the Ma'in Formation (47 m), the Dardur Formation (59 m) and the Ain Musa Formation (100 m). This sequence is dominated by sandstones, dolomites and few thin layers of light-grey, green, variegated bituminous marls, claystones and siltstones. Fig. 13 shows the sample locations. In total 29 samples was palynologically processed, fourteen samples appeared to be barren, eight samples appeared to yield only few palynomorphs, whereas seven samples were productive.

Index taxa: *Aratrisporites paenulatus, Densoisporites nejburgii, D. playfordii, Endosporites papillatus, Kraeuselisporites apiculatus, K. varius, Lapposisporites echinatus, Lundbladispora obsoleta, Punctatisporites fungosus* and *Veryhachium* spp.

Composition: The *Endosporites papillatus-Veryhachium* spp. Zone is characterized by a low taxonomic diversity, a sharp decrease of the bisaccates and an abundance of acritarchs. The assemblages from this zone are dominated by spores, e.g. *Apiculatisporites spiniger, Aratrisporites paenulatus, A.* spp., *Densoisporites* *nejburgii, D. playfordii, Endosporites papillatus, Kraeuselisporites apiculatus, K. echinatus, K. varius, , K.* sp., *Lapposisporites echinatus, Lundbladispora obsoleta,* and by the acritarchs *Veryhachium* spp. and *Micrhystridium* spp. Other (rarer) constituents are *Concavisporites* sp., *Cyclotriletes pustulatus, Leisphaeridia* sp., *Punctatisporites fungosus* and *Retitriletes* sp.

The lower part of the *Endosporites papillatus*-*Veryhachium* spp. Zone is characterized by the rare to very rare occurrence of bisaccate pollen, e.g. *Lunatisporites pellucidus, Lunatisporites noviaulensis, Distriatites insolitus, Striatoabieites* sp., *Falcisporites stabilis, Alisporites* sp., *Platysaccus papilionis* and *Stereisporites* sp.

Age: The unconformity between the Upper Permian and the Lower Triassic indicates the presence of a hiatus. Palynological studies indicate that the Induan (= Griesbachian and Dienerian) is missing. The *Endosporites papillatus*-*Veryhachium* spp. Zone can tentatively be dated as early Olenekian (= Smithian). The Ain Musa Formation is conformably overlain by the Hisban Formation which has been dated as middle Anisian (Pelsonian) but the upper boundary of this zone remains unclear since the upper part of the Ain Musa Formation barren.

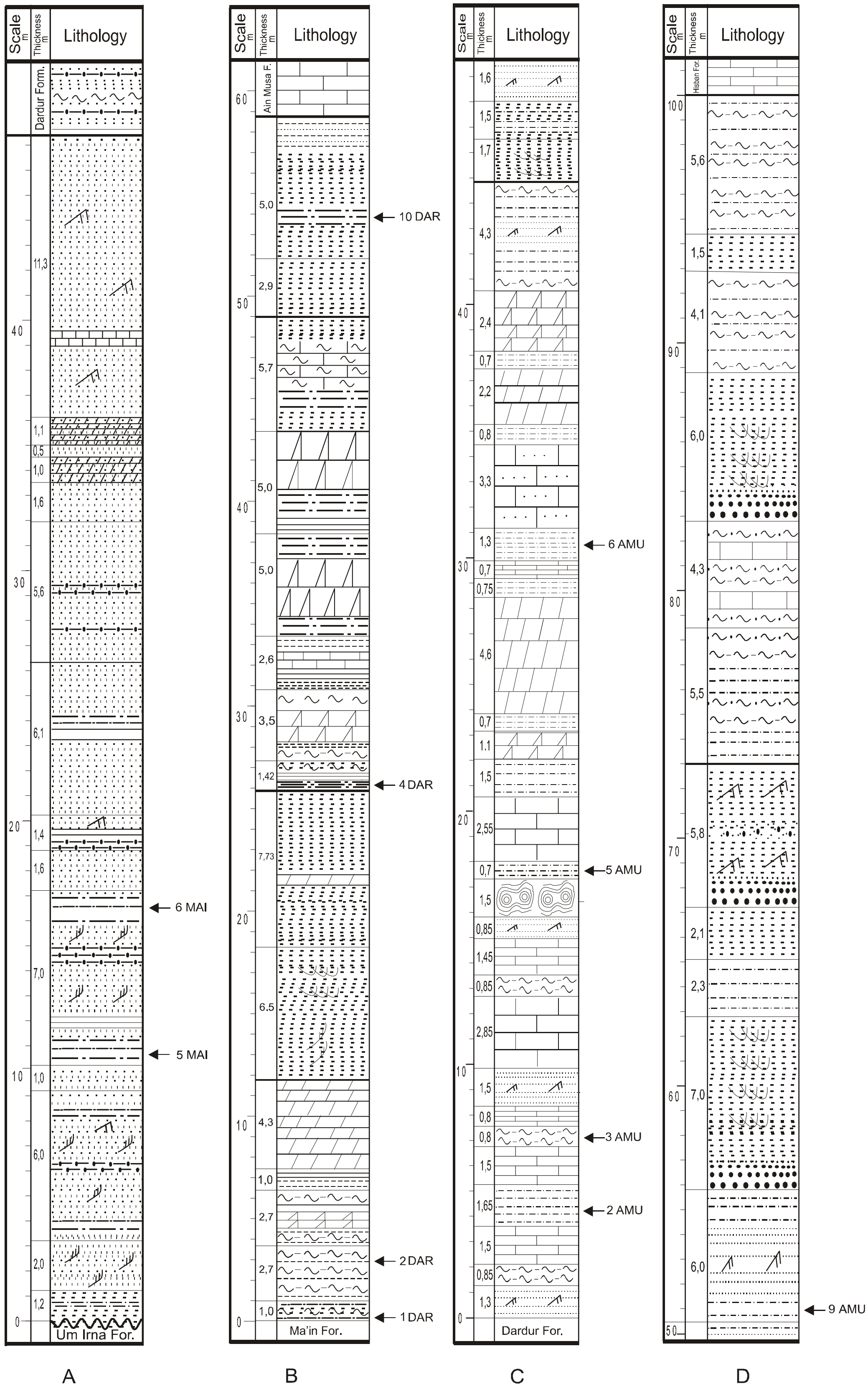

Fig.(13): Samples location of the *Endosporites papillatus*-*Veryhachium* spp. Zone. A-Ma'in Formation, B-Dardur Formation, C & D-Ain Musa Formation.

Comparisons and correlations

The Scythian is palynologically generally poorly known. Worldwide, only relatively few regions have yielded rich and well preserved associations. In large areas the Lower Triassic is completely developed in a terrestrial redbed facies.

Israel

Early Triassic (Scythian) palynomorphs have been described by Eshet (1983, 1990) and Eshet and Cousminer (1986). Most of this work is based on the Maktesh Qatan 2 well (Negev), which has also been regarded as reference section for the correlation with other boreholes in Israel (Eshet, 1990). Associations from the Lower Triassic have been assigned to Zone III by Eshet (1983, 1990) which is also referred to as *Endosporites papillatus-Kraeuselisporites* spp. Assemblage Zone (Eshet and Cousminer, 1986). The assemblages assigned to the *Endosporites papillatus-Veryhachium* spp. Zone from Jordan are very similar to those from Israel. Taxa reported from Israel and Jordan include *Aratrisporites* sp., *Cyclotriletes* sp., *Densoisporites nejburgii*, *D. playfordii*, *Endosporites papillatus*, *Falcisporites stabilis, Kraeuselisporites apiculatus*, *K.* spp., *Lunatisporites noviaulensis*, *L. pellucidus*, *Lundbladispora* sp., *Micrhystridium* spp. and *Veryhachium* spp. In Israel acritarchs are very abundant in the Lower Triassic (> 70%), like in the upper part of the *Endosporites papillatus-Veryhachium* spp. Zone. An Early Triassic Age for Zone III is supported by foraminifera, ostracods and conodonts (Eshet 1990).

Australia

Balme (1963) published a Scythian microflora from the Kockatea Shale Formation, Perth Basin, Western Australia. Some of these taxa from this flora are also common in the *Endosporites papillatus-Veryhachium* spp. Zone in Jordan, i.e. *Punctatisporites fungosus*, *Lundbladispora* sp. and *Kraeuselisporites* sp. Some of the common bisaccates from Australia are rare in Jordan, i.e. *Lunatisporites noviaulensis*, *L. pellucidus* and *Platysaccus papilionis.* Some taxa from Jordan have not been recorded from the Lower Triassic of the Perth Basin (*Endosporites papillatus*, *Densoisporites* spp. and *Aratrisporites* spp.).

Dolby and Balme (1976) established two palynozones for the Scythian of the Carnarvon Basin, Western Australia. Most of the significant palynomorphs reported from the upper part lower zone and the lower part of the upper zone have also been found in Jordan, i.e. *Aratrisporites* spp., *Densoisporites playfordii*, *Falcisporites* sp., *Kraeuselisporites* spp., *Lunatisporites pellucidus*, *L. noviaulensis*, *Lundbladispora* spp., *Punctatisporites fungosus*, and acritarchs. *Endosporites papillatus* and *Lapposisporites* spp. were not reported from the Carnarvon Basin.

Early Triassic microfloras from the Bowen Basin, Queensland, were described by De Jersey (1979) and Foster (1982). Significant forms like *Densoisporites playfordii*, *Falcisporites stabilis Kraeuselisporites* sp., and *Lunatisporites noviaulensis, L. pellucidus* and *Lundbladispora obsoleta*. have also been found in Jordan. Foster (1982) recognized two zones in the Scythian; their composition is rather similar but they can be distinguished on the basis the first appearance of *Aratrisporites* spp. Therefore, the *Endosporites papillatus-Veryhachium* spp. Zone can be correlated with Foster's *Protohaploxypinus samoilovichii* Zone.

India

There are numerous publications on the palynology of the Triassic of India. Unfortunately, most Indian authors use a different taxonomy. Moreover, they also have rather different species concepts, making it virtually impossible to compare their data with those from other countries, as has also been noted by Eshet (1983).

The *Endosporites papillatus-Veryhachium* spp. Zone from Jordan can be correlated with the Zone (I) from the Raniganj Coalfield established by Bharadwaj and Tiwari (1977), based on on the common occurrence of taxa such as *Lundbladispora* spp., *Densoisporites playfordii* and *Lunatisporites* spp.

The associations from the *Endosporites papillatus-Veryhachium* spp. Zone from Jordan show some similarity with those from the Lower Triassic Zone IV of Prasad (1997) from the Krishna-Godavari Basin, India; taxa known from both zones are *Aratrisporites* spp., *Falcisporites stabilis, F.* spp., *Lunatisporites pellucidus*, *Lundbladispora* spp., *Densoisporites playfordii* and *Punctatisporites*. However, *Endosporites papillatus, Kraeuselisporites* spp., *Lapposisporites* spp. and acritarchs have not been reported from the Krishna-Godavari Basin.

Pakistan

Many taxa recorded by Balme (1970) from the Kathwai Member at Wargal and from the lower part of the Mittiwali Member in Nammal Gorge, which have both been dated as early Scythian, have also been found in the assemblages of the *Endosporites papillatus-Veryhachium* spp. Zone in Jordan, i.e. *Alisporites* sp., *Densoisporites* *playfordii*, *Falcisporites stabilis*, *Kraeuselisporites* spp., *Platysaccus* sp., *Lunatisporites noviaulensis*, *L. pellucidus*, *Lundbladispora obsoleta*, *Punctatisporites fungosus* and a high percentage of acritarchs. The middle Member of the Mianwali Formation is characterized by the first appearance of *Aratrisporites fischeri*, *A. paenulatus*, *Densoisporites nejburgii* and *Lundbladispora* sp. This microflora, which is well comparable to the assemblages from Jordan, has been dated as late Scythian.

North Africa

The assemblages of the *Endosporites papillatus-Veryhachium* spp. Zone are very similar to those from the Bir-El Jaja Unit (Lower Triassic) of the Tripolis Basin, Libya (Adloff *et al.*, 1986) and the Lower Triassic of southern Tunisia (Kilani-Mazraoui *et al.*, 1990). Like in Jordan, the Triassic unconformably overlies the Permian in Tunisia and in Libya. Assemblages from both regions are dominated by spores, acritarchs and spores, whereas bisaccates are rare. Common taxa include *Apiculatisporites* sp., *Densoisporites nejburgii*, *D. playfordii*, *Endosporites papillatus* and *Kraeuselisporites apiculatus*, *Lunatisporites* sp., *Micrhystridium* sp. and *Veryhachium* sp.

Eastern Africa

The *Endosporites papillatus-Veryhachium* spp. Zone from Jordan is younger than the so-called "Younger assemblage" from the Maji ya Chumvi Formation, Mombasa Basin, Kenya which has been dated as Griesbachian (Hankel, 1992). Typical constituents of this latter flora are *Densoisporites playfordii*, *Lundbladispora* spp, *Kraeuselisporites* sp. *Lunatisporites noviaulensis*, *L. pellucidus* and *Tympanicysta stoschiana*; it is dominated by bisaccates and acritarchs are absent.

The Germanic Basin

The association of Visscher's (1971) Assemblage II from the Kingscourt Outlier, Ireland, resembles those from the *Endosporites papillatus-Veryhachium* spp. Zone. Both show a decrease of the number of bisaccate pollen and an increase of cavate spores. Common elements are *Densoisporites* spp., *Endosporites papillatus* (illustrated as *Lundbladispora* sp.; see Eshet 1983) and *Lunatisporites noviaulensis* and acritarchs of the *Veryhachium-Micrhystridium* complex.

The Buntsandstein from Germany has yielded only few good associations. The following taxa, which are also known from Jordan, have been reported from the Middle Buntsandstein of Thuringia: *Densoisporites nejburgii, Endosporites papillatus*, *Lu-*

natisporites noviaulensis and *Lundbladispora* sp. (Schulz, 1965, Reinhardt and Schön, 1967).

Several Early Triassic index species from the *Endosporites papillatus-Veryhachium* spp. Zone from Jordan have been also recorded from the Polish Middle Bunter i.e. *Endosporites papillatus*, *Densoisporites nejburgii*, *Densoisporites playfordii*, *Lundbladispora* spp., *Lunatisporites noviaulensis* and *Platysaccus papilionis* (Orłowska-Zwolinska,1977).

The *Protohaploxypinus* sp. div. and *Densoisporites playfordii* Assemblage Zone from the Holy Cross Mountains, Poland (Fijałkowska, 1994) shows some resemblance with *Endosporites papillatus-Veryhachium* spp. Zone from Jordan. Taxa recorded for both include: *Densoisporites playfordii*, *Endosporites papillatus*, *Lunatisporites novi-aulensis*, *Lundbladispora* cf. *obsoleta*, *Punctatisporites* sp., *Platysaccus papilionis*, *Tympanicysta stoschiana* and acritarchs. The top of this zone is defined by the first appearance of the *Densoisporites nejburgii*. Furthermore, elements which are generally considered to be typical for the Late Permian forms well represented in the lowermost Triassic of Poland (up to 8.5% *Klausipollenites*), while some typical Early Triassic taxa (*Aratrisporites*, *Kraeuselisporites*, *Lapposisporites*) have not been recorded from this zone. Therefore, it must be concluded that the Polish *Protohaploxypinus* sp. div. and *Densoisporites playfordii* Assemblage Zone is older than the Jordanian *Endosporites papillatus-Veryhachium* spp. Zone.

The Arctic and Canada

The assemblages from *Endosporites papillatus-Veryhachium* spp. Zone from Jordan seem to be slightly younger than those from the Lower Triassic from the Continental Shelf, off-shore Mid-Norway (Vigran and Mangerud, 1991), where cavate spores are dominant but acritarchs are rare. Microfloral elements present in both regions are *Alisporites* sp., *Aratrisporites* spp., *Densoisporites nejburgii*, *D. playfordii*, *Endosporites papillatus*, *Kraeuselisporites apiculatus*, *K.* sp., *Lapposisporites* sp., *Lundbladispora obsoleta*, *Lunatisporites noviaulensis*, *L. pellucidus*, *Micrhystridium* sp. and *Veryhachium* sp., However, the samples from Jordan contain some bisaccates and *Aratrisporites* sp., whereas *Vittatina* is absent. This suggests that the microflora from Norway material is somewhat older.

The *Lundbladispora obsoleta-Tympanicysta stoschiana* Assemblage Zone from the Barents Sea has been dated as early Induan/Griesbachian (Mangerud, 1994). In addition to *Endosporites papillatus*, *Densoisporites playfordii*, *D. nejburgii*, *Kraeuselisporites apiculatus, K.* spp. *Lundbladispora obsoleta*, and *Lunatisporites pellucidus.* The associations contain some "Late Permian" elements which are absent in Jordan, while *Aratrisporites* sp. is present there and does not occur in the Barents Sea samples. Therefore, Mangerud's *Lundbladispora obsoleta-Tympanicysta stoschiana* Assemblage Zone is older than the *Endosporites papillatus-Veryhachium* spp. Zone from Jordan.

Vigran *et al*. (1998) established a very detailed zonation for the marine Lower and Middle Triassic of the Svalis Dome, Central Barents Sea, Norway. There is no unconformity between the Permian and the Triassic and there is no transitional association, like it has been reported from some other regions. The lower four zones (Svalis 1-4) have been dated as Early Triassic, also with ammonoids. The range of *Densoisporites playfordii* which has been recorded from the basis of Svalis 2 to the top of Svalis 3 suggests that the Jordanian samples might be dated as Smithian-early Spathian.

A direct correlation with the associations from the Peace River area, western Canada is not possible because Jansonius (1962) refrained from giving a zonation. Although these associations are qualitatively comparable, they look quite different because bisaccates are abundant pollen grains, whereas trilete spores are rarer.

The *Tympanicysta stoschiana-Striatoabieites richteri* Assemblage Zone from the Sverdrup Basin, Arctic Canada, has been dated as Griesbachian by Utting (1989). He identified the following taxa in the earliest Triassic: *Lunatisporites noviaulensis*, *Lundbladispora obsoleta*, *Striatoabieites* sp. and *Tympanicysta stoschiana,* which are all common in the lower Triassic *Endosporites papillatus-Veryhachium* spp. Zone from Jordan. However, the absence of several important markers in the *Tympanicysta stoschiana-Striatoabieites richteri* Assemblage Zone suggests that the Jordanian assemblages are younger.

Many taxa from the *Endosporites papillatus-Veryhachium* spp. Zone from Jordan are also present in Fischer's (1979) "Assemblage III" from the Canadian Arctic. The top of this zone is defined by the last appearances of *Densoisporites playfordii* and *Endosporites papillatus*, whereas its base is defined by the first appearance of *Aratrisporites*; the range of *Lapposisporites villosus* is restricted to "Assemblage III" which is considered to be Smithian in age.

China

Although the assemblages from the Lower Triassic of Jordan contain a number of species that have also been recorded from China, e.g. Shaanxi, North China (Ouyang and Norris, 1988), Meishan, Changxing County, Zhejiang Province (Ouyang and Utting, 1990) and the Junggar Basin, NW China (Ouyang and Norris, 1999), they are quite different and cannot be compared. The associations from Shaanxi are dominated by bisaccates.

Associations from the lowermost two Triassic assemblage zones from Meishan still contain a number of taxa which are normally regarded to be Late Permian (Ouyang and Utting, 1990). These two palynozones are older than the *Endosporites papillatus-Veryhachium* spp. Zone from Jordan, but some taxa occur in both, i.e. *Endosporites papillatus*, *Lunatisporites* sp., *Lundbladispora* sp. and *Platysaccus papilionis*.

Samples from the Guodikeng and Jiucaiyuan formations from the Junggar Basin, NW China, have been dated as Induan (Ouyang and Norris, 1999). Several of the genera described from the Junggar Basin are also known from Jordan, but some specific elements are missing. This earliest Triassic microflora still comprises several typical "Permian" taxa, representing relicts of the Palaeozoic. Remarkable is that *Falcisporites* is well represented.

5.f. The Middle Triassic

While the Lower Triassic starts with continental redbeds, the Middle Triassic is more marine in Jordan. Therefore, age assessments with micro- and macrofossils are possible. A Scythian Age was tentatively inferred for all the sediments underlying the well-dated Anisian (Pelsonian) Hisban Formation, even if no fossils were known from the Lower Triassic. From the Hisban Formation bivalves like *Claraia*, *Myophoria* and *Praeorbicularis* have been described (Cox 1924, 1932, Wagner, 1934). An Anisian to Early Ladinian age was suggested by Wetzel and Morton (1959), Parnes (1975) assigned an early Anisian age. Bandel and Khoury (1981) proposed Anisian age based on lithostratigraphical correlation with the equivalent Ra'af Formation that is exposed in Israel. Based on conodonts and holothurian sclerites Sadeddin (1992, 1998) assigned an Early –Late Anisian age to Hisban Formation.

The Scythian-Anisian boundary is not clearly defined. Virtually all the samples from the upper part of the Ain Musa Formation, underlying the Hisban Formation (Pelsonian, Anisian) appeared to be barren; only very few samples have yielded some acritarchs. The Hisban Formation predominantly consists of carbonates. Five samples have been processed; only two yielded a low diversity of poorly preserved palynomorphs indicating an Anisian Age and confirming previous age assessments. The recovery from the overlying Mukheiris Formation appeared to be much better; all 19 samples appeared to be productive. The very rich associations show a high diversity and palynomorphs are excellently preserved.

The Anisian-Ladinian boundary is not well defined, because the Lower Cretaceous erosion surface cuts into the Anisian Mukheiris Formation in the Dead Sea region. The upper Ladinian is exposed further to the North, nearly 20 km NE of the Dead Sea, in the West Naur area. Therefore, the Anisian-Ladinian boundary interval can only be studied from subsurface samples.

The Aratrisporites saturnii Zone

This zone named after its marker and major constituent *Aratrisporites saturnii.* The base of this zone not defined because the top of the Ain Musa and the base of Hisban formations did not yield microfloras. The top of the *Aratrisporites saturnii* Zone cannot be defined, because the upper Anisian Mukheiris Formation was truncated by the Lower Cretaceous Kurnub Formation.

Samples: Samples (1HIS, 2 HIS) from the Hisban Formation and all samples from the Mukheiris Formation are assigned to this zone. The sequence comprises the well stratified rocks of the Hisban Formation (30 m) and the Mukheiris Formation (76 m). (Fig .14).

Index taxa: *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.*

Composition: The Early Triassic (Scythian) index palynomorphs, i.e. *Endosporites papillatus*, *Kraeuselisporites* spp., *Lundbladispora* spp. and *Densoisporites nejburgii*, have all disappeared and are replaced by the index taxa listed above. Bisaccates are the major constituents in this zone. The *Triadispora* complex is dominant. Other common forms are: *Alisporites magnus*, *A. grauvogelii*, *Microcachryidites doubingeri, Platysaccus papilionis, P. queenslandi, P. leschikii* and *Vestigisporites* sp. The following taxa are rare to common: *Cyclotriletes margaritatus*, *C. oligogranifer*, *C. microgranifer*, *C. granulates, Falcisporites stabilis, Triplexisporites playfordii, Verrucosisporites remyanus*, *V. jenensis* and *V. reinhardtii*. Additional taxa include: *Echinitosporites iliacoides*, *Crustaesporites* sp., *Guthoerlisporites cancellosus*, *Lunatisporites acutus*, *L. noviaulensis*, *L. pellucidus*, *L.* sp., *Osmundacidites* sp., *Punctatisporites uniformis*, *Punctatosporites crassexinis*, *Rimaesporites potoniei*, *Saccizonata* sp., *Sellaspora* sp., *Todisporites cinctus*, *Uvaesporites gadensis*, and *Veryhachium* sp; Many palynomorphs from this zone are also known from the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone (Ladinian).

Age: The *Aratrisporites saturnii* Zone can be dated as late Pelsonian-Illyrian (late Anisian).

Comments

From the Anisian onwards, palynofloras from Israel and Jordan (Eshet, 1990, this study) are well comparable to those from Europe and North America, due to the disappearance of typical Gondwana elements which were still well represent in the Lower Triassic.

In many older publications a single zone is applied for the Anisian and the Ladinian, because many taxa first appearing in the Anisian (e.g. *Aratrisporites* spp., *Triadispora* spp., and *Lunatisporites* spp.) continue into the Ladinian. Therefore, it can at first sight indeed be difficult to distinguish the *Aratrisporites saturnii* Zone from the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone. However, a number of taxa are restricted to the Ladinian i.e., *Alisporites microreticulatus*, *Eucommiidites microgranulatus, Fuldaesporites* sp., *Heliosaccus dimorphus, Hexasaccites muelleri, Keuperisporites microreticulatus, Lueckisporites singhii*, *Podosporites*

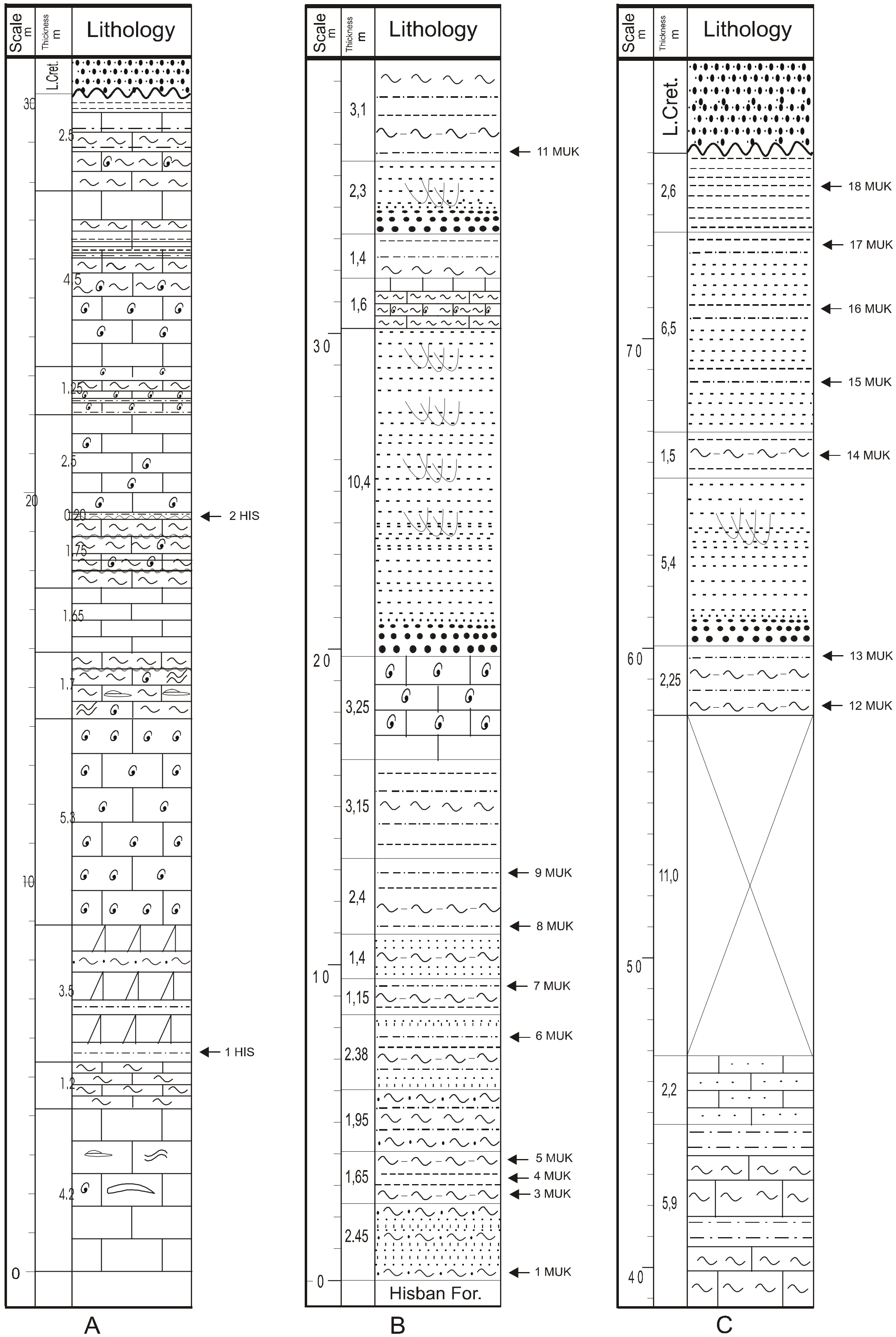

Fig.(14): Samples location of the *Aratrisporites saturnii* Zone. A- Hisban Formation, B & C-Mukheiris Formation.

amicus, Staurosaccites quadrifidus and *Vitreisporites pallidus* In Jordan, Ladinian microfloras are less diverse than Anisian ones and also the disappearance of taxa like *Osmundacidites* sp., *Brachysaccus ovalis*, *Voltziaceaesporites heteromorphus* and *Guthoerlisporites cancellosus* justifies the establishment of two zones.

For the Alpine/Tethyan Middle Triassic a very detailed zonation has been established (Van der Eem, 1983, Brugman, 1986). This zonation is primarily based on the application of the phase concept of Schuurman (1977) and Van der Zwan (1980), using qualitative and quantitative analyses of densely sampled successions. It is often difficult to compare and integrate data from older publications with the new zonation scheme. The correlation of the Alpine/Tethyan Middle Triassic with the Germanic Middle Triassic is still problematic. Even though a good palynological framework for the Alpine/Tethyan Middle Triassic is now available, several recent publications refrain from giving age assessments according to the marine standard time scale.

Because the microfloras from Jordan are well comparable to those from Europe and North America, comparisons primarily concentrate on other regions in the Middle East, Europe and North America. Although it has been attempted to correlate the Jordanian assemblages with Van der Eem's (1983) and Brugman's (1986) zonation scheme for the Middle Triassic, a one-to-one correlation with individual phases could not always be achieved because this would have required a denser sampling. Such detailed analyses were not possible within the broad framework of this thesis which covers the Upper Permian to Upper Triassic and deals with megafloral remains, cuticles and the palynology.

Comparisons and correlations

Because many authors apply a single zone for the Anisan and Ladinian, comparisons and correlations will be discussed after the characterization of the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone.

The Echinitosporites iliacoides-Eucommiidites microgranulatus Zone

This zone is named after the two index species *Echinitosporites iliacoides* and *Eucommiidites microgranulatus*. It comprises the entire Iraq Al-Amir Formation. The base of this zone is cannot be defined because the lower part of the Iraq Al-Amir Formation is not exposed. The top is defined in the top of the upper Member of Iraq

Al-Amir Formation (Shita Member), where Carnian palynomorphs start to appear gradually. This enables an estimate of the Ladinian-Carnian boundary.

The Triassic rocks exposed in the Wadi Naur area dated as Ladinian-? early Carnian based on conodonts (Bandel and Waksmundzki, 1985) and conodonts and holothurian sclerites (Sadeddin, 1990, Abu Hamad, 1994).

Samples: Samples 1 IRA - 9 IRA from the Iraq Al-Amir Formation are assigned to the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone. This interval comprises the upper Ladinian (Langobardian) Iraq Al –Amir Formation, samples location are presented in Fig. 15.

Index taxa: *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.*

Additional taxa: Other taxa present in the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone are. *Alisporites* spp*., Aratrisporites fimbriatus, Ar. playfordii, Ar.* cf. *quadriiuga, Ar. saturnii, Ar. parvispinosus, Ar.* sp., *Carnisporites* cf. *mesozoicus, Cyclotriletes microgranulatus, Fuldaesporites* sp*., Guttatisporites* cf. *elegans, Lueckisporites singhii, Lunatisporites acutus, L. noviaulensis, L. pellucidus, L.* sp*., Platysaccus reticulates, Polypodiisporites crassus, Reticulatisporites muricatus, Triadispora* sp., *Triplexisporites playfordii, Rimaesporites* sp., *Punctatisporites* sp*., Leiosphaeridia* sp*., Cycadopites* sp*., Laevigatosporites* sp*.,* and *Verrucosisporites thuringiacus.*

Some taxa already occurring in the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone (late Ladinian) become abundant in the *Patinasporites densus* Zone (Carnian), i.e. *Camerosporites secatus, Duplicisporites* spp., *Enzonalasporites vigens, Patinasporites densus, Paracirculina scurrilis* and *Praecirculina granifer.*

Age: Langobardian (late Ladinian).

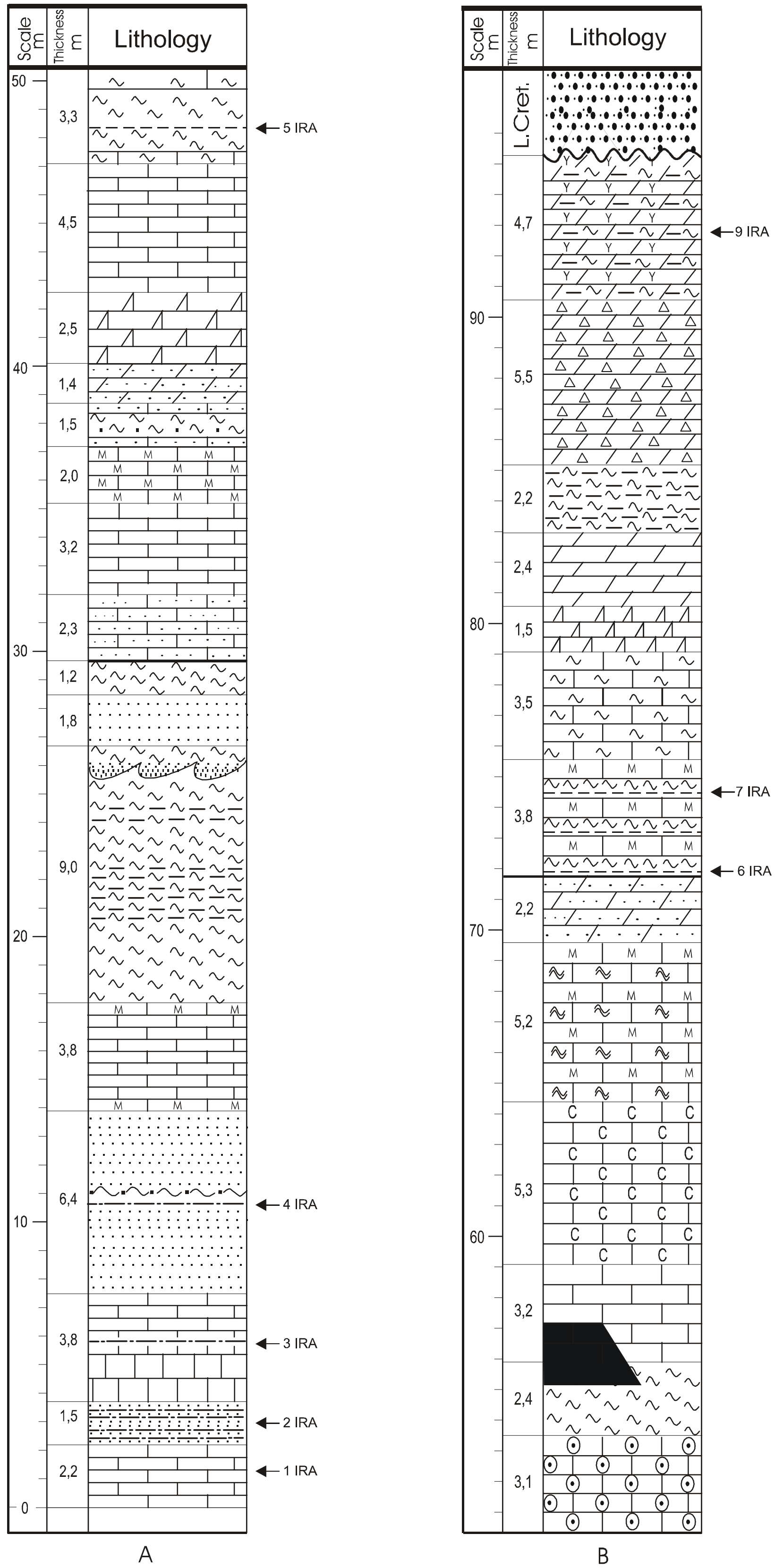

Fig.(15): Samples location of the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone. A & B-Iraq Al-Amir Formation.

The Onslow Microflora

Dolby and Balme (1976) introduced the term **Onslow Microflora** for mixed associations of Gondwanan and Euramerian[1] elements from the *Staurosaccites quadrifidus* Zone Anisian-Carnian*)*, the *Samaropollenites speciosus* Zone (Carnian) and the *Minutosaccus crenulatus* Zone (Carnian-Norian?) of the Carnarvon Basin, Western Australia. These associations differ considerably from Triassic assemblages from eastern and southern Australia in which such distinctive Euramerian elements are lacking. These latter floras which have a pure Gondwana aspects have been named **Ipswich Microflora**.

Some typical Gondwana forms in the Onslow Microflora are *Staurosaccites quadrifidus* and *Samaropollenites speciosus.* Both species are easily recognizable by their outstanding morphology. The first species was first described from the Ladinian-Carnian of the Onslow No. 1 Well, Carnarvon Basin (Dolby and Balme, 1976), whereas the latter was originally described from the Carnian of NW Malagasy (Goubin, 1965). Typical Euramerian elements present in the Onslow Microflora include *Camerosporites*, *Enzonalasporites*, *Infernopollenites*, *Minutosaccus* and *Ovalipollis.*

The Ipswich Microflora is less diverse than the Onslow Microflora and consists primarily of gymnosperm pollen of the *Falcisporites-Alisporites* group and taeniate bisaccate pollen. According to Dolby and Balme (1976, p. 133) "…there is no single pollen taxon in the Ipswich Microflora that can be confidently compared to a closely circumscribed European species".

Now a fair number of reports on additional occurrences of Onslow Microfloras are available. These are listed in Table 6. The geographic distrubution of the Onslow Microfloras is largely restricted to a narrow belt along the continental margins of the southern and western margin of the Tethys (Fig. 16). Visscher and Van der Zwan (1981) suggested that the Onslow Microfloras occur in two latitudinal belts, north and south

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[1] Dolby & Balme (1976) used the term "European" in their original description, but because several of these taxa are also known from North America it would be better to use the term "Euramerian".

Region	Stratigraphy	*'Onslow taxa'*	Selected accompanying elements	Author(s)
Carnarvon Basin, W Australia	Anisian-Carnian (not well dated; probably Ladinian)	*Staurosaccites quadrifidus*	*Au. astigmosus, C. secatus, E. vigens, I. claustratus, O. ovalis*	Dolby & Balme 1976
Southern Spain	Ladinian	*Staurosaccites quadrifidus*	*Ar. coryliseminus, Ar. paraspinosus, Ang.* sp., *C. secatus, Du. Du. Verrucosus, granulatus, Par. scurrilis, , K. meieri, Part.* sp., *S. aytugii, T. crassa, T. plicata*	Besems 1981
Libya	Ladinian	*Staurosaccites quadrifidus*	*Ar. granulatus, Ar.* spp., *H. dimoprhus, Keup. baculatus. L. acutus, T. falcata, T. staplinii, O. cultus.*	Adloff et al. 1985
Central Barents Sea	Ladinian	*Staurosaccites quadrifidus*	*Ar.* spp., *Eu. microgranulatus, L. acutus, L. noviaulensis, Part.* spp., *Podosporties amicus, T. aurea, T. crassa, T, onscura, T. modesta, T. plicata*	Vigran et al.1998
SE India	Uppermost Anisian-Ladinian	*Staurosaccites quadrifidus*	*Au. Astigmosus, C. secatus, E. densus, E. vigens, L.* sp., *O. pseudoalatus*	Prasad 1997
Na'ur Area, Jordan	Upper Ladinian	*Staurosaccites quadrifidus*	*Ang. klausii, Ar. saturnii, Ar. spp., Ech. iliacoides, H. dimoprhus, Hex. muelleri, Keup. baculatus, Eu. microgranulatus, L. acutus, L. noviaulensis, T. crassa, T. sulcata*	This study
Franconia, Germany	Upper Ladinian	*Staurosaccites quadrifidus*	*Ang. klausii, Ar. fimbriatus, Ar. paenulatus, Ar. parvispino-sus, Ar. saturnii, C. secatus, Du. granulatus, E. vigens, H. dimor-phus, Keup. granulatus, L. acutus, L. noviaulensis, O. pseudo-alatus, Part. novimundanus, T. crassa, T. plicata*	Heunisch 1986
Franconia, Germany	Upper Ladinian	*Staurosaccites quadrifidus*	*Ar. saturnii, A.* spp., *Cyclotriletes Ech. iliacoides, H. dimor-phus, Keup. baculatus, L.* spp., *T. crassa, T. plicata, T. su-specta,*	Brugman et al. 1994
Carnarvon Basin, W Australia	Carnian	*Samaropollenites speciosus Staurosaccites quadrifidus*	*C. secatus, C. pseudoverrucatus, De. delineatus, Du. gyratus, E. vigens, M. crenulatus, R. aquilonalis*	Dolby & Balme 1976
NW Malagasy	Carnian	*Samaropollenites speciosus*	*E. vigens*	Goubin 1965
Southern Spain	Carnian	*Samaropollenites speciosus*	*Ar. coryliseminus, Ar. paraspinosus, Ang.* sp., *C. secatus, Du. granulatus, Du. tenebrosus, Du. verrucosus, Kug. meieri, Part.* sp., *T. crassa, T. plicata,O. pseudoalatus*	Besems 1981, 1982
SE India	Carnian	*Samaropollenites speciosus*	*C. secatus, C. verrucatus, E.densus, E. vigens, M. crenulatus, O. pseudoalatus, S. aytugii*	Maheswari 1976 Prasad 1997
Northern Italy	Carnian	*Samaropollenites speciosus*	?	Visscher, pers comm., in Cirilli & Eshet 1991
Israel	(?Middle) Carnian	*Staurosaccites quadrifidus Samaropollenites speciosus*	*C. secatus, E. vigens, L. acutus, Para. scurrilis, Pati. densus, T. verrucata, T.* spp.	Cirilli & Eshet 1991
Na'ur and Zerqa River Area, Jordan	Middle Carnian	*Samaropollenites speciosus*	*C. secatus, Cor. tosora, Du. granulatus, Du. verrucosus, E. vigens, Pati. densus, I. salcatus, M.* sp., *L. acutus, O. ovalis, Part. novimundanus, Pati. densus, S. aytugiii*	This study
Sicily	Upper Carnian	*Samaropollenites speciosus*	*An. puncta, C. secatus, Du. granulatus, L. acutus, M.* sp., *O. pseudoalatus, Para. quadruplices, Para. tenebrosa, Pati. densus, V. ignacii, Z. cinctus*	Visscher & Krystyn 1978
Libya	Upper Carnian	*Samaropollenites speciosus Staurosaccites quadrifidus*	*Ar. granulatus, C. secatus, Du. granulatus, E. leschikii, O. minimus, O. pseudoalatus, T. falcata, T. plicata, T. staplinii, Para. scurrilis*	Adloff *et al.* 1985
Turkey	Lowermost Norian	*Samaropollenites speciosus*	?	Visscher, pers comm., in Cirilli & Eshet 1991
Syria	Norian	*Samaropollenites speciosus*	?	Khoga 1972, Yaroshenko et al. 1982 (non vid.)

Table (6): Reports of Onslow Microfloras

Ar. = Aratrisporites; Ang. = Angustisulcites; Ann. = Annulispora; Au. = Aulisporites; C.. = Camerosporites; Cor. = Corollina; De. = Decussatisporites; Du. = Duplicisporites; E. = Enzonalasporites; Ech. = Echinitisporites; Eu. = Eucommiidites; H. = Heliosaccus; Hex. = Hexasaccus; Keup. = Keuperisporites; Kug. = Kuglerina; L. = Lunatisporites; M. = Minutosaccus; O. = Ovalipollis; Par. = Paracirculina; Part. = Partitisporites; Pati. = Patinasporites; R. = Rimaesporites; S. = Striatoabietites; T. = Triadispora; V. = Vallasporites; Z. = 'Zonalasporites

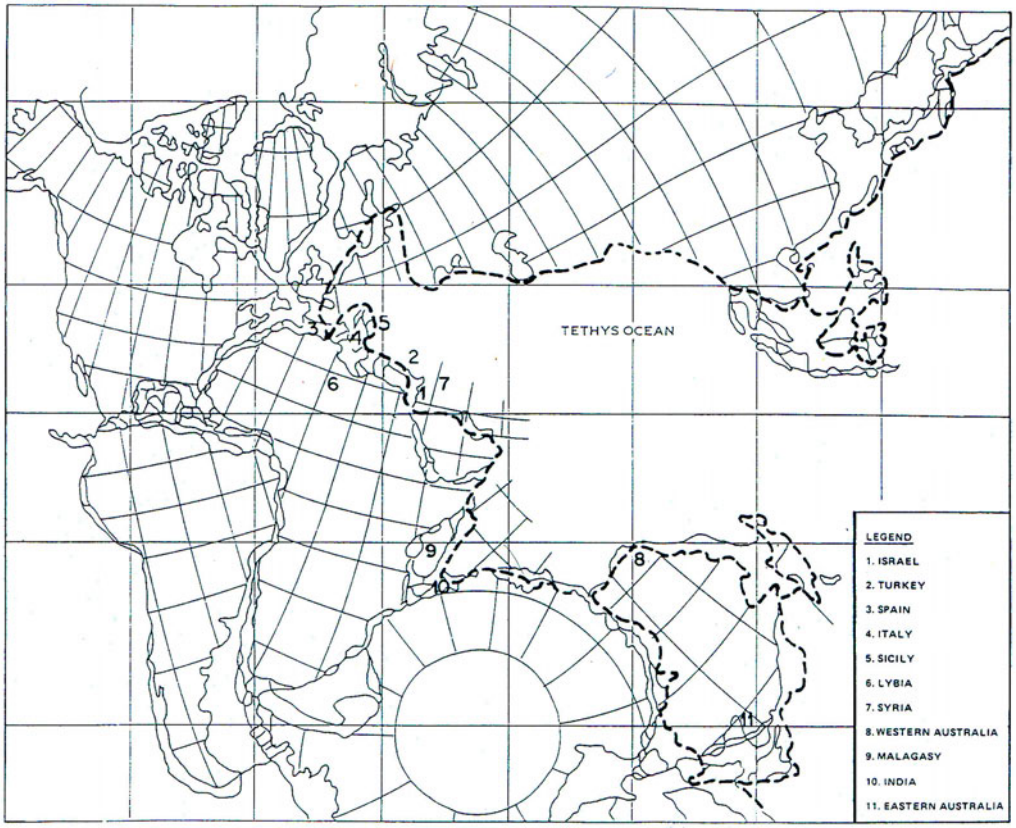

Fig. (16): The geographic distribution of the Onsllow Microflora, after Cirilli & Eshet (1991). Paleogeographic map modified from Smith *et al.* (1973).

of the palaeoequator, within a *Camerosporites* equatorial domain. The occurrence of *Staurosaccites quadrifidus* in the Central Barents Sea (Vigran *et al.* 1998) represents the northernmost extension of the Onslow Microflora. This latter occurrence does not fit palaeogeographically. May be, *Staurosaccites quadrifidus* had a much wider distribution than just the margins of the Tethys.

Comparisons and correlations

The following comparisons and correlations concentrate on well-dated microfloras, particularly from the Middle East, Europe and the Arctic; for comparisons with Onslow Microfloras (including North Africa and southern Spain) refer to are Table 6.

Israel

Several studies dealt with Middle Triassic microfloras of Israel, (e.g. Horowitz, 1973, Eshet, 1983, 1990, Eshet and Cousminer, 1983). The zonation of Eshet (1990) will here be used as a reference, because this is the most recent zonation scheme in which results of previous studies are summarized.

Eshet (1990) presents a correlation of 11 deep wells, using the Maktesh Qatan 2 Well, Negev, as a reference section. He established the *Aratrisporites saturnii* Zone which is dated as Anisian. This age is supported by ammonoids, foraminifera, ostracods and conodonts. Eshet's *Aratrisporites saturnii* Zone from Israel is practically identical to the one applied here for Jordan; almost the same species occur in Jordan and the top has been defined on the basis of the first appearances of the same taxa.

The subsequent *Podosporites amicus* Zone (Eshet 1990) is very similar to the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone with the same characteristic taxa. This zone is dated as Ladinian and this age is supported by foraminifera, conodonts and ostracods. The only difference between Israel and Jordan is that the diversity remains very high in Israel, whereas associations become less diverse in Jordan. Like in Jordan, several taxa which will later become dominant in the Carnian first appear in the upper part of this zone, i.e. *Camerosporites secatus, Duplicisporites granulatus, Lunatisporites acutus* and *Paracirculina scurrilis.*

Iraq

Al-Ameri (1990) described a microflora from Borehole 5/8, Western Desert, Iraq, for which he proposed an Anisian-Ladinian Age. Most of the taxa reported by Al-Ameri have been found in the *Aratrisporites saturnii* Zone and he listed no typical Ladinian taxa.

The Alpine and the Mediterranean Triassic

The Middle Triassic stages and substages have been defined in the Alps. Early Triassic microfloras from Israel and Jordan still show a mixture of Euramerian and Gondwana elements, but from the Middle Triassic onwards they are completely Euramerian (Eshet 1990; this study). Systematic studies of the Alpine Triassic have been published by: Brugman (1986): Scythian-Anisian); Van der Eem (1983): Ladinian-lower Carnian; Scheuring (1978): Upper Ladinian-lower Carnian. Ranges of selected palynomorphs in the Alpine Triassic of Europe were published by Visscher and Brugman (1981).

Brugman (1986), who applied the phase concept introduced by Schuurman (1977) and improved by Van der Zwan (1980), recognized nine phases for the Anisian and Ladinian of the Vicentinian Alps (northern Italy) and the Transdanubian Central Range (Hungary). The Anisian comprises four phases; the assemblages from these phases are very similar to those from Jordan. The occurrence of *Aratrisporites* spp., and *Uvaesporites* sp. and the first appearance of *Kuglerina meieri* enables a correlation of the *Aratrisporites saturnii* Zone with Brugman's *crassa-thiergartii* and *vicentinense-scheuringii* phases which are dated as late Pelsonian-Illyrian (see also Van der Eem 1983, p. 237-242).

In the classical succession in the western Dolomites, Italy, Van der Eem (1983) recognized seven phases covering the Illyrian to the Julian. The assemblages described by Van der Eem are very similar to those from Jordan, although *Aratrisporites* is more dominant in the latter region. The *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone comprises Van der Eem's *plurianulatus-novimundanus* to *secatus-vigens* phase (Fassanian-Langobardian). The last appearance of *Angustisulcites* and *Uvaesporites* marks the top of the *plurianulatus-secatus* phase (Fassanian) and the first appearance of *Camerosporites secatus* and *Heliosaccus dimorphus* the base of *seccatus-dimorphus* phase (Langobardian), whereas *Enzonalasporites vigens* first appears in the top of this latter phase.

Langobardian and earliest Cordevolian microfloras from the Meride Limestone, Monte San Giorgio, Tessin, Switzerland (Scheuring, 1978) contain many forms that have also been found in the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone in Jordan, e.g. *Echinitosporites iliacoides, Eucommiidites microgranulatus Kuglerina meieri, Lunatisporites acutus, L. noviaulensis, Podosporites amicus, Triadispora suspecta, T, sulcata, T. plicata, T.* sp. and *Vitreisporites pallidus*. With the first appearance of taxa that will become dominant in the Carnian (e.g., *Duplicisporites* spp., *Camerosporites* spp. and *Patinasporites densus*), most of the typical Anisian elements (e.g., *Aratrisporites* spp., *Platysaccus* spp., *Alisporites* sp. and *Voltziaceaesporites heteromorphus*) disappear, like in Jordan.

Microfloras from the south-eastern Dolomites were correlated with Van der Eem's *secatus-dimorphus* and *secatus-vigens* phases (Blendinger, 1988). In addition to Van der Eem (1983), Blendinger (1988) listed several other taxa from Langobardian, which are all common in Jordan.

The Germanic Basin

Although several classical palynological studies (e.g., Klaus, 1964, Mädler, 1964, Schulz, 1966) have been carried out in the Germanic Basin, correlations of the Germanic Triassic with the marine standard stages have been problematic for a long time and most older publications refer to the stratigraphic subdivision of the Germanic Triassic. It was indeed by means of palynology that firm correlations for parts of the German Triassic could be established in the 1980s and 1990s (e.g. Brugman, 1986, Van Bergen and Kerp, 1990, Visscher *et al.*, 1993, Brugman *et al.*, 1994), however, a general zonation and correlation scheme is not available yet.

Heunisch (1986) published a detailed study on the lower Keuper in Franconia. The assemblages were correlated with Van der Eem's (1983) *secatus-dimorphus* phase and dated as Langobardian. Some typical forms are *Angustisulcites klausii, Aratrisporites fimbriatus, A. paenulatus, A. parvispinosus, A. saturnii, Camerosporites secatus, Duplicisporites granulatus, Enzonalasporites vigens, Heliosaccus dimorphus, Keuperosporites granulatus, Lunatisporites acutus, L. noviaulensis, Ovalipollis pseudoalatus, Partitisporites novimundanus, Staurosaccites quadrifidus, Triadispora crassa, T. plicata* and *Uvaesporites gadensis*. A largely similar microflora with *Echinitosporites iliacoides* and *Heliosaccus dimorphus*, was published from the Lower Keuper of Bedheim, Thuringia, Germany (Bittniok and Mohr, 2002), however, these authors refrained from an age assessment according to the marine standard zonation.

The assemblages from the Lettenkeuper of the Obernsees well, Franconia, Germany (Brugman *et al*., 1994), which were assigned to the *perforatus-dimorphus* phase and the *dimorphus-iliacoides* phase (Langobardian), are very similar to those from the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone in Jordan. Present in both are: *Aratrisporites saturnii*, *A.* spp., *Cyclotriletes* spp., *Echinitosporites iliacoides, Eucommiidites microgranulatus, Heliosaccus dimorphus, Keuperisporites baculatus, Lunatisporites* spp., *Podosporites amicus*, *Punctatisporites* spp., *Staurosaccites quadrifidus, Triadispora crassa*, *T. plicata*, *T. suspecta*, and *Verrucosisporites* spp.

One of the most detailed palynological studies was published by Scheuring (1970) on the Keuper of the Bölchentunnel, c. 25 km SE of Basel, Switzerland. The 162.5 m thick succession starts with Lettenkohle and includes Gipskeuper up to the "Bunte Mergel". Scheuring distinguished six zones (A-F). The lower two zones A and B have been dated as late Ladinian (see also Mostler and Scheuring, 1974, Heunisch, 1986). The Ladinian-Carnian boundary lies in the lowermost Gipskeuper; this boundary is marked by the first appearance of the Circumpolles group and *Infernopollenites*. Zone A is characterized by a dominance of *Triadispora*, whereas *Striatoabieites aytugii* is common. Other, usually rare, elements are *Echinitosporites iliacoides, Lunatisporites* and *Ovalipollis*. The microflora of Zone B is very similar but is characterized by the appearance of *Eucommiidites microgranulatus* and *Podosporites amicus*. The microfloras of the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone in Jordan are well comparable to those of Scheuring's zones A and B, except for the fact that *Aratrisporites* seems to be completely absent in Scheuring's samples. *Aratrisporites* was produced by lycopsids, probably pioneer plants in humid environments; the dominance of *Triadispora* in Scheuring' material suggests the existence of a drier gymnosperm flora. If present, *Aratrisporites* often dominates the assemblages.

The Arctic

The microflora of the Svalis-7 Zone from the Central Barents Sea (Vigran *et al*., 1998) has been dated as late Anisian. Abundant are *Aratrisporites* spp., *Lunatisporites* spp. and *Striatoabieites* spp. together with acritarchs. Taxa occurring in the *Aratrisporites saturnii* Zone and in the Svalis 7 Zone are *Alisporites grauvogelii*, *Alisporites* spp., *Angustisulcites klausii, Aratrisporites* spp., *Lunatisporites acutus*, *L. noviaulensis*, *L. pellucidus*, *L.* sp., *Osmundacidites* sp., *Todisporites* sp., *Triadispora crassa, T. plicata, T.* spp., *Verrucosisporites remyanus, Veryhachium* spp. and *Voltziaceaesporites heteromorphus.* The abundance of acritarchs in the Barents Sea assemblages reflects the more marine environment; in Jordan sediments were deposited in a coastal to shallow marine depositional environment and therefore acritarchs are very rare. The top of the Barents Sea succession is formed by the Svalis 8 Zone which has been dated as Ladinian. The base of Svalis 8 is defined by the first appearances of *Ovalipollis pseudoalatus* and *Echinitosporites iliacoides*. The microfloras of Svalis 8 also contain also *Alisporites microreticulatus, Angustisulcites klausii, Aratrisporites parvispinosus, Cyclotriletes microgranulatus, Eucommiidites microgranulatus, Lunatisporites acutus, L. noviaulensis, L. pellucidus, Podocarpidites* sp., *Podosporites amicus, Staurosaccites quadrifidus, Triadispora crassa and Vitreisporites pallidus.* All these taxa have also been recorded from the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone in Jordan.

It should be noted that ranges for individual taxa given by Fisher (1979) for Middle Triassic microfloras from the Canadian Arctic seem to differ from in the Middle East.

Microfloras are very similar but individual species seem to appear one stage later in Israel as has been noted by Eshet (1983) and in Jordan.

5.g. The Upper Triassic

The Patinasporites densus Zone

The clear palynological composition in this stratigraphical level, allow recognition of distinct assemblage zone. This zone named after its major component and worldwide Carnian marker species *Patinasporites densus*. To a certain extant the base of this zone is difficult to defined accurately, hence many of its significant palynomorphs initiated in the lower Zone, however, it could be tentatively evaluated depending on the clear change of the incoming up ward palynomorphs, and the disappearance of some others, i.e. the disaccate palynomorphs (*Lunatisporites*, *Triadispora* and *Alisporites*) and the *Aratrisporites* diminished in this zone, while its replaced by other palynomorphs, i.e. *Circumpolles* subturma (*Paracirculina*, *Duplicisporites* and *Camerosporites*), moreover this section is dated by many author as Carnian, (see chapter two). The top of this zone is truncated by the Triassic-Jurassic unconformity which documented in the field, furthermore, the palynological record did not indicate younger than Middle Carnian age to this section .

Samples: This zone comprises in the Wadi Naur area the entire 62 m of Um Tina Formation, and the complete (42 m) of Abu Ruweis Formation in the lower area of Zarqa River, ca. 30 km North of Naur. In total 25 samples have been processed; four samples from the Um Tina Formation and seven samples from Abu Ruweis Formation appeared to be productive. Samples location are presented in Fig. 17

Index 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.*

Additional taxa: *Chasmatosporites apertus, Convolutispora microrugulata, Deltoidospora toralis, Heliosporites reissingeri, Matoni-sporites equiexinus, Pityosporites, Triadispora crassa, Paracircullina* sp., *Camerosporites* sp., *Microcachryidites sittleri, Minutosaccus* sp., *Partitisporites novimundanus, Sella-*

spora rugoverrucata, Semiretisporites gothae, Tigrisporites cf. *halleinis, Trachysporites* cf. *sparsus, Triadispora suspecta* and *Vesicaspora fuscus.*

Composition: Associations from this zone are less diverse than those from the Middle Triassic. The material is less well preserved; the sediments were deposited in a saline environment. The Circumpolles group is dominant. The *Patinasporites densus* Zone can be clearly distinguished from the *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone; the typical Middle Triassic generea *Aratrisporites* and *Triadispora* have disappeared, as well as many bisaccate forms. The assemblages of the *Patinasporites densus* Zone are well comparable to other Carnian microfloras, especially from Laurasia. However, *Samaropollenites speciosus* has originally been described from the Southern Hemisphere. The presence of this form has special phytogeographic implications which are briefly discussed below under "The Onslow Microflora".

Age: As will be discussed below a late Cordevolian-Julian (latest early Carnian-middle Carnian) Age can be attributed to the *Patinasporites densus* Zone.

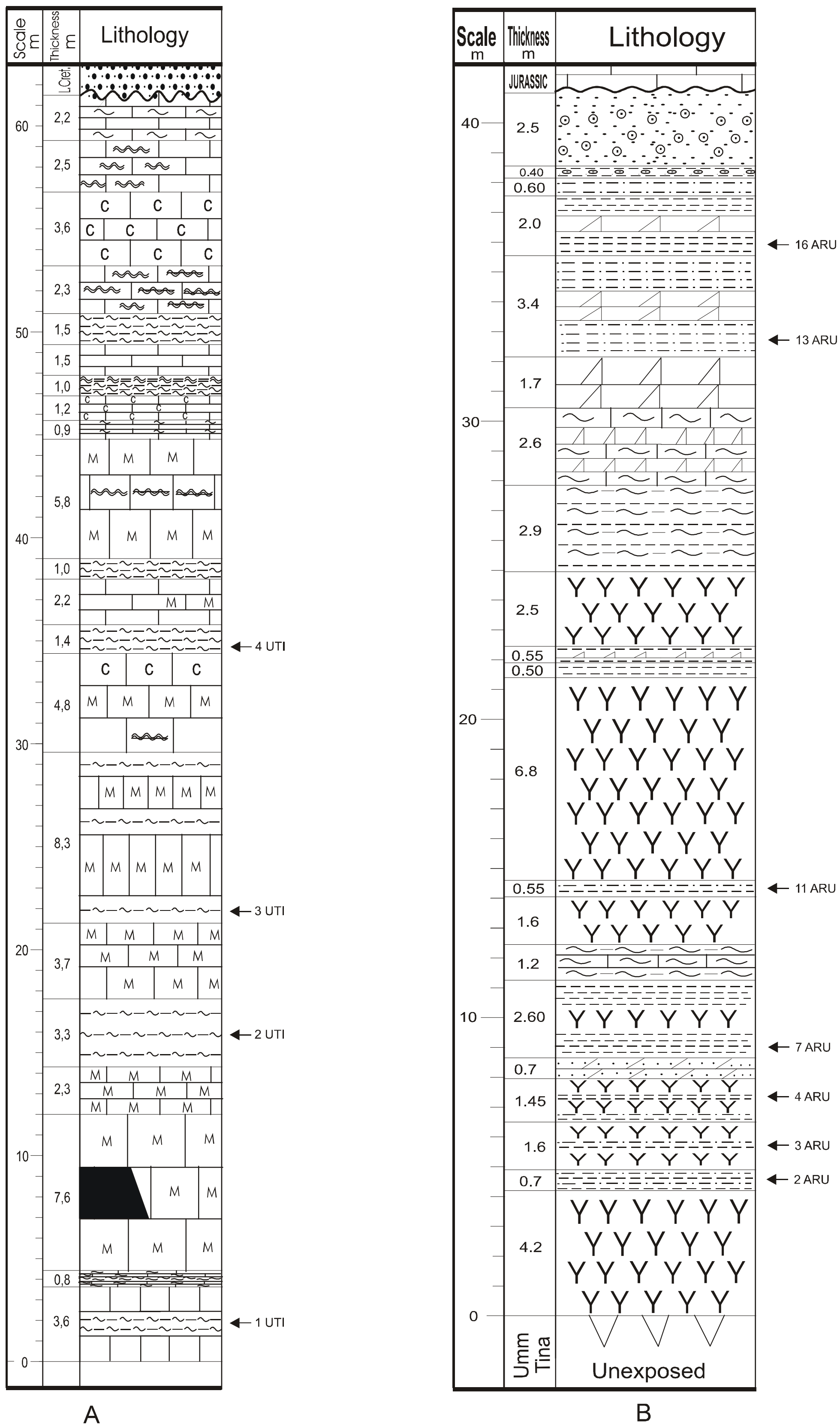

Fig.(17): Samples location of the *Patinasporites densus* Zone.
A-Um Tina Formation. B-Abu Ruweis Formation.

Comparisons and correlations

The following comparisons and correlations concentrate on well-dated microfloras, particularly from the Middle East, Europe, North America and the Arctic; for comparisons with Onslow Microfloras (including North Africa and southern Spain) refer to are Table 6.

Israel

Several studies have dealt with Upper Triassic microfloras of Israel, (e.g. Horowitz 1973, Eshet 1983, 1990; Eshet and Cousminer 1986). The zonation of Eshet (1990) will here be used as a reference, because this is the most recent zonation scheme in which results of previous studies are summarized.

Eshet (1990) presented a correlation of 11 deep wells, using the Maktesh Qatan 2 Well, Negev, as a reference section. Although he previously had recognized two zones for the Carnian (Eshet 1983), in 1990 only a single zone is distinguished, the *Patinasporites densus* Zone which is dated as Carnian. This evapotitic interval has, apart form palynomorphs, yielded only few fossils. However, the conodont *Metapolygnatus polygnathiformis* clearly indicates a Carnian Age. The microfloral composition of Eshet's (1990) *Patinasporites densus* Zone is almost identical to that of the *Patinasporites densus* Zone. The assemblages are dominated by pollen of the Circumpolles group. The following taxa which have also been reported from Jordan have been recognized in Israel: *Camerosporites secatus*, *Convolutispora* sp., *Corollina torosa, Corollina* sp., *Duplicisporites granulatus, Duplicisporites* sp., *Enzonalasporites vigens, Infernopollenites salcatus*, *Lunatisporites acutus*, *Matonisporites equiexinus*, *Minutosaccus* sp., *Ovalipollis ovalis, Paracirculina scurrilis*, *Patinasporites densus, Pityosporites* spp., *Pseudenzonalasporites summus, Striatoabieites aytugii, Triadispora suspecta*, *Triadispora* spp. and *Verrucosisporites* sp.

Cirilli and Eshet (1991) reported "Onslow Microflora" with *Samaropollenites speciosus* and *Staurosaccites quadrifidus* from the Lower Carnian of the Makhtesh Qatan 2 Well.

The Alpine Upper Triassic

Several classical studies have been carried out in the Alpine Upper Triassic, e.g., by Klaus (1960, 1964), Bharadwaj and Singh (1964), Kavary (1966, 1972), Corna (1969), Kullmanova *et al.* (1969), Praehauser-Enzenberg (1970), Planderova (1972) and Mostler and Scheuring (1974). Most authors, ecxept for Klaus, Kavary and Kullmanova *et al.*, concentrated on the taxonomy. The first stratigraphic survey was published by Dunay and Fischer (1978), however, this study was based on just a few samples. Van der Eem (1983) gave a zonation which comprises the lower and lower part of the middle Carnian. Although some of the very early palynological studies were carried out in the Alpine Carnian, a comprehensive zonation of the Alpine Carnian is still not available yet.

Many of the taxa listed by Dunay and Fisher (1978) have also been found in the *Patinasporites densus* Zone in Jordan, i.e. *Camerosporites secatus*, *Duplicisporites granulatus*, *Enzonalasporites vigens*, *Infernopollenites* sp., *Lunatisporites acutus*, *Ovalipollis ovalis*, *Paracirculina scurrilis*, *Patinasporites densus Pityosporites neomundanus*, *Paracirculina granifer*, *Striatoabieites aytugii* and *Triadispora* spp.

The *Patinasporites densus* Zone can be correlated with the *densus-maljavkinae* phase (late Cordevolian), which was established in the Western Dolomites.

Blendinger (1988) characterized each of the three substages of the Carnian in the Eastern Dolomites palynologically. The assemblages from the upper Cordevolian and Julian are comparable to those of the *Partitisporites densus* Zone. Characteristic taxa include *Camerosporites secatus*, *Convolutispora* spp., *Duplicisporites granulatus*, *D. verrucosus*, *Enzonalasporites vigens*, *Infernopollenites* sp., *Ovalipollis* sp., *Paracirculina scurrilis*, *Patinasporites densus*, *Pseudenzonalasporites summus* and *Striatoabieites* sp.

The Germanic Basin

Several classical studies have been carried out in the Upper Triassic of the Germanic Basin, e.g., Leschik (1955), Klaus (1960), Mädler (1964), Schulz (1965) and Geiger and Hopping (1968). Comparisons concentrate on Scheuring (1970) because this is the most detailed study for the Carnian in the Germanic Triassic which is currently available. The base of the Carnian is correlated with the base of Zone C. The Ladinian-Carnian boundary lies in the lowermost Gipskeuper; this boundary is marked by the first appearance of the Circumpolles group and *Infernopollenites*. In the uppermost part of Zone C (= C’) *Echinitosporites iliacoides* disappears, *Triadisopora* becomes less frequent, and *Ovalipollis* and the Circumpolles group become more abundant. The top of Zone C is characterized by the disappearance of *Triadispora suspecta*, *Podosporites amicus* and *Retisulcites perforatus*. The Middle part of the Gipskeuper is assigned to Zone D contains an impoverished microflora. Zone E is essentially similar to Zone D, and its base is marked by the last appearance of the *Eucommiidites microgranulatus.* Zone F is characterized by the first appearance of *Triadispora verrucata*, *Patinasporites densus* and (slightly below) *Paracirculina quadruplices*. The top of Zone F is marked by the disappearance of *Lunatisporites acutus.* Since *Lunatisporites acutus* is still present in the highest productive samples below the unconformity at the base of the Jurassic, it must be concluded that the upper Carnian, Norian and Rhaethian are missing.

6. CONCLUSIONS

The here described Wadi Himara locality represents the earliest and most northern occurrence of a genus that apparently originated during the Late Permian and survived the Permian-Triassic biotic crises. Although no megafloral data were previously available, the pollen record already suggested that *Dicroidium* may have occurred already in the Late Permian. The pollen attributed to *Dicroidium* has been described as *Falcisporites* (Balme, 1995), a taxon that first appeared in the Upper Permian and was originally described from the German Zechstein (Leschik, 1956). The high abundance of *Falcisporites* in the Late Permian Wadi Himara palynoflora is not surprising because these grains were produced by *Dicroidium*, the dominant floral element in this hypautochthonous megaflora. The range of *Dicroidium*, which is traditionally regarded as a typical Triassic genus, can now be extended into the Permian. This is the first unequivocal record of the Corystospermales. Five species of *Dicroidium* are known from the Upper Permian of Jordan. Therefore, it may be assumed that the Corystospermales have developed earlier than is commonly thought.

The geographical distribution of *Dicroidium* was not restricted to Gondwana. The genus apparently evolved in the palaeotropics. With the climatic amelioration in the Early Triassic (e.g., Kidder and Worsley 2004) the genus migrated southward and finally colonized the entire Gondwana region, where in the Middle and Late Triassic, it became one of the dominating floral elements. The early representatives of *Dicrodium* grew in hot and humid basinal environments. This is in contrast to the common belief that evolutionary innovations, especially within the gymnosperms, primarily occurred in extrabasinal environments. During the Triassic the genus adapted to drier habitats. Also peltasperms originated in the tropics (*Autunia* and *Peltaspermum*: Late Carboniferous-Permian: Kerp, 1988) and migrated southward during the Early Triassic (*Lepidopteris callipteroides*: Retallack, 2002).

Based on the charcoal investigated in this work, most remain are identified as *Dadoxylon*-type gymnosperm wood. From the occurrence of the charcoal in the Late Permian Um Irna Formation it can be stated that the source-vegetation must have experienced fires in dry conditions.*From this, it could be assume, that the Late Permian palaeoflora growing during the deposition of the Um Irna Formation may have experienced more or less dry conditions at least during some time of the year. Up to now there is no direct palaeobotanical evidence, like growth rings, for such a seasonallity.* On the other hand such an interpretation is in full agreement with sedimentological data for the Um Irna Formation, which indicate a low latitude tropical savannah climate, with alternating wet and dry seasons (Bandel and Khoury 1981, Makhlouf *et al.* 1991). These interpretations are corroborated by the results of climate modelling, which predicted a monsoonal climate in Arabia during the Late Permian, with summer precipitation. Such a climate would favour the establishment of a warm and seasonally humid savannah climate with a more or less marked dry-season Fluteau *et al.* (2001). However, the lack of growth rings in the specimens investigated from Wadi Himara, does not indicate that there were no such seasonal changes (Schweitzer 1962, 1986).

Nevertheless, the lack of growth rings in all specimens investigated, may point to the fact that the source plants grew under favourable conditions, well within the limits of their climatic and environmental tolerance. This may reflect very local conditions with enough moisture near the abandoned channels during all the year, in contrast to the regional climate which has been reconstructed as a low latitude tropical savannah climate, with alternating wet and dry seasons Bandel and Khoury (1981), Makhlouf *et al.* (1991), Fluteau *et al.* (2001).

Palynologically, based on the analysis of 98 palynological samples comprises the Permo-Triassic expousers in Jordan , five assemblage zones were recognized (Fig.18). The zones defined are characterized by a combination of index taxa, rather than by a single taxon.These zones was compared with other parts of the Middle East and other relevant regions where good zonations have been established are made.
These zones are in ascending stratigraphic order:

- *Lueckisporites virkkiae* Zone (Late Permian)
  This zone is restricted to the entire 67 m Um Irna Formation. The microfloral assemblages of this zone can be compared with assemblages from the Upper

Permian of Israel, Saudi Arabia, Oman, Iraq, Africa, India, Pakistan, European Zechstein, Alps and Mediterranean. Fig. 19.

- *Endosporites papillatus-Veryhachium* spp. Zone (Smithian/early Olenekian; Scythian).
  This zone coprises the entire nearly 206 m thick Lower Triassic sequence underlaying the Hisban Formation (Anisian). It includes the Ma'in Formation (47 m), the Dardur Formation (59 m) and the Ain Musa Formation (100 m).
  Inspite of the less palynological data worldwide, this zone is correlatable to assemblages reported in Israel, Australia, India, Pakistan, Africa, Germanic Basin, Artic and Canada. Fig. 20.

- *Aratrisporites saturnii* Zone (late Pelsonian-Illyrian ; late Anisian).
  The zone comprises the well dated Middle Triassic (Anisian) Hisban Formation (30 m) and the Mukheiris Formation (76m).

- *Echinitosporites iliacoides-Eucommiidites microgranulatus* Zone (Langobardian; late Ladinian)
  This zone is restricted to the entire 95m of the I raq al Amir Formation. This Formation dated as Ladinian based on conodonts (Bandel & Waksmundzki 1985) and (Sadeddin 1990).
  The Anisian-Ladinian palynomorphs from Jordan are well comparable to those from Israel, Iraq, Alps, Mediterranean, Germanic Basin, Artic and Onslow Microfloras. Figs. 21, 22. The typical Gondwana elements which were well represent in the Upper Permian and Lower Triassic are disappeared in the Middle – Upper Triassic.

- *Patinasporites densus* Zone (late Cordevolian-Julian; late early Carnian-middle Carnian)
  This zone comprises the entire 62 m of Um Tina Formation and the 42 m of the Abu Ruweis Formation. The assemblages of this zone are well comparable to other Carnian microfloras, especially from Lurasia. Comparisons and correlation concentrated on well-dated microfloras, particularly, Middle East and Europe. Fig. 23.
  Based on the macro-microfloras identified in this work the Permo-Triassic exposed sequence could be dated as its shown in Fig. 24.

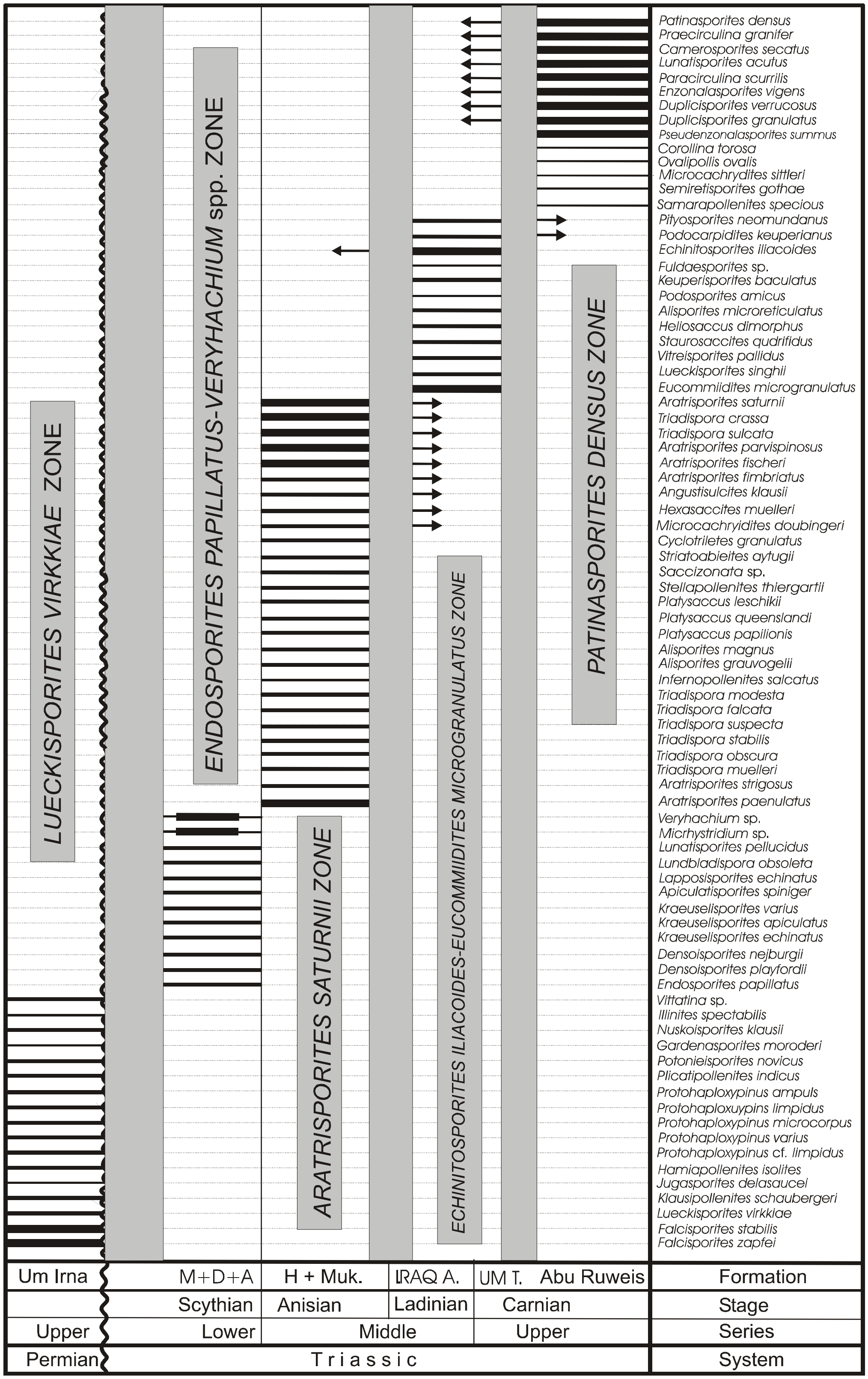

Fig. (18): Range chart of selected Permo-Triassic palynomorphs in Jordan. M= Ma'in Formation, D=Dardur For., A= Ain Musa For., H= Hisban For., Muk=Mukheiris For., UMT= Um Tina For.

12	11	10	9	8	7	6	5	4	3	2	1	Author
China	North America	Artic	Alps & N. Mediterr.	European Zechstein	Africa	North Africa	Australia	India & Pakistan	Iraq	S. Arabia & Oman	Israel	Region / Palynomorphs
●	●	●	●	●	●			●			●	*Vittatina* spp.
			●		●							*Illinites tectus*
			●	●	●				●		●	*Nuskoisporites klausii*
											●	*Gardenasporites moroderi*
					●				●		●	*Potonieisporites novicus*
					●			●			●	*Plicatipollenites indicus*
							●					*Protohaploxypinus amplus*
					●		●	●			●	*Protohaploxypinus limpidus*
			●	●	●		●	●		●	●	*Protohaploxypinus microcorpus*
		●			●			●			●	*Protohaploxypinus varius*
					●			●			●	*Hamiapollenites insolitus*
			●	●								*Jugasporites delasaucei*
●	●	●	●		●	●		●		●	●	*Klausipollenites schaubergeri*
●		●	●	●	●	●		●	●	●	●	*Lueckisporites virkkiae*
					●			●			●	*Falcisporites nuthallensis*
			●					●			●	*Falcisporites stabilis*
			●	●	●	●		●			●	*Falcisporites zapfei*
							●		●		●	*Striatopodocarpites fusus*
3	2	4	9	6	13	3	4	11	4	3	15	Total

Fig. (19): Regional distribution of selected Upper Permian palynomorphs based on :1-Eshet & Cousminer 1986 and Eshet 1990. 2-Stephenson & Filatoff 2000 and Stephenson *et al.* 2003. 3-Singh 1964. 4-Bharadwaj & Tiwari 1977,Srivastava *et al.* 1997, Ram-Awatar 1997, Kumar 1997, Tripathi 2001 and Balme 1970. 5-Foster 1982. 6-Kilani-Mazraoui *et al.* 1999. 7-Jardinie 1974, Broutin *et al.*1990 and Hankel 1992. 8-see the text. 9-Klaus 1963, Massari *et al.* 1994,Visscher *et al.* 1974, Doubinger *et al.* 1990 and Broutin *et al.* 1992. 10-Mangerud 1994. 11-Wilson 1962. 12-Qu 1980, Ouyang & Wang 1983, Ouang 1986 and Ouyang & Utting 1990.

9	8	7	6	5	4	3	2	1	Author
China	The Artic and Canada	The Germanic Basin	Eastern Africa	North Africa	Pakistan	India	Australia	Israel	Region / Palynomorphs
	●	●		●	●			●	*Veryhachium* sp.
	●	●	●	●	●			●	*Micrhystridium* sp.
	●				●	●	●	●	*Lunatisporites pellucidus*
	●				●		●		*Lundbladispora obsoleta*
	●	●			●	●	●	●	*Aratrisporites* sp.
								●	*Apiculatisporites spiniger*
						●	●	●	*Falcisporites stabilis*
	●			●				●	*Kraeuselisporites apiculatus*
		●	●				●	●	*Lunatisporites noviaulensis*
	●	●		●	●			●	*Densoisporites nejburgii*
	●	●	●	●	●	●	●	●	*Densoisporites playfordii*
●	●	●		●				●	*Endosporites papillatus*
1	9	7	3	6	7	4	6	11	Total

Fig. (20): Regional distribution of selected Lower Triassic palynomorphs based on:1-Eshet & Cousminer 1986 and Eshet 1990. 2-Balme 1963, Dolby & Balme 1976, De Jersy 1979 and Foster 1982. 3-Bharadwaj & Tiwari 1977 and Prasad 1997. 4-Balme 1970. 5-Adloff *et al.* 1986 and Kilani-Mazraoui *et al*. 1990. 6-Hankel 1992. 7-Visscher 1971, Schultz 1965, Reinhardt & Schön 1967, Orlowska-Zwolinska 1977 and Fijalkowska 1994. 8- Vigran & Mangerud 1991, Mangerud 1994, Vigran *et al.* 1998, Fiscer 1979 and Utting 1989. 9- Ouyang & Utting 1990.

5 Arctic	4 Germanic Basin	3 Alpine & Mediterranean	2 Iraq	1 Israel	Author / Region / Palynomorphs
●	●			●	*Alisporites grauvogellii*
				●	*Alisporites magnus*
●	●	●	●	●	*Triadispora crassa*
	●			●	*Aratrisporites fimbriatus*
	●			●	*Aratrisporites saturnii*
	●		●	●	*Aratrisporites paenulatus*
●		●		●	*Angustisulcites klausii*
	●			●	*Microcachryidites daubingeri*
	●			●	*Brachysaccus ovalis*
●	●	●		●	*Voltziaceaesporites heteromorphus*
				●	*Sellaspora rugoverrucata*
		●			*Stellapollenites thiergartii*
	●	●			*Uvaesporites gadensis*
		●		●	*Kuglerina meieri*
4	9	6	2	12	Total

Fig. (21): Regional distribution of selected Middle Triassic (Anisian) palynomorphs based on: 1-Eshet 1990. 2-Al-Ameri 1990. 3- Van der Eem 1983, Brugman 1986. 4- Klaus 1960,64. Mädler 1964. Heunisch 1986 and Brugman *et al.* 1994. 5- Vigran *et al*. 1998.

5 Arctic	4 Germanic Basin	3 Alpine & Mediterranean	2 Iraq	1 Israel	Author / Region / Palynomorms
		●		●	*Podocarpidites keuperianus*
●	●	●		●	*Podosporites amicus*
	●	●		●	*Heliosaccus dimorphus*
●		●	●	●	*Vitreisporites pallidus*
●	●	●			*Staurosaccites qudrifidus*
	●				*Pityosporites neomundanus*
	●	●		●	*Keuperisporites baculatus*
		●		●	*Lueckisporites singhii*
		●		●	*Triadispora sulcata*
●	●	●		●	*Echinitosporites iliacoides*
●	●	●		●	*Eucommiidites microgranulatus*
5	7	10	1	9	Total

Fig. (22): Regional distribution of selected Middle Triassic (Ladinian) palynomorphs based on: 1-Eshet 1990. 2-Al-Ameri 1990. 3-Scheuring 1978, Van der Eem 1983, Blendinger 1988, Brugman *et al.* 1994, Bittniok and Mohr 2002. 4-Scheuring 1970, Heunisch 1986, Brugman *et al.* 1994, Bittnoik and Mohr 2002. 5-Vigran *et al.* 1998.

3	2	1	Author
Germanic Basin	Alpian Upper Triassic	Israel	Region / Palynomorphs
●	●	●	*Patinasporites densus*
●	●	●	*Praecirculina granifer*
●	●	●	*Camerosporites sucatus*
●	●	●	*Lunatisporites acutus*
●	●	●	*Paracirculina scurrilis*
●	●	●	*Enzonalasporites vigens*
●			*Duplicisporites verrucosus*
●	●	●	*Duplicisporites granulatus*
●	●	●	*Ovalipollis ovalis*
●		●	*Pseudenzonalasporites summus*
●	●	●	*Striatoabieites aytugii*
11	9	10	Total

Fig. (23): Regional distribution of selected Upper Triassic (Carnian) palynomorphs based on :1- Eshet 1990. 2- Dunay & Fisher 1978 and Blendinger 1988. 3- Scheuring 1970.

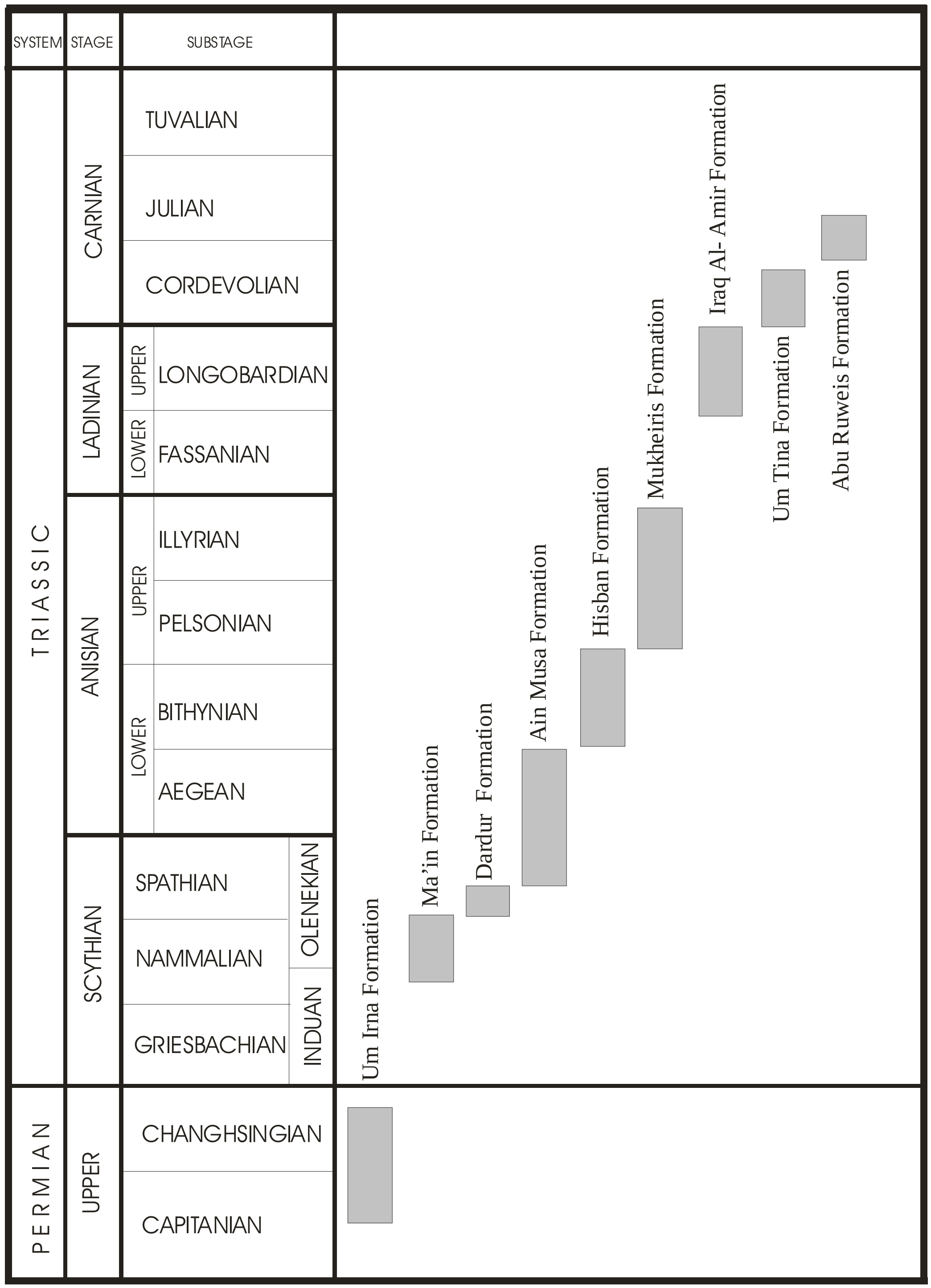

Fig. (24): Chronostratigraphic ranges of the Permo-Triassic rocks croping out in Jordan, based on the present palynological study.

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Appendix 1-19

Appendix (1): Alphabatic listing of all palynomorphs identified

Acanthotriletes tereteangulatus Balme and Hennelly 1956
Alisporites magnus Jain 1968
Alisporites progrediens Klaus 1964
Alisporites grauvogelii Klaus 1964
Alisporites microretculatus Reinhardt 1964
Alisporites sp..Daugherty 1941 emend. Jansonius 1971
Alisporites townrorii Helby 1966
Anapiculatisporites sp. Potonie and Kremp 1954
Anapiculatisporites spiniger (Leschik 1956a) Reinhardt 1961
Anaplanisporites stipulates Jansonius 1962
Angustisulcites klausii (Freudenthal 1964) emend. Visscher 1966
Apiculatisporites spiniger (Leschik 1955) Qu 1980
Aratrisporites fimbriatus (Klaus 1960) Mädler 1964
Aratrisporites paenulatus Playford and Dettmann 1965
Aratrisporites parvispinosus (Leschik 1955) emend. Playford 1965
Aratrisporites saturnii (Thiergardt 1949) emend. Mädler 1964a
Aratrisporites sp. .(Leschik 1955) emend. Playford and Dettmann 1965
Aratrisporites strigosus Playford and Dettmann 1965
Aratrisporites cf. *quadriiuga* Visscher 1966 emend
Aratrisporites fischeri (Klaus 1960) emend. Playford and Dettmann 1965
Aulisporites astigmosus Klaus 1960
Aulisporites sp.Leschik 1955
Brachysaccus ovalis Mädler 1964
Calamospora diversiformis Balme and Hennelly 1956
Calamospora sp. Schopf, Wilson and Bentall 1944
Camerosporites secatus Leschik 1955
Camerosporites sp. (Leschik 1956a) emend. Scheuring 1970
Camptotriletes sp.Potonie and Kremp 1954
Camptotriletes warchianus Balme 1970
Carnisporites cf. *mesozoicus* (Klaus 1960) emend. Mädler 1964
Cedripites sp.Wodehouse 1933
Chasmatosporites apertus (Rogalska 1954) emend. Nilsson 1958
Concavisporites sp. Pflug in Thomson and Pflug 1953
Concavisporites toralis (Leschik 1956a) emend. Nilsson 1958
Convolutispora microrugulata Schulz 1967
Convolutispora sp.Hoffmeister, Staplin and Malloy 1955
Cordaitina sp. (Samoilovich 1953) Hart 1963
Corollina sp. Malyavkina 1949 (Tetrad)
Corollina torosa (Reissiner 1950) Cornet and Traverse 1975
Crustaesporites globosus Leschik 1956
Crustaesporites sp. Leschik 1956
Cycadopites sp. (Woodhouse 1935) Wilson and Webster 1946
Cyclogranisporites arenosus Mädler 1964
Cyclogranisporites sp. Potonie and Kremp 1954
Cyclotriletes granulatus Mädler 1964
Cyclotriletes margaritatus Mädler 1964
Cyclotriletes microgranifer Mädler 1964
Cyclotriletes oligogranifer Mädler 1964

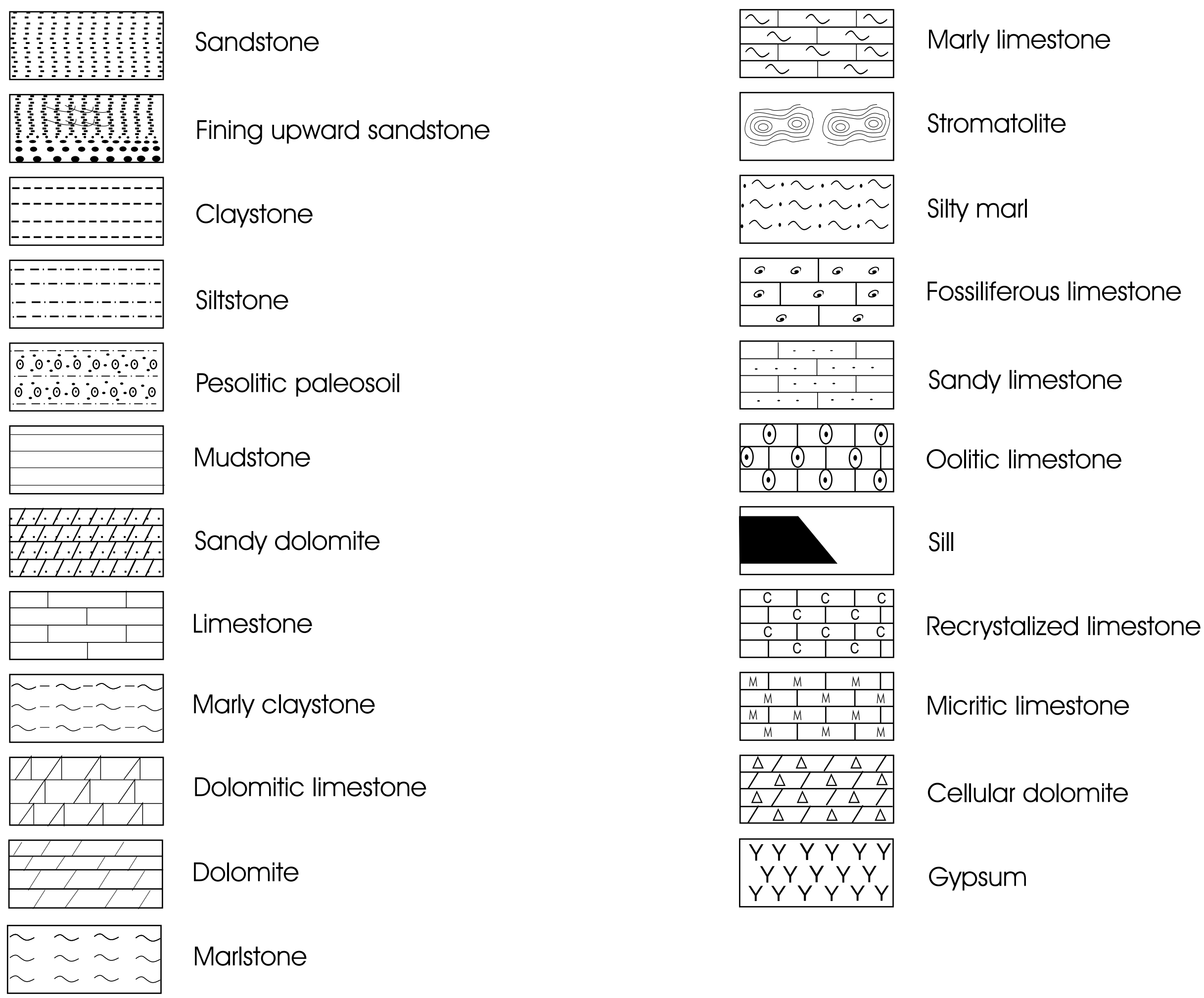
Cyclotriletes pustulatus Mädler 1964
Deltoidospora sp. (Miner 1935) Potonie 1956 c
Deltoidospora toralis (Lischik 1955) emend. : Lund 1977
Densoisporites nejburgii (Schulz 1964) Balme 1970
Densoisporites playfordii Balme 1963
Densoisporites sp.Weyland and Krieger 1953 emend. Dettmann 1963
Distriatites isolites Bharadwaj and Salujha 1964
Duplicisporites verrucosus Leschik 1956a
Duplicisporites . sp. (Leschik 1956a) emend. Scheuring 1970
Duplicisporites granulatus Leschik 1956a
Echinitosporites iliacoides Schulz and Krutzsch 1961
Endosporites papillatus Jansonius 1962
Enzonalasporites vigens Leschik 1956a
Eucommiidites microgranulatus Scheuring 1970
Falcisporites sp. Leschik 1956, emend. Klaus 1963
Falcisporites stabilis Balme 1970
Falcisporites zapfei Potonie and Klaus 1954
Falcisporites nuthalensis. (Clarke 1965) Balme 1970
Foraminifera remains
Foveotriletes sp. Balme 1957
Fuldaesporites sp. Leschik 1956
Gardenasporites moroderi Klaus 1963
Guthoerlisporites cancellosus Playford and Dettmann 1965
Guttatisporites cf. *elegans* Visscher 1966
Guttulapollenites hannonicus Goubin 1965
Hamiapollenites isolates Bharadwaj and Salujha 1964
Heliosaccus dimorphus Mädler 1964
Heliosporites reissingeri (Harris 1957) emend. Muir and Van Konijnenburg-Van Cittert 1970
Hexasaccites muelleri Reinhardt and Schmitz 1965
Horriditriletes brevis Bharadwaj and Salujha 1964
Illinites tectus (Leschik 1956) Clarke 1965
Illinites parvus Leschik 1956
Illinites spectabilis Leschik 1956
Inaperturopollenites nebulosus Balme 1970
Infernopollenites salcatus (Putsch 1958) Scheuring 1970
Jugasporites delasaucei (Potonie and Klaus) Leschik 1956
Keuperisporites baculatus Schulz 1965
Klausipollenites schaubergeri (Potonie and Klaus1954) Jansonius 1962
Kraeuselisporites apiculatus Jansonius 1962
Kraeuselisporites echinatus Reinhardt and Schön 1967
Kraeuselisporites sp. Leschik 1956, emend. Jansonius 1962
Kraeuselisporites varius Ouyang and Norris 1999
Kuglerina meieri Scheuring 1978
Laevigatosporites sp. Ibrahim 1933
Laevigatosporites vulgaris (Ibrahim 1932) Loose 1934
Lapposisporites echinatus Ouyang and Norris 1999
Leiosphaeridia sp. (Eisenack 1938) Dovnie, Evitt and Sarjeant 1963
Leiotriletes adnatus (Kosanke) Ptonie and Kremp 1955
Leiotriletes sp. (Naumova 1939) Potonie and Kremp 1954
Lueckisporites virkkiae Potonie and Klaus 1954
Lueckisporites singhii Balme 1970

Lunatisporites acutus Leschik 1955
Lunatisporites pellucidus (Goubin 1965) Balme 1970
Lunatisporites sp. Leschik 1955
Lunatisporites fuscus Bharadwaj and Salujha 1964
*Lunatisporites noviaulensis (*Leschik 1956) Foster 1979
Lundbladispora obsolete Balme 1970
Matonisporites equiexinus Couper 1958
Micrhystridium sp. (Deflandre 1937) Sarjeant 1967
Microcachryidites daubingeri Klaus 1964
Microcachryidites sittleri Klaus 1964
Microfoveolatispora sp. Bharadwaj 1962
Microreticulatisporites sp. (Knox) Potonie and Kremp 1954
Minutosaccus sp Mädler 1964
Monosulcites minimus (Cookson 1947) emend. Couper 1953
Nuskoisporites klausii Grebe 1957
Osmundacidites sp. Couper 1953
Ovalipollis ovalis Krutzsch 1955
Ovalipollis sp Krutzsch 1955
Paracirculina quadruplicis Scheuring 1970
Paracirculina scurrilis Scheuring 1970
Paracirculina sp.Klaus 1960
Partitisporites novimundanus Leschik 1956a
Patinasporites densus Leschik 1956a
Pinuspollenites thoracatus Balme 1970
Pityosporites neomundanus Leschik 1955
Pityosporites sp.Seward 1914
Platysaccus fimbriatus . (Naumova 1937) Potonie and Klaus 1954
Platysaccus leschikii Hart 1960
Platysaccus papilionis Potonie and Klaus 1954
Platysaccus queenslandi De Jersy 1962
Platysaccus reticulates Mädler 1964
Platysaccus sp. Potonie and Klaus 1954
Plicatipollenites indicus (Lele 1964) Srivastava 1970
Podocarpidites keuperianus (Mädler 1964a) Schuurman 1977
Podosporites amicus Scheuring 1970
Polypodiidites sp. Ross 1949
Polypodiisporites crassus Dolby and Balme 1975
Potonieisporites novices Bharadwaj 1954
Potonieisporites sp. Bharadwaj 1954
*Praecirculina granifer.*Klaus 1960
Protohaploxypinus amplus (Balme and Hennelly 1955) Hart 1964
Protohaploxypinus cf. *limpidus* (Balme and Hennelly 1955) Balme and Hennelly 1958
Protohaploxypinus limpidus (Balme and Hennelly 1955) Balme and Hennelly 1958
Protohaploxypinus microcorpus (Schaarschmidit 1963) Klarke 1965
Protohaploxypinus varius (Bharadwaj 1962) Balma 1970
Protohaploxypinus sp. (Schaarschmidit 1963) Klarke 1965
Pseudenzonalasporites summus Scheuring 1970
Punctatisporites crassexinis Mädler 1964
Punctatisporites fungosus Balme 1963
Punctatisporites gretensis Balme and Hennelly 1956
Punctatisporites minutes (Ibrahim 1933) Potonie and Kremp 1956

Punctatisporites uniformis (Ibrahim 1933) Tiwari 1968
Punctatisporites. sp. (Ibrahim 1933) Potonie and Kremp 1954
Reticulatisporites muricatus Kosanke 1950
Retitriletes sp. Pierce 1961
Retusotriletes sp. (Naumova 1953) emend. Streel 1964
Rimaesporites potoniei Leschik 1955
Rimaesporites sp. Leschik 1955
Saccizonati sp. Bharadwaj 1957
Samaropollenites specious Goubin 1965
Sellaspora rugoverrucata Van Der Eem 1983
Sellaspora sp. Van Der Eem 1983
Semiretisporites gothae Reinhardt 1961
Spinotriletes sp.Mädler 1964
Staurosaccites quadrifidus Dolby in Dolby and Balme 1976
Stellapollenites thiergartii(Mädler 1964) Clement-Westerhof et. al. 1974,emend. Brugman 1983
Stereisporites sp. Pflug in Thomson and Pflug 1953
Striatoabieites aytugii Visscher 1966
Striatoabieitites sp. (Sedova 1956) Hart 1964
Striatopodocarpites fusus (Balme and Hennelly) Potonie 1958
Striatopodocarpites sp. Zoricheva and Sedova 1954, Sedova 1956, emend. Hart 1964
Sulcatisporites cf. *kraeuselii* Mädler 1964
Tigrisporites cf. *halleinis* Klaus 1960
Todisporites marginales Bharadwaj and Singh 1964
Todisporites cinctus (Maljavkina 1949) Orlowska-Zwolinska 1971
Trachysporites cf. *sparsus* (Bharadwaj and Singh1964) emend. Lund 1977
Triadispora crassa .(Klaus 1964) sensu Brugman 1979
Triadispora falcata Klaus 1964
Triadispora modesta Scheuring 1970
Triadispora muelleri (Reinhardt and Schmitz 1965) Visscher 1966
Triadispora obscura Scheuring 1970
Triadispora stabilis Scheuring 1970
Triadispora suspecta Scheuring 1970
Triadispora sulcata Scheuring 1978
Triadispora sp. .(Klaus 1964) sensu Brugman 1979
Triplexisporites playfordii (De Jersey and Hamilton 1967) Foster 1979
Triplexisporites sp.De Jersey and Hamilton 1967
Triquitrites proratus Balme 1970
Tympanicysta stochiana Balme 1980
Uvaesporites gadensis Praehauser- Enzenberg 1970
Verrucosisporites jenensis Reinhardt and Schmitz 1965
Verrucosisporites krempii Mädler 1964
Verrucosisporites reinhardtii Visscher 1966.
Verrucosisporites remyanus Mädler 1964
Verrucosisporites sp.Ibrahim 1933 emend. Smith and Butterworth 1967
Verrucosisporites thuringiacus Mädler 1964
Veryhachium sp. (Deunff 1954) emend. Loebil and Tappan 1976
Vesicaspora fuscus (Pautsch 1958) emend Morbey 1975
Vestigisporites sp. (Balme and Hennelly 1955) emend. Hart 1960
Vitreisporites pallidus Reissinger 1938) emend. Nilsson 1958
Vittatina sp. (Luber 1941) Wilson 1962
Voltziaceaesporites heteromorphus Klaus 1964

Appendix (2)

Legend:

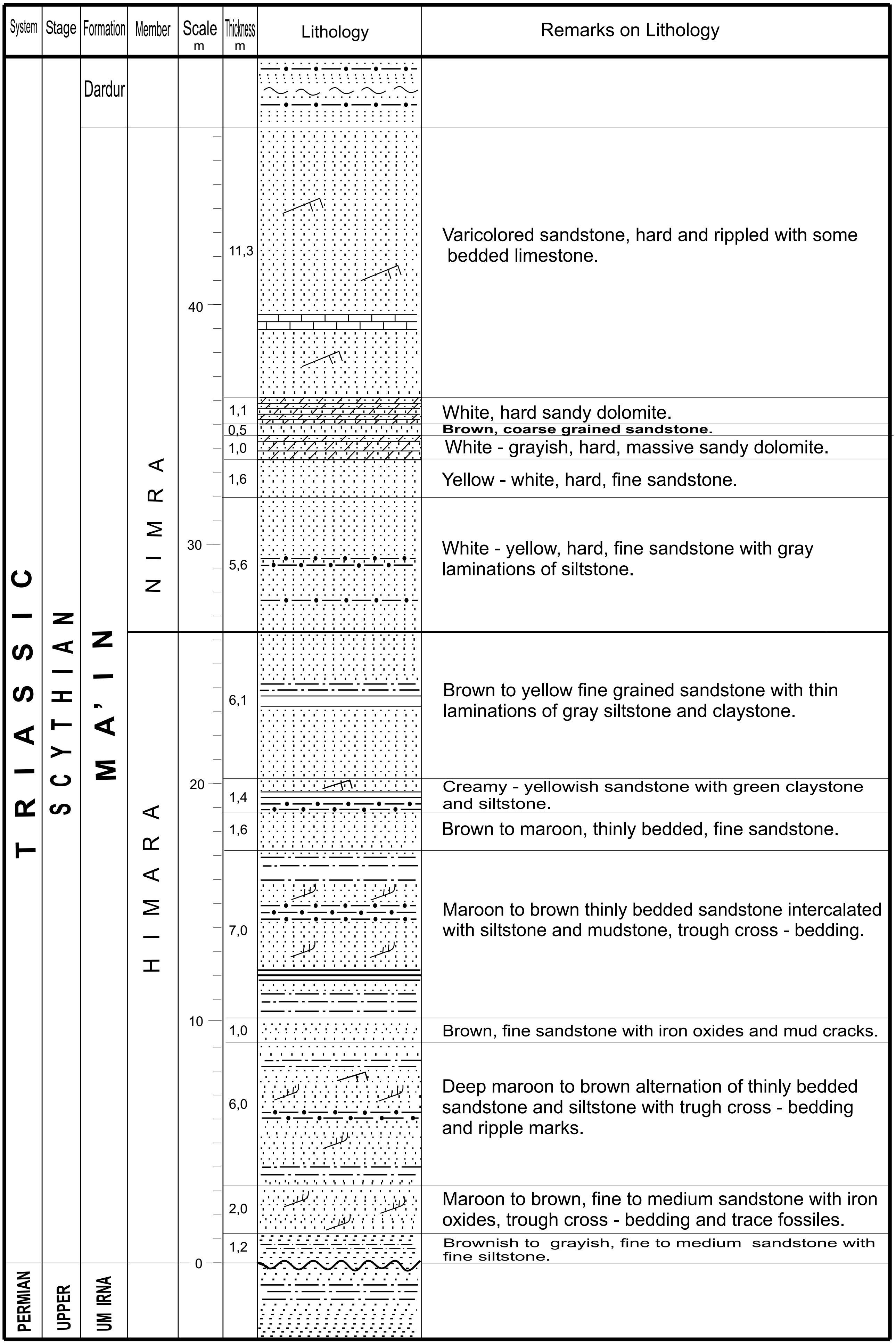


Appendix.(3)

System	Stage	Formation	Member	Scale (m)	Thickness (m)	Lithology	Remarks on Lithology
Triassic	Scythian	Ma'in	Himara				
PERMIAN	UPPER	UM IRNA		60	6.9		Vary coloured, mostly redish, pesolitic paleosoil intercalated with thin laminations of gray siltstone and claystone.
					1.7		Redish, hard, fine - medium, lime - cemented sandstone.
					3.9		Redish, highly weathered, paleosoil intercalated with gray siltstone laminations.
				50	4.5		Rdish, hard, trough, cross - bedded, pesolitic fining upward sandstone.
					2.8		Redish - vary coloured, highly weathered pesolitic paleosoil.
					2.0		Gray, hard, fining upward sandstone.
				40	5.3		Brown, hard, fine - medium grained, cross - bedded sandstone.
					2.1		Vary coloured, weathered paleosoil.
					0.9		Redish, hard, thinly laminated claystone and siltstone.
					1.7		Redish, weathered, pesolitic paleosoil.
					2.2		Yellowish, hard, fine - medium grained sandsone.
					1.0		Redish, weathered pesolitic paleosoil.
				30	2.2		White - yellow, fine - medium sandstone with thin laminations of gray, rippled siltstone.
					0.8		Redish - purble pesolitic paleosoil.
					2.5		Yellowish - redish, trough, cross - bedded, fining upward sandstone.
					1.8		Brown - redish siltstone intercalated with thin laminations of brown pesolitic paleosoil.
					1.2		Brown - redish, weathered paleosoil with pesoliths.
				20	3.8		Dark gray, hard, thinly bedded claystone intercalated with pesoliths rich siltstone.
					1.3		White - yellow, hard, trough, cross - bedded fining upward sandstone.
					0.9		Brown, fine - medium grained sandstone intercalated with coal and plant remains rich siltstone laminations.
					1.8		Brown, hard, coarse grained, cross - bedded fining upward sandstone.
					0.9		Dark gray, plant remains and sulphur rich siltstone.
				10	7.5		Red - brown, hard, coarse grained, trough, cross - bedded fining upward sandstone.
					1.0		Dark black, thinly bedded intercalation of coal and sulphur rich claystone and siltstone.
					1.0		Gray, thinly bedded, sulphur and coal rich claystone.
					1.1		Dark green, organic and sulphur rich claystone and siltstone.
					2.0		White - redish, hard, trough, cross - bedded, fining upward sandstone.
				0	1.7		Maroon, thinly bedded siltstone and claystone.
Cambrian		Um Ishrin					

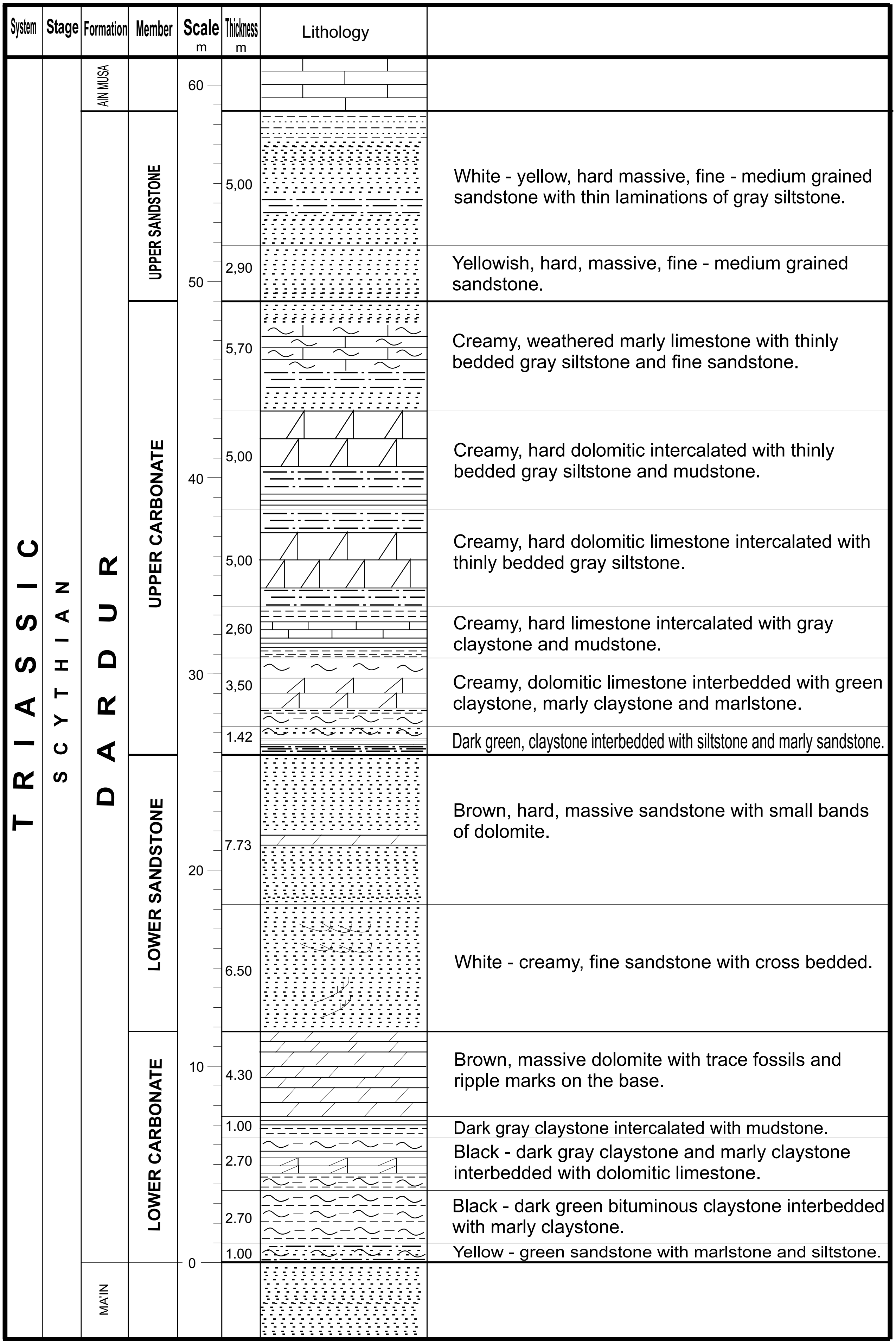
Appendix.(3): Columnar Section of Um Irna Formation

Appendix.(4)



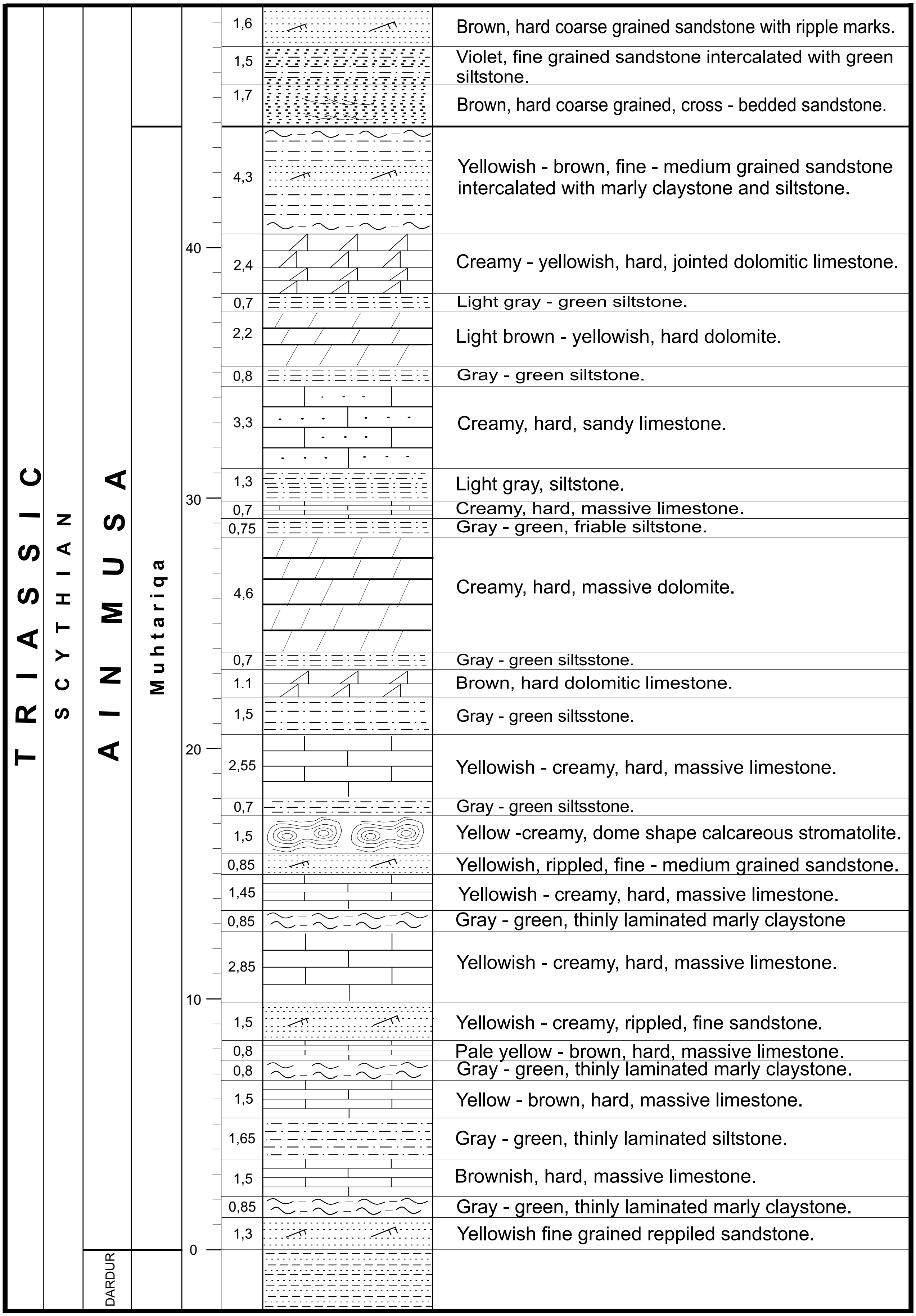
Appendix.(4): Columnar Section of Ma'in Formation

Appendix (5)



Appendix (5): Columnar Section of Dardur Formation

Appendix (6 A)

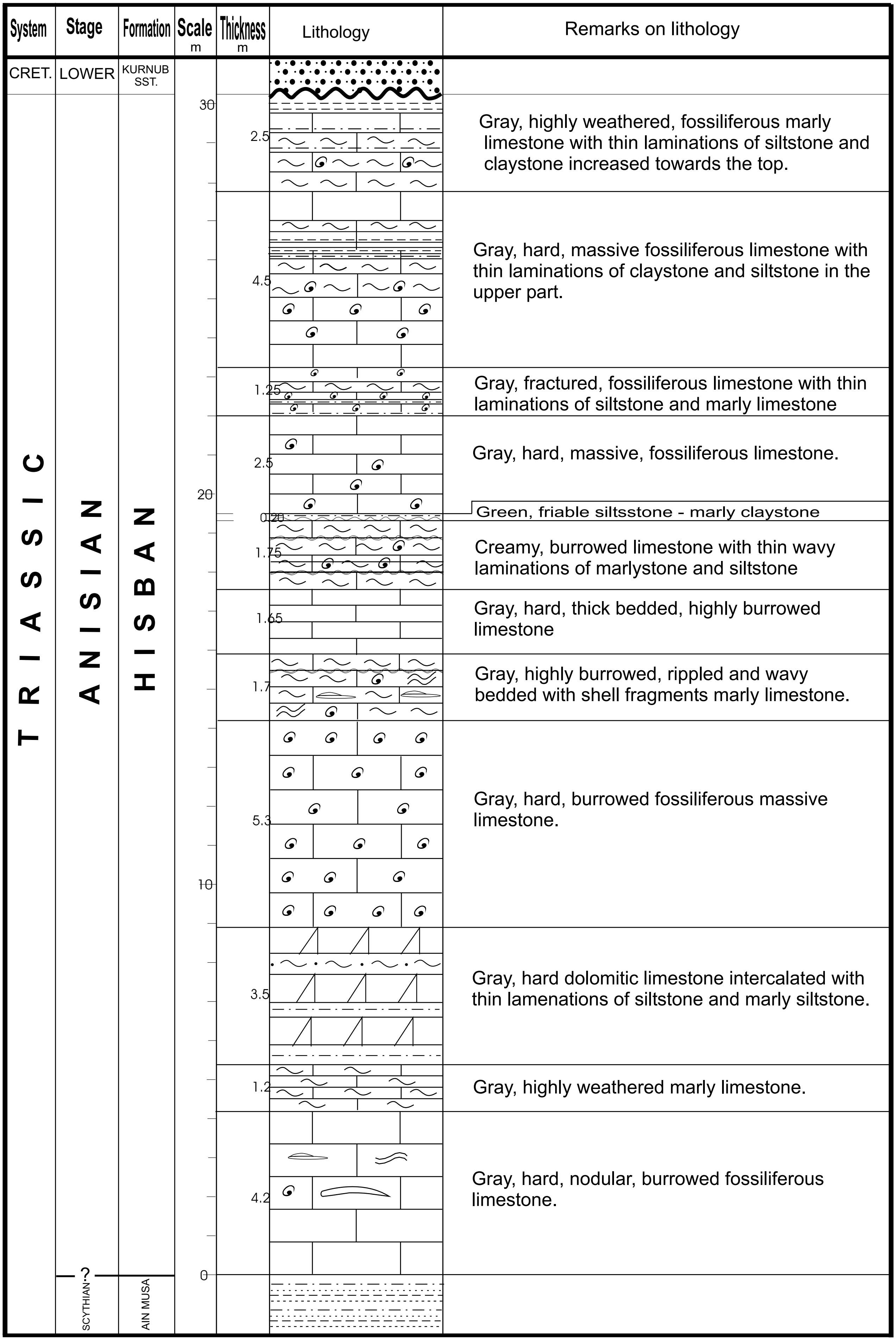


Appendix (6 A):Columnar Section of Ain Musa Formation

System	Stage	Formation	Member	Scale m	Thickness m	Lithology	Remarks on Lithology
TRIASSIC	ANISIAN	Hisban					
TRIASSIC	ANISIAN / ? / SCYTHIAN	AIN MUSA	Siyale	100	5,6		Yellowish - gray thinly bedded marly claystone intercalated with dark green siltstone.
					1,5		Yellowish, hard, fine - medium grained sandstone.
				90	4,1		Greenish, thinly bedded marly claystone intercalated with siltstone.
					6,0		Brown, fining upward, trough cross - bedded sandstone.
				80	4,3		Greenish - gray silty marl, marly claystone interbedded with calcareous limestone.
					5,5		Yellowish - greenish thinly bedded of siltstone, marly claystone and silty marl.
			Jamala	70	5,8		Yellow - dark brown, fining upward sandstone.
					2,1		Yellow - brown, medium grained sandstone.
					2,3		Voilet - green siltstone.
				60	7,0		Brownish, hard, conglomratic - coarse grained, fining upward, trough cross bedded sandstone with channal fill sediments in the base.
				50	6,0		Green, thinly bedded siltstone with fine grained, cross - bedded, rippled sandstone.

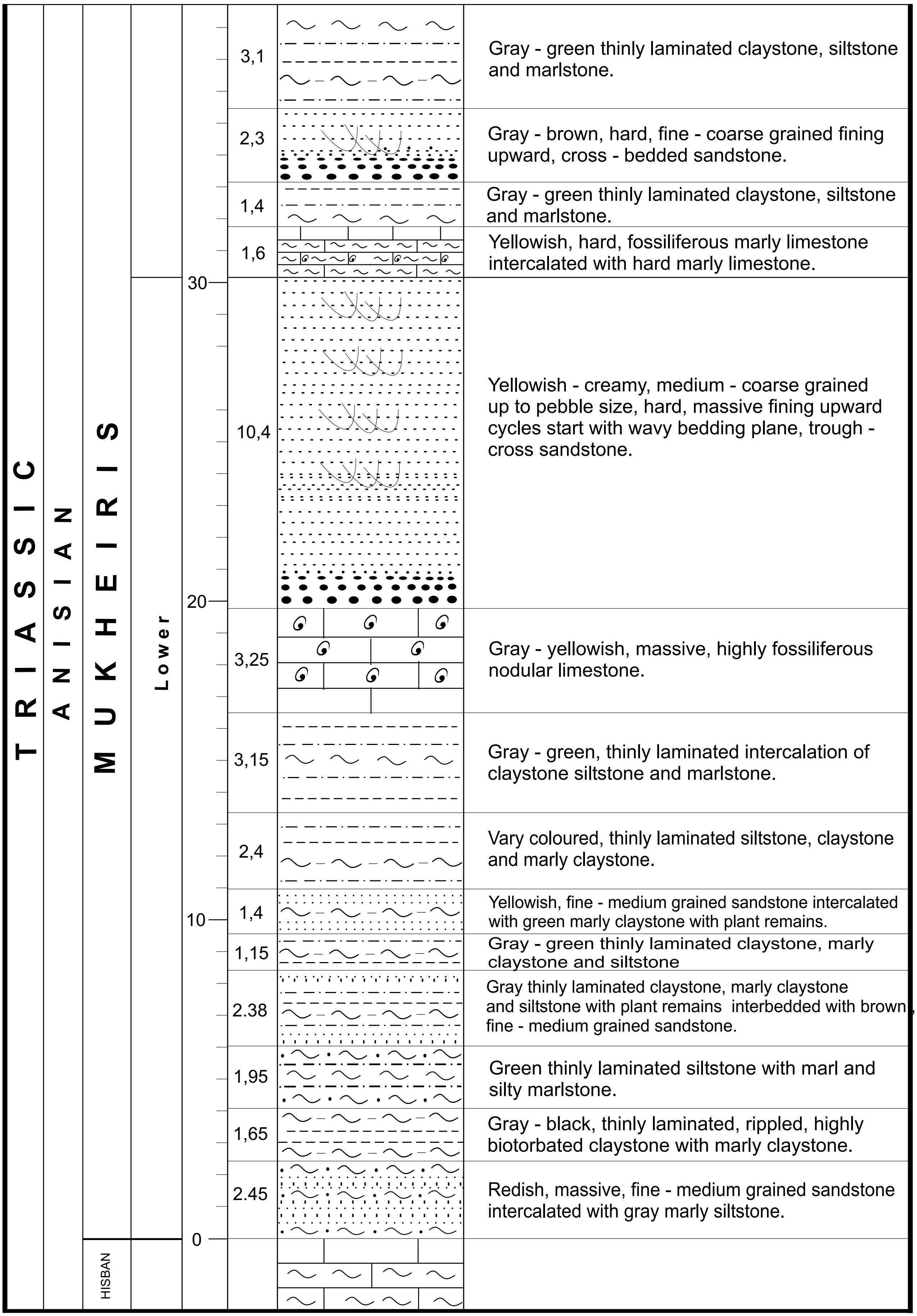
Appendix (6 B): Columnar Section of Ain Musa Formation

Appendix (7)

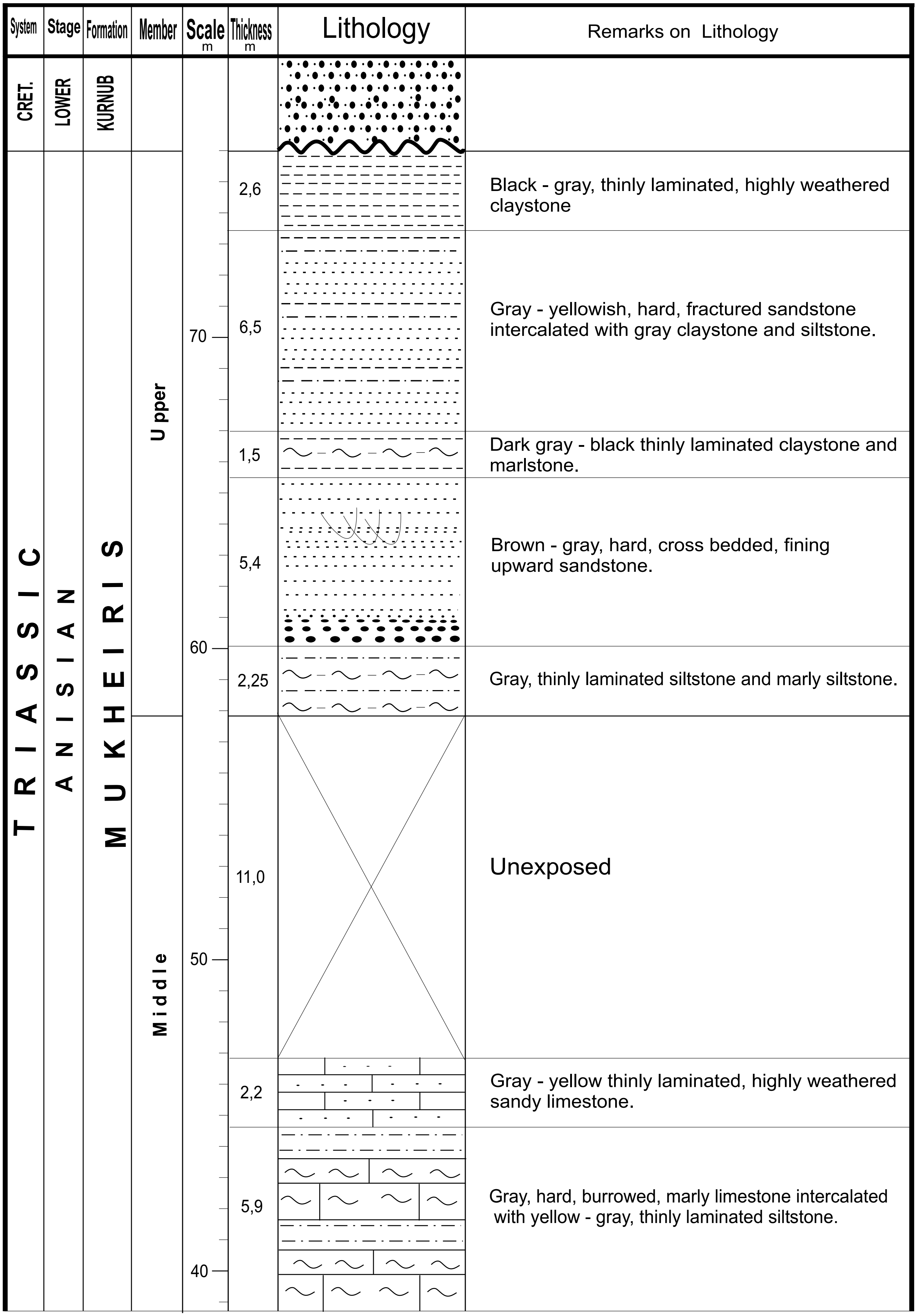


Appendix (7): Columnar Section of Hisban Formation

Appendix (8 A)



Appendix (8 A): Columnar Section of Mukheiris Formation



Appendix (8 B): Columnar Section of Mukheiris Formation

Appendix (9 A)

System	Stage	Formation	Member	Scale m	Thickness m	Lithology	Remarks of Lithology
TRIASSIC	LADINIAN	IRAQ AL-AMIR		50	3,3		Yellowish, fractured, marly limestone intercalated with friable marl and claystone.
					4,5		Yellowish, hard, fossiliferous limestone.
					2,5		Yellowish, hard, dolomitic limestone.
				40	1,4		Yellowish, hard, sandy dolomite.
					1,5		Yellowish, hard sandy limestone intercalated with friable marl.
					2,0		Light gray, hard, micritic limestone.
					3,2		Yellowish, hard fossiliferous limestone.
				30	2,3		Yellowish, hard, fossiliferous sandy limestone.
			Bahhath		1,2		Yellowish, friable marl.
					1,8		Yellowish, hard, lime - cemented fine grained sandstone.
				20	9,0		Yellowish, friable marl intercalated with light gray marly claystone and fine sandstone as channel filled sediments in the top.
					3,8		Light gray, hard, massive, nodular micritic limestone.
				10	6,4		Yellowish, hard, lime - cemented, fine sandstone with siltstone and marly siltstone.
					3,8		Greenish, rippled, fossiliferous limestone with thin laminations of siltstone.
					1,5		Light brown, fine sandstone intercalated with siltstone.
					2,2		Gray, hard, thinly bedded fossiliferous limestone.
		Mukheiris		0			Unexposed

Appendix (9 A): Columnar Section of Iraq Al-Amir Formation →

System	Stage	Formation	Member	Scale m	Thickness m	Lithology	Remarks on Lithology
Cret.	Lower	Kurnub SST.					
TRIASSIC	CARNIAN	IRAQ AL-AMIR	Shita		4,7		Yellowish, hard dolomite intercalated with thinly laminated marly claystone with fragmented chips of gypsum.
				90	5,5		Yellowish, hard, cellular dolomite.
	- ? -						
	LADINIAN				2,2		Light gray thinly laminated marly claystone.
					2,4		Light yellowish, hard dolomite.
				80	1,5		Light yellowish, dolomitic limestone.
					3,5		Yellowish , fractured marly limestone.
					3,8		Light - gray, hard, micritic limestone intercalated with thinly bedded dark gray claystone and marl.
			Abu Yan	70	2,2		Light - gray, hard, sandy dolomite.
					5,2		Light - brown, hard, micritic limestone with algal laminations.
				60	5,3		Gray, hard, recrystallized limestone.
					3,2		Yellowish, hard, jointed fossiliferous limestone.
					2,4		Yellowish, friable marl.
					3,1		Light gray, hard, massive, oolitic limestone.

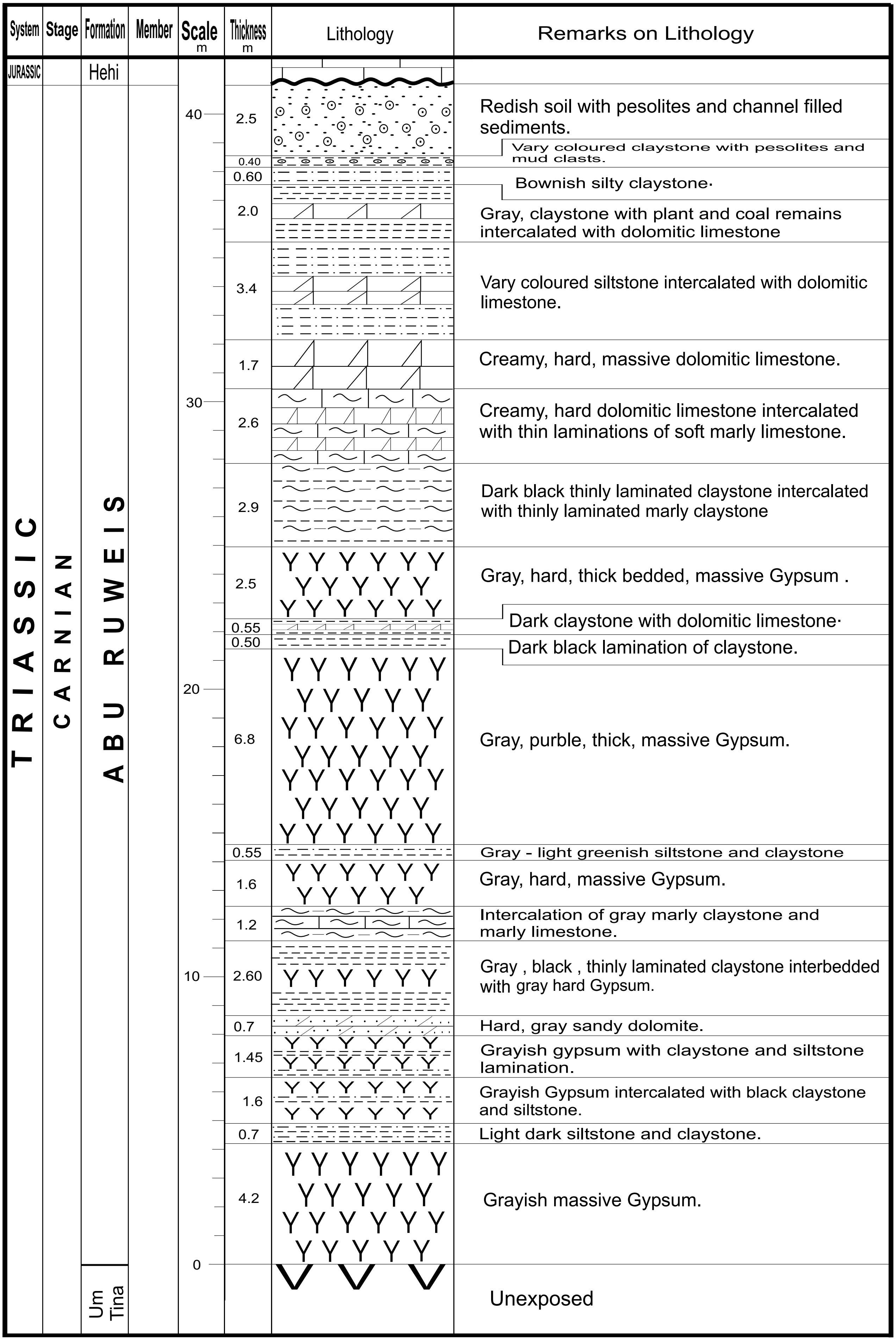
Appendix (9 B): Columnar Section of Iraq Al-Amir Formation

Appendix (10)

System	Stage	Formation	Member	Scale m	Thickness m	Lithology	Remarks on Lithology
Cret.	Lower	Kurnub SST.					
TRIASSIC	CARNIAN	UM TINA		60	2,2		Yellowish, hard, fractured, limestone intercalated with yellowish, fractured, marly limestone.
					2,5		Yellowish, hard, stromatolitic limestone.
					3,6		Yellowish, hard, jointed, recrystallized limestone.
					2,3		Yellowish, hard burrowed stromatolitic limestone.
				50	1,5		Light, gray thinly laminated marly claystone.
					1,5		Yellowish, hard limestone.
					1,0		Light gray thinly laminated marly claystone.
					1,2		Light, gray hard recrystallized limestone.
					0,9		Yellowish, hard limestone with marly limestone
				40	5,8		Intercalation of yellowish hard, burrowed,micritic limestone and stromatolitic limestone.
					1,0		Dark, gray thinly laminated marly claystone
					2,2		Light gray, hard, stylolitic, micritic limestone.
					1,4		Dark - gray, thinly laminated marly claystone.
				30	4,8		Yellowish, hard, micritic limestone intercalated with recrystallized limestone and stromatolitic limestone.
					8,3		Intercalation of yellowish hard micritic limestone and gray, soft marly claystone.
				20	3,7		Yellowish, hard, micritic limestone.
					3,3		Light gray, thinly laminated marly claystone.
					2,3		Light - yellowish, hard, micritic limestone.
				10	7,6		Light gray, hard massive, micritic limestone.
					0,8		Yellowish, fractured marly limestone and marl.
				0	3,6		Gray, hard fossiliferous limestone intercalated with thinly laminated gray marly claystone.
		Iraq Al-Amir					Unexposed

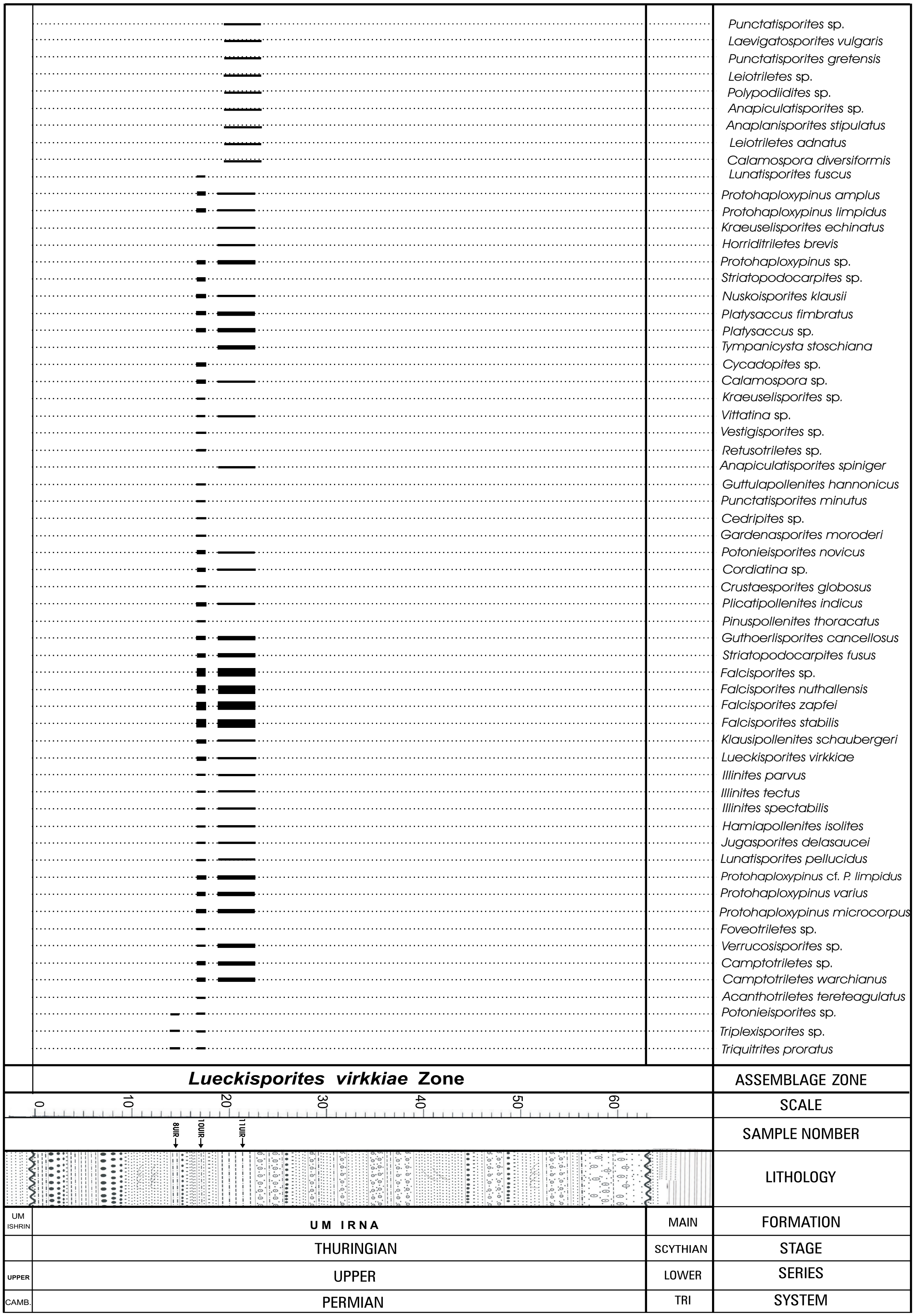
Appendix (10): Columnar Section of Um Tina Formation

Appendix (11)



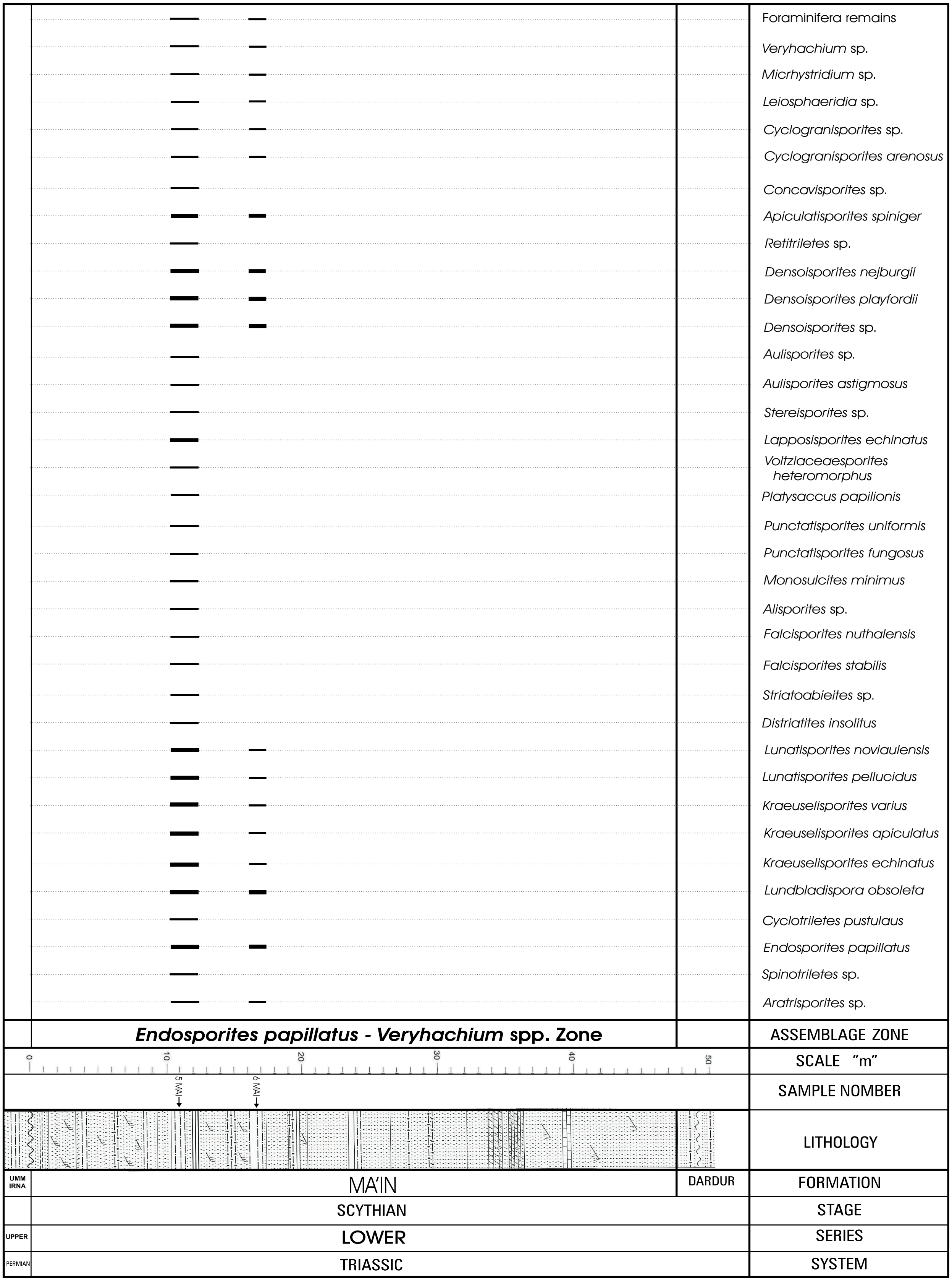
Appendix (11): Columnar Section of Abu Ruweis Formation.

Appendix (12)



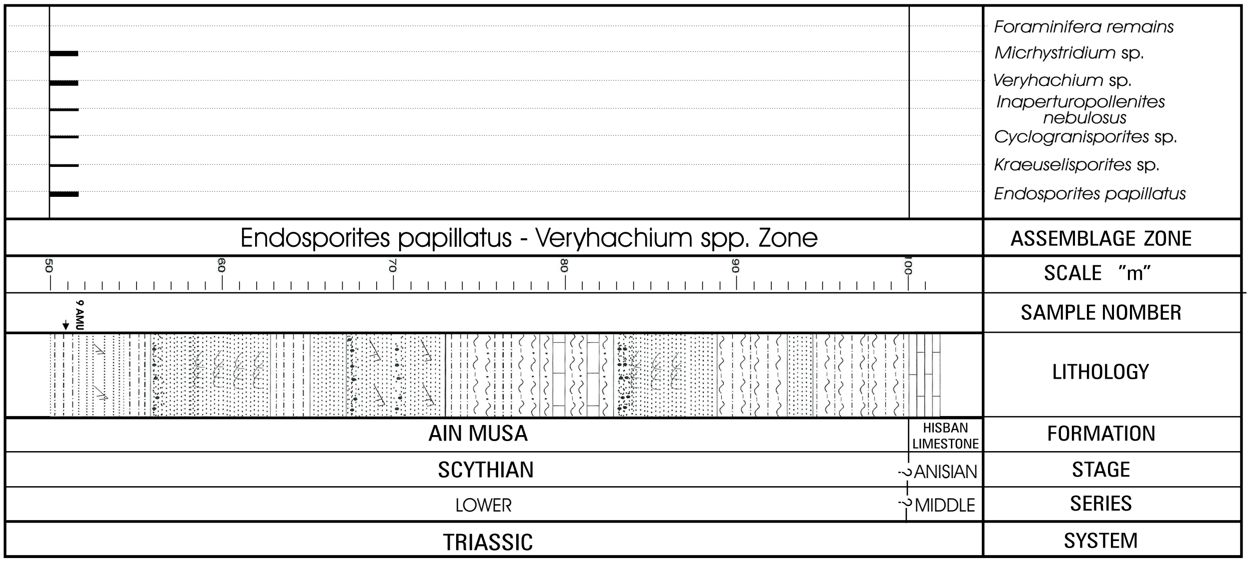
Appendix (12): Range chart of all taxa in Um Irna Formation.

Appendix (13)

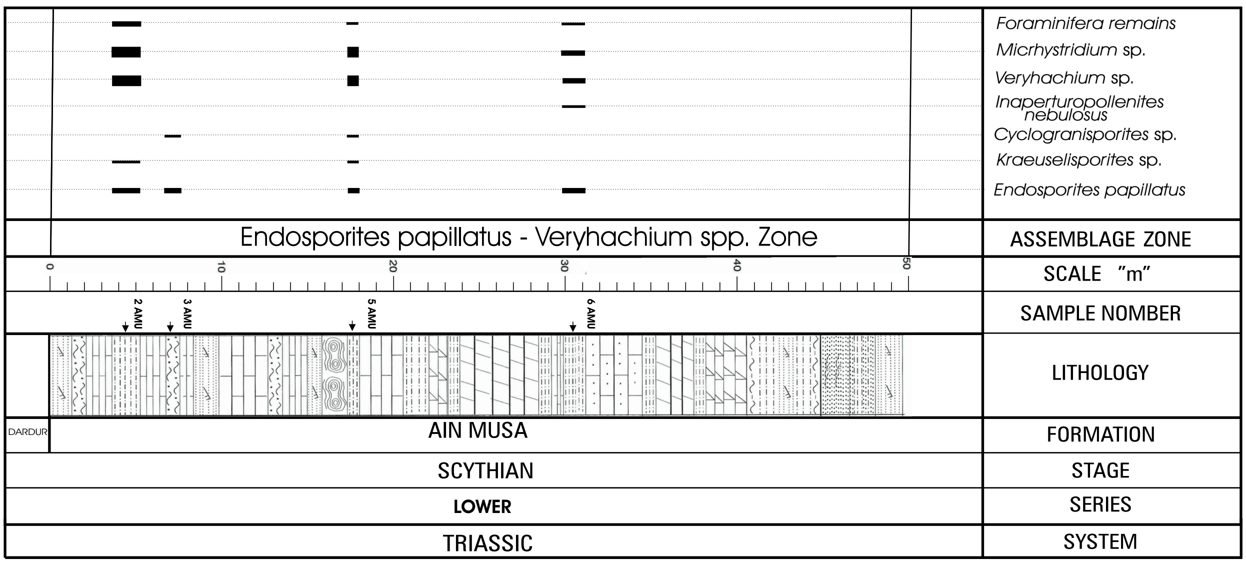


Appendix (13): Range chart of all taxa in the Ma'in Formation.

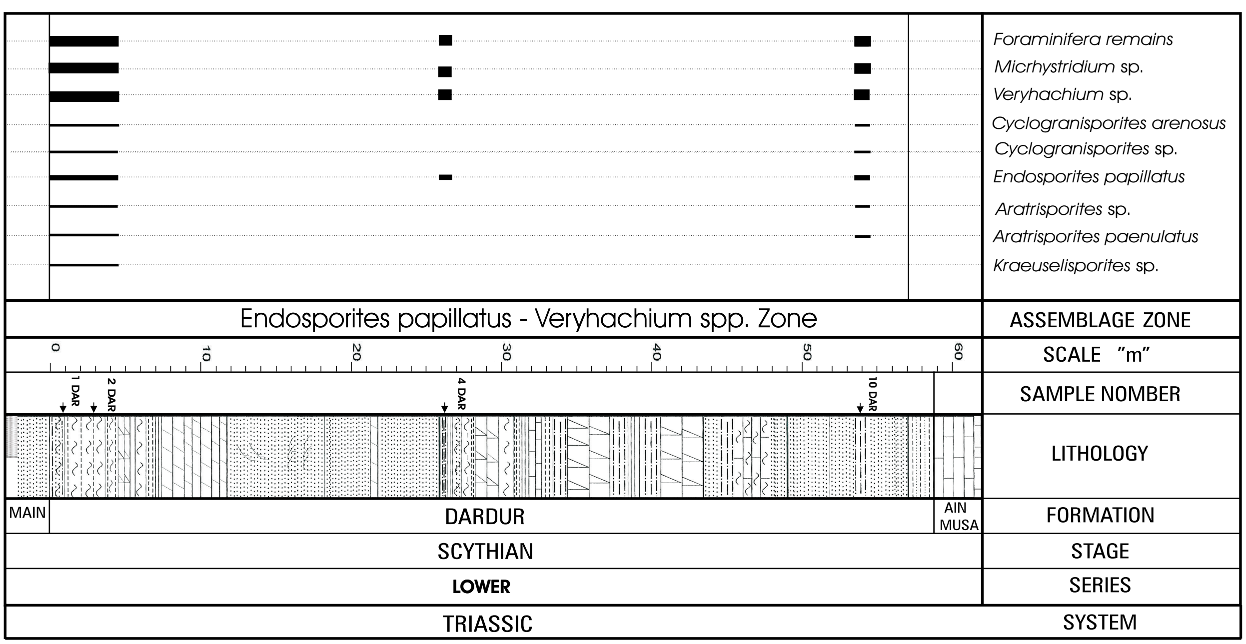
Appendix (14)



C



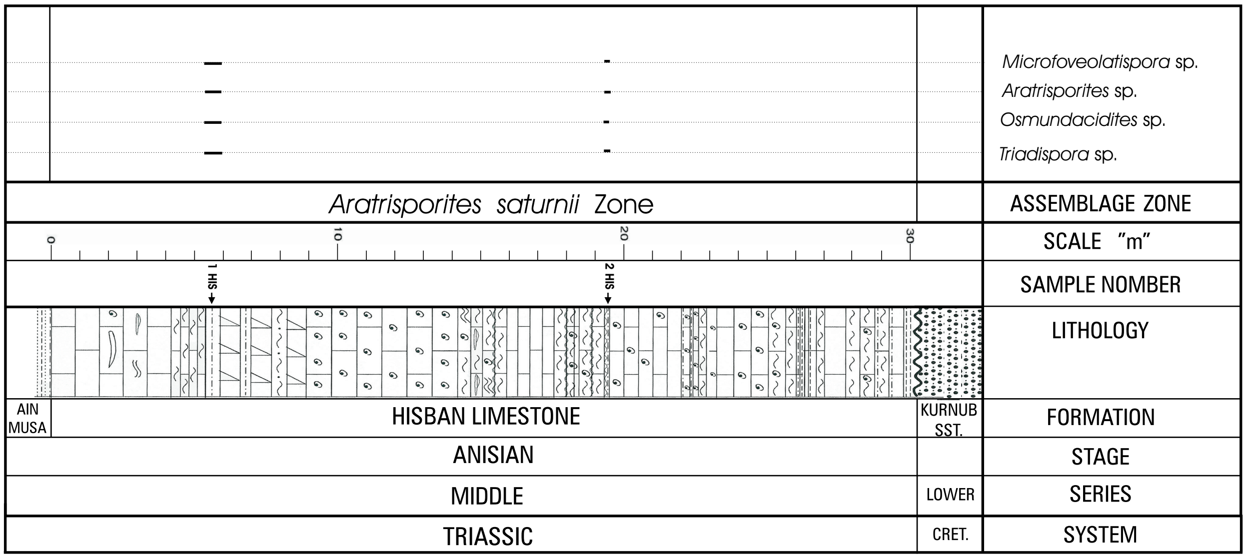
B



A

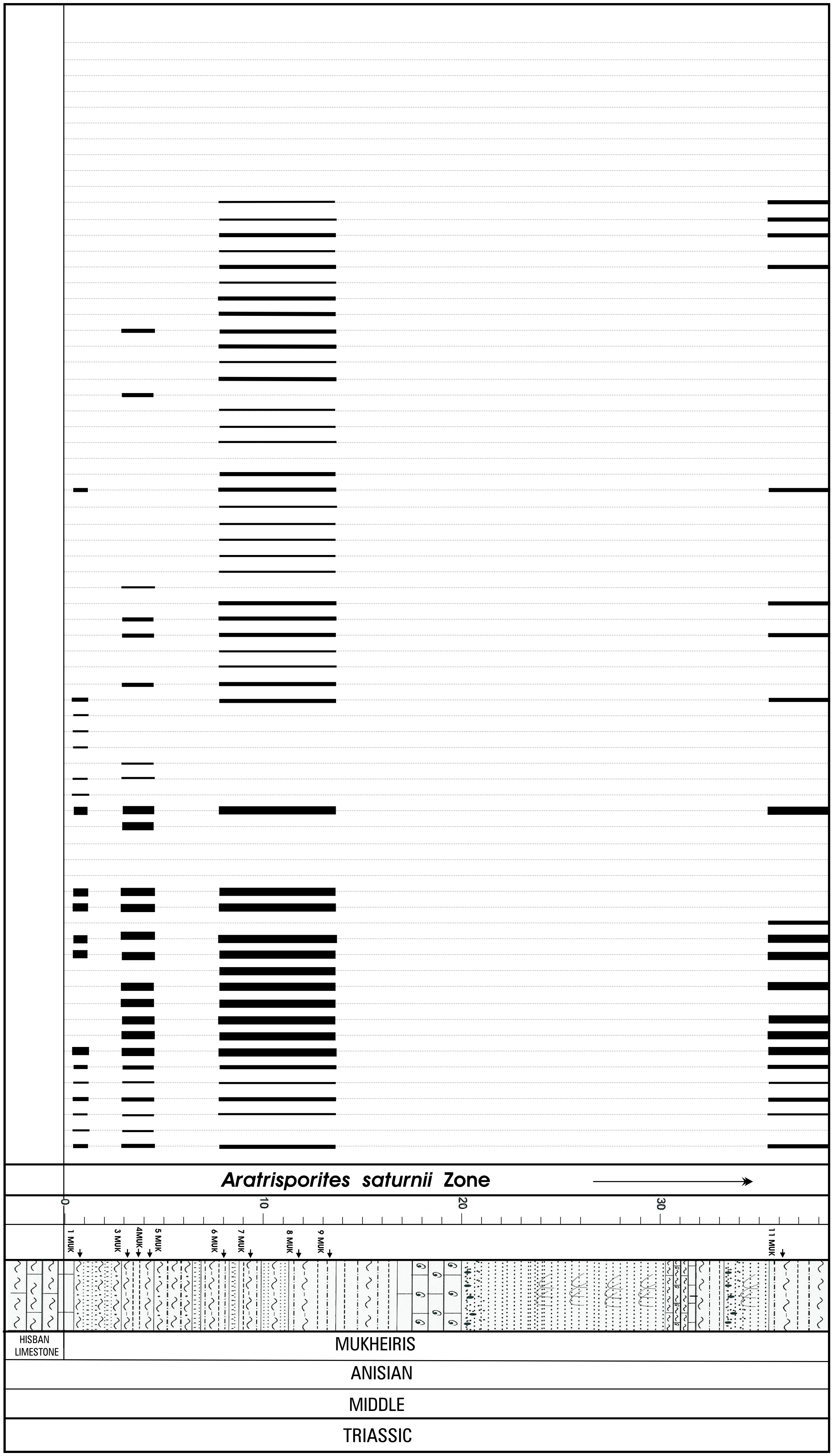
Appendix (14): Range charts of all taxa in the, A- Dardur Formation, B&C Ain Musa Formation.

Appendix (15)



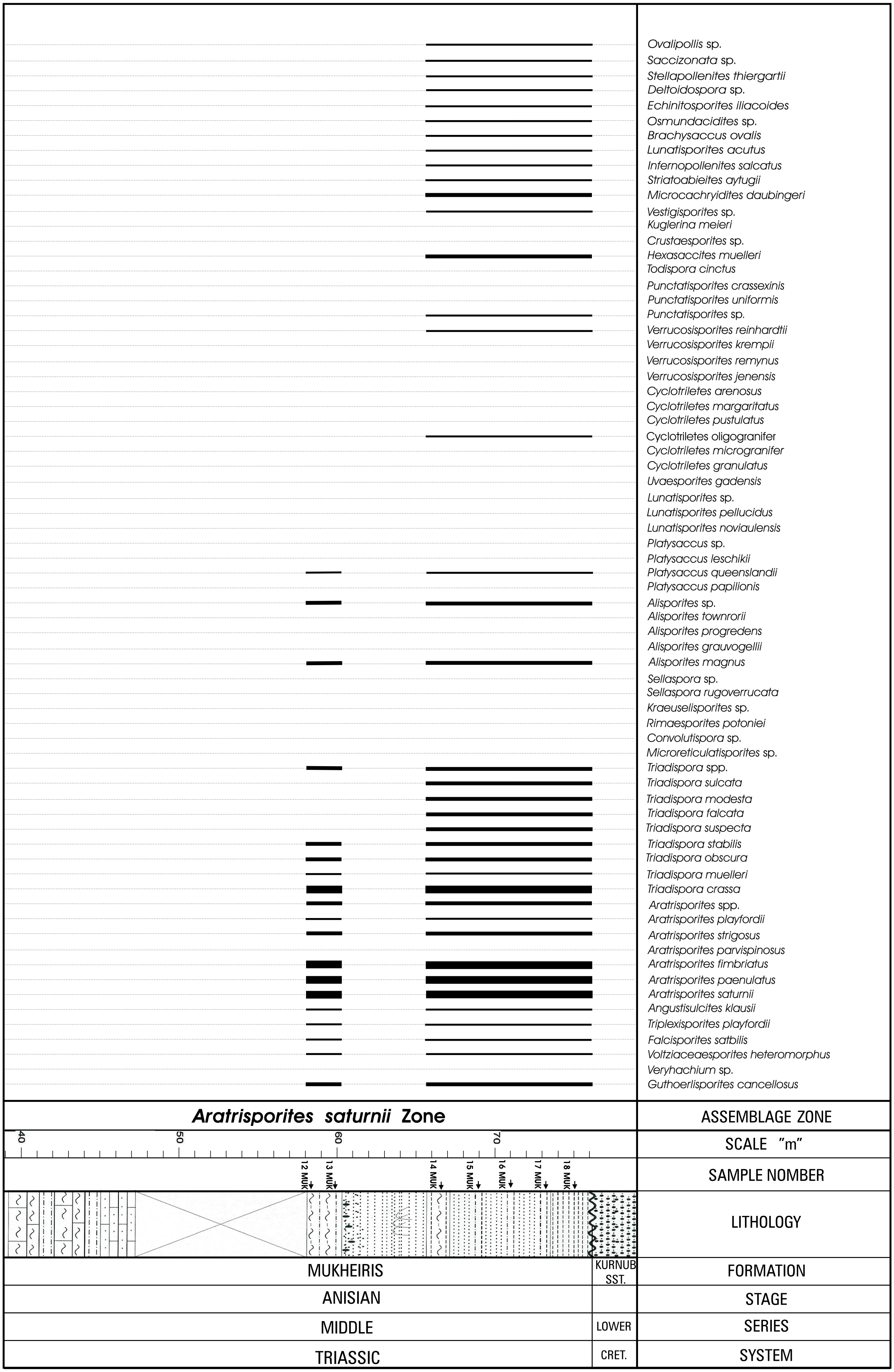
Appendix (15): Range chart of all taxa in the Hisban Formation.

Appendix (16 A)



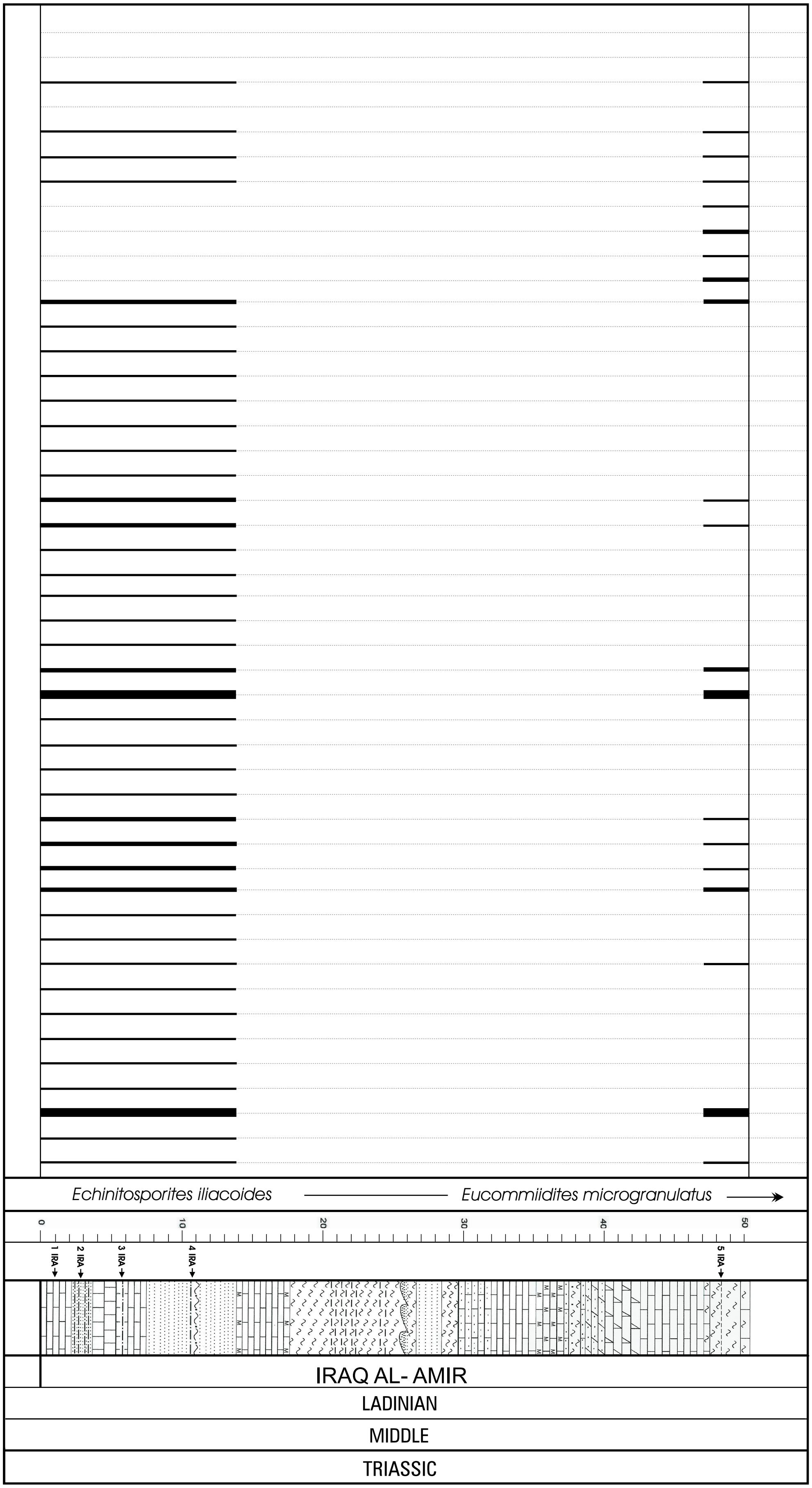
Appendix (16 A): Range chart of all taxa in the Mukheiris Formation.

Appendix (16.B)



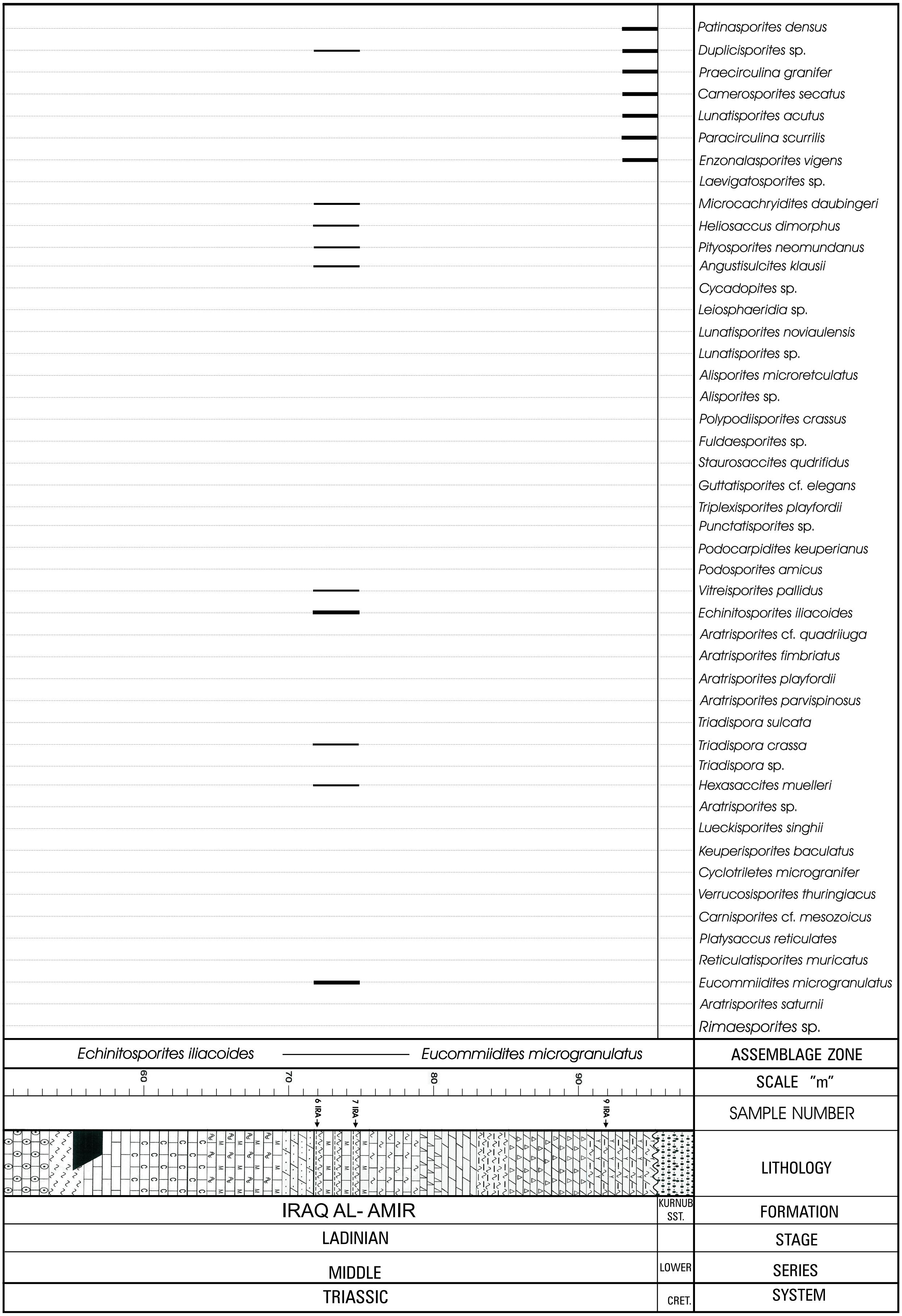
Appendix (16.B): Range chart of all taxa in the Mukheiris Formation.

Appendix (17 A)



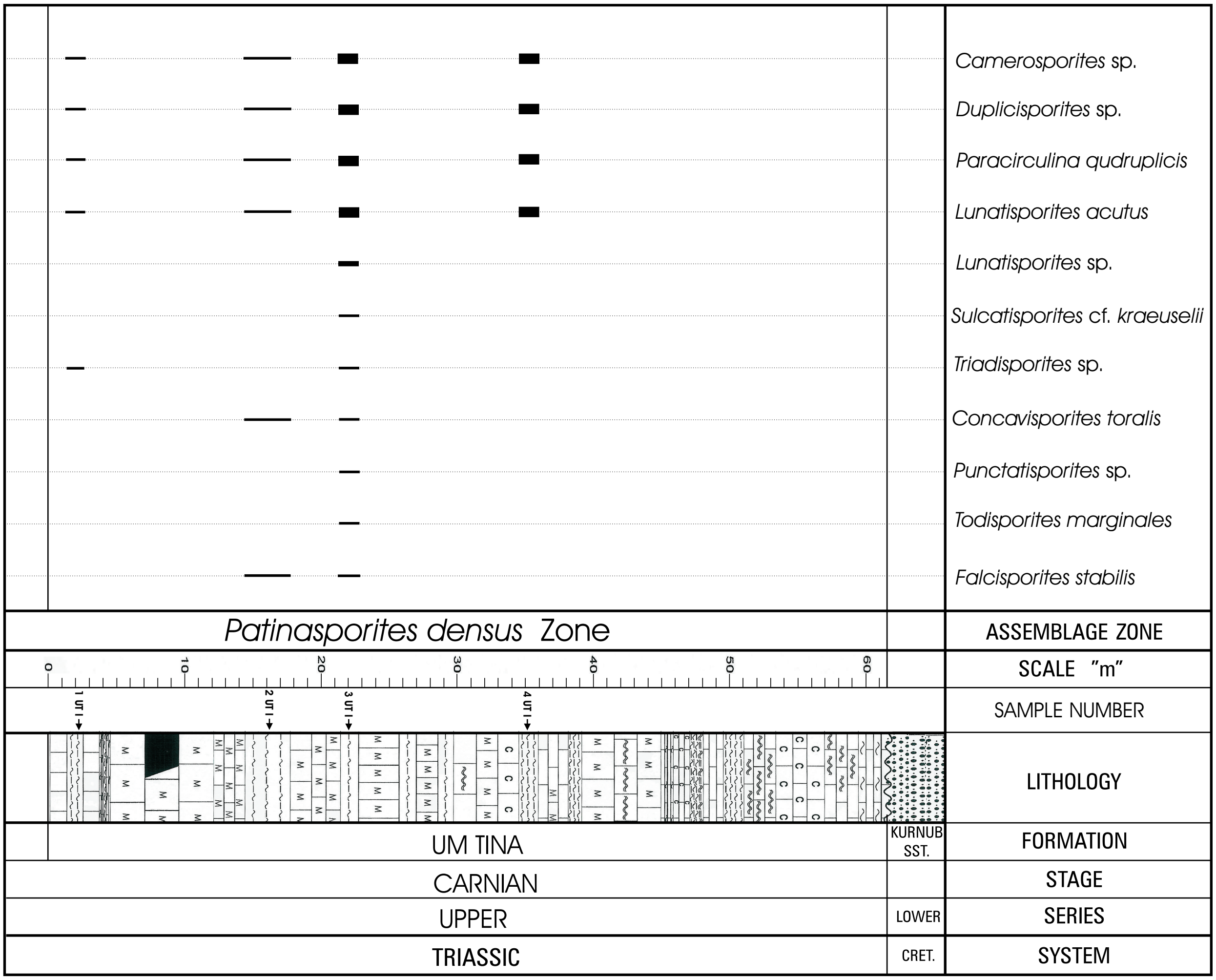
Appendix (17 A): Range chart of all taxa in the Iraq Al-Amir formation. ⟶

Appendix (17 B)



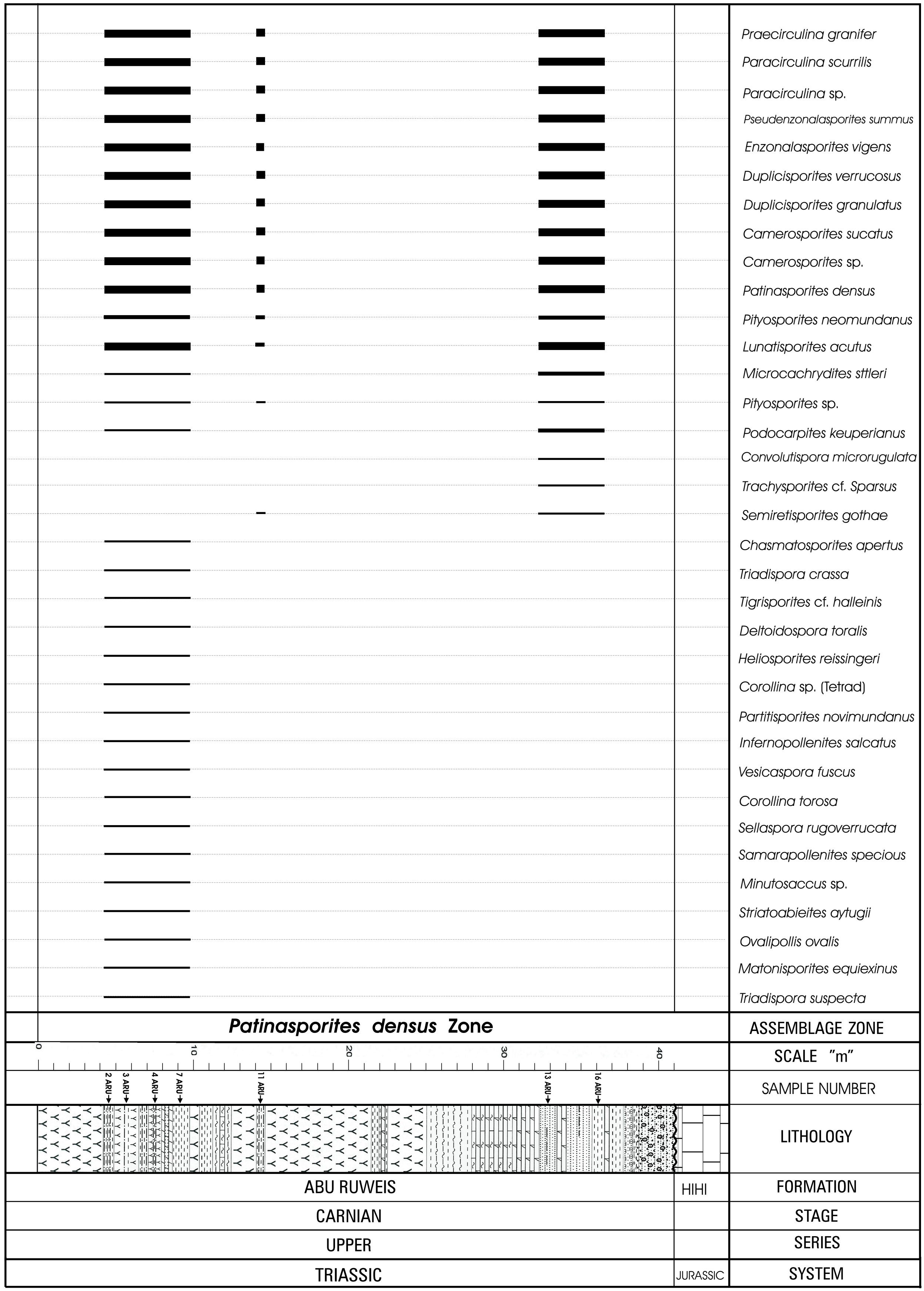
Appendix (17 B): Range chart of all taxa in the Iraq Al-Amir formation.

Appendix (18)



Appendix (18): Range chart of all taxa in the Um Tina Formation.

Appendix (19)



Appendix (19): range chart of all taxa in the Abu Ruweis Formation.

Plate 1-66

PLATE 1

Dicrodium irnensis nov. sp. Holotype

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster, Coll. No. PbO UmIr

1. Frond portion showing the bifurcation. X 1.25.
2. Detail of Fig. 1. X 1.5
3. Detail of Fig. 1 showing the apex of a pinna. X 4.

Plate 1

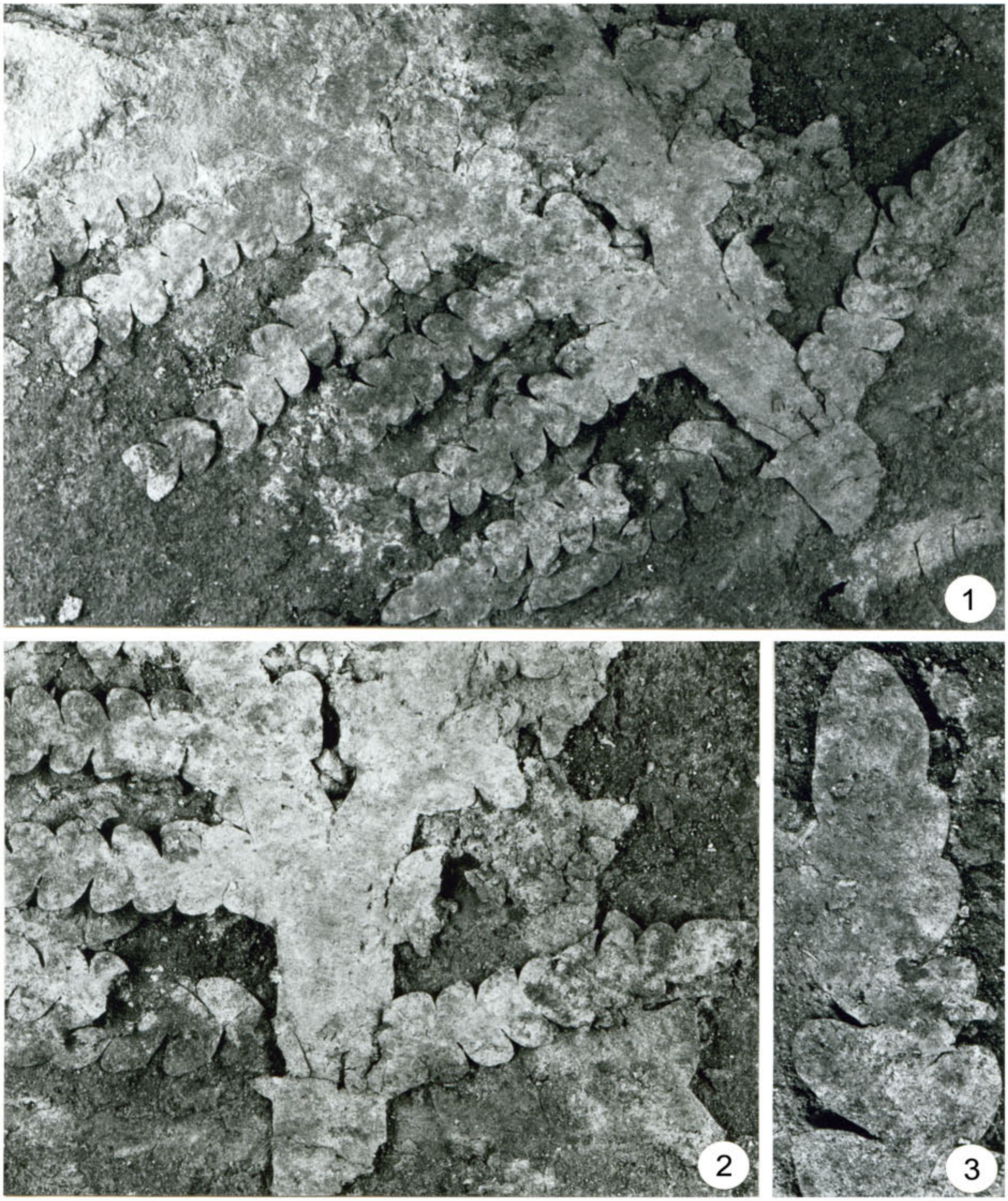


PLATE 2

Dicrodium irnensis nov. sp.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

1. Portion of a frond showing tongue-shaped pinna apices. x 1. Coll. No. PbO UmIr
2. Portion of a frond showing the bifurcation. X 1. Coll. No. PbO UmIr 2.
3. Portion of a pinna faintly showing the venation. X 3. Coll. PbO UmIr 50.
4. Detail of Fig. 3. X 4.
5. Slightly macerated pinna fragment faintly showing the venation. X 4. Slide No. P/O 0358.

Plate 2

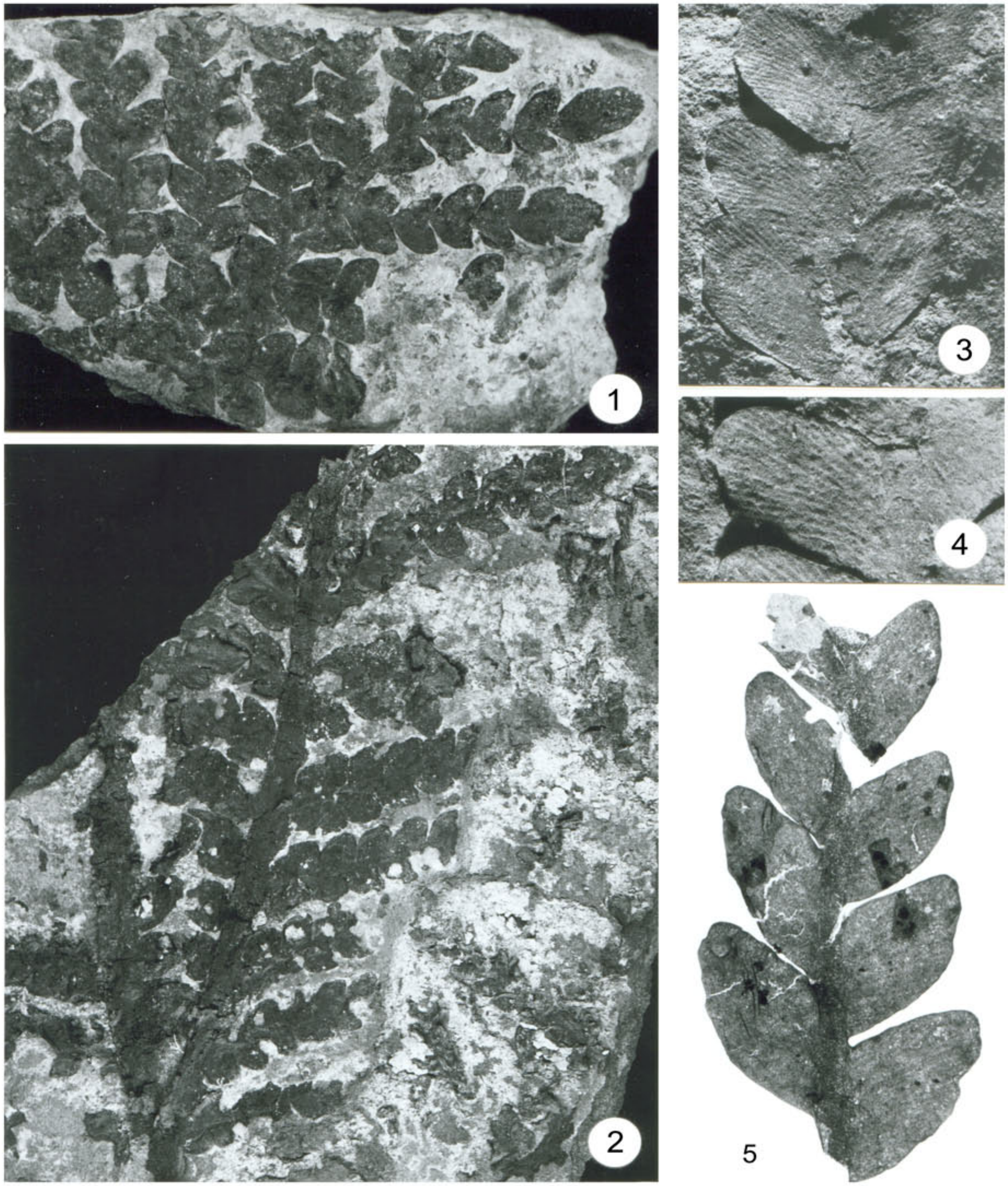


PLATE 3

Dicrodium irnensis nov. sp.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

1-8. Macerated pinna apices showing the tongue-shaped terminal pinnules. 1. = Slide No. PbO LC1; 1. = Slide No. PbO LC2; 3. = Slide No. PbO LC3; 4. = Slide No. PbO LC4; 5. = Slide No. PbO LC5; 6. = Slide No. PbO LC1; 7. = Slide No. PbO LC6; 8. = Slide No. PbO LC7; 9. = Slide No. PbO LC8.

1-5. Scale bar = 0.5 mm.

6-9. Scale bar = 0.5 mm.

Plate 3

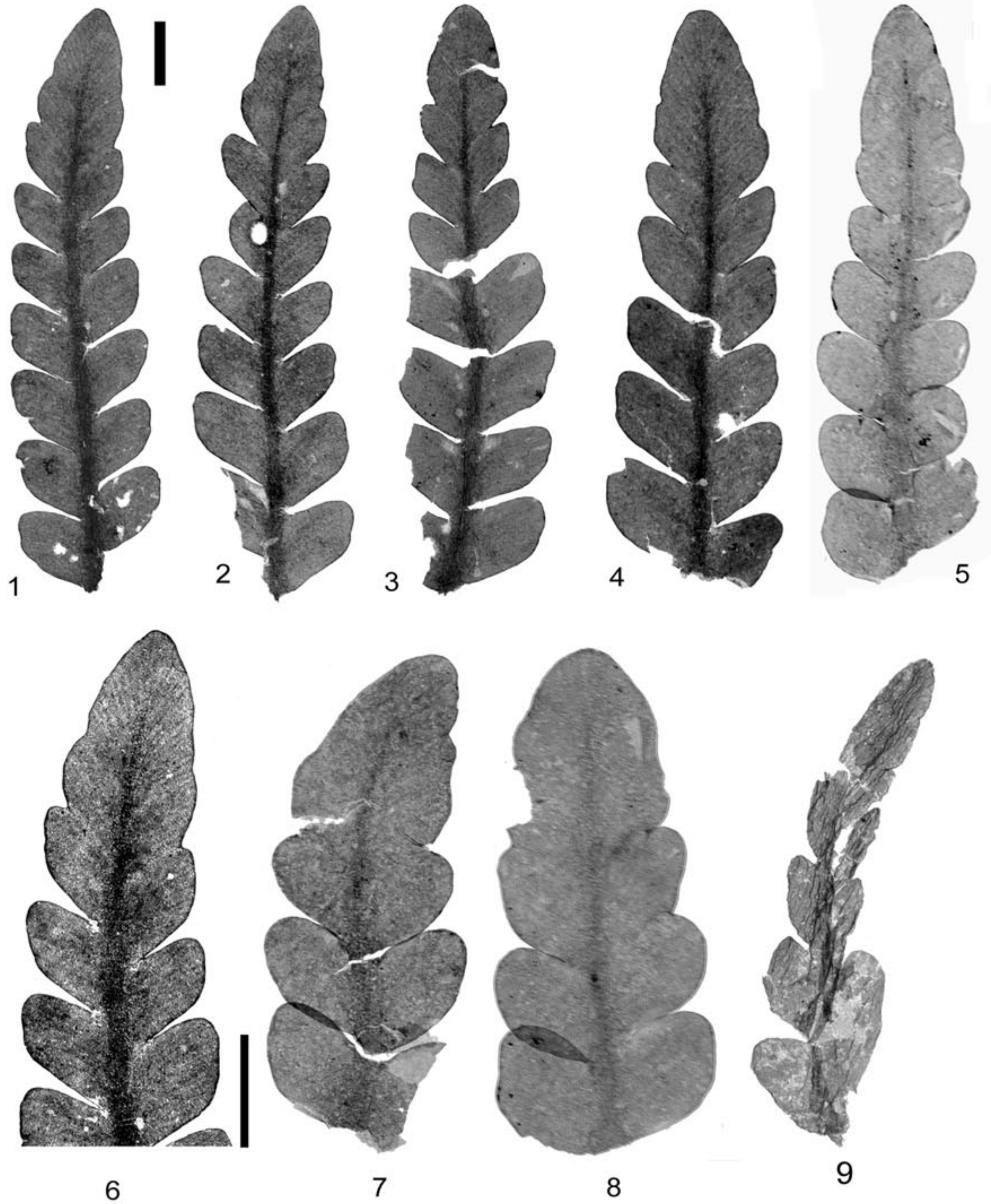


PLATE 4

Dicrodium irnensis nov. sp.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

1-2. Macerated pinna apices showing the tongue-shaped a terminal pinnule and the distribution of stomata within a single pinnule.

1. Upper pinule surface; Slide No. LCU 21;

2. Lower pinnule surface LCL 21.

3-4. Details of Figs. 1 and 2. showing the differences in the distribution of stomata and cell sizes.

Plate 4

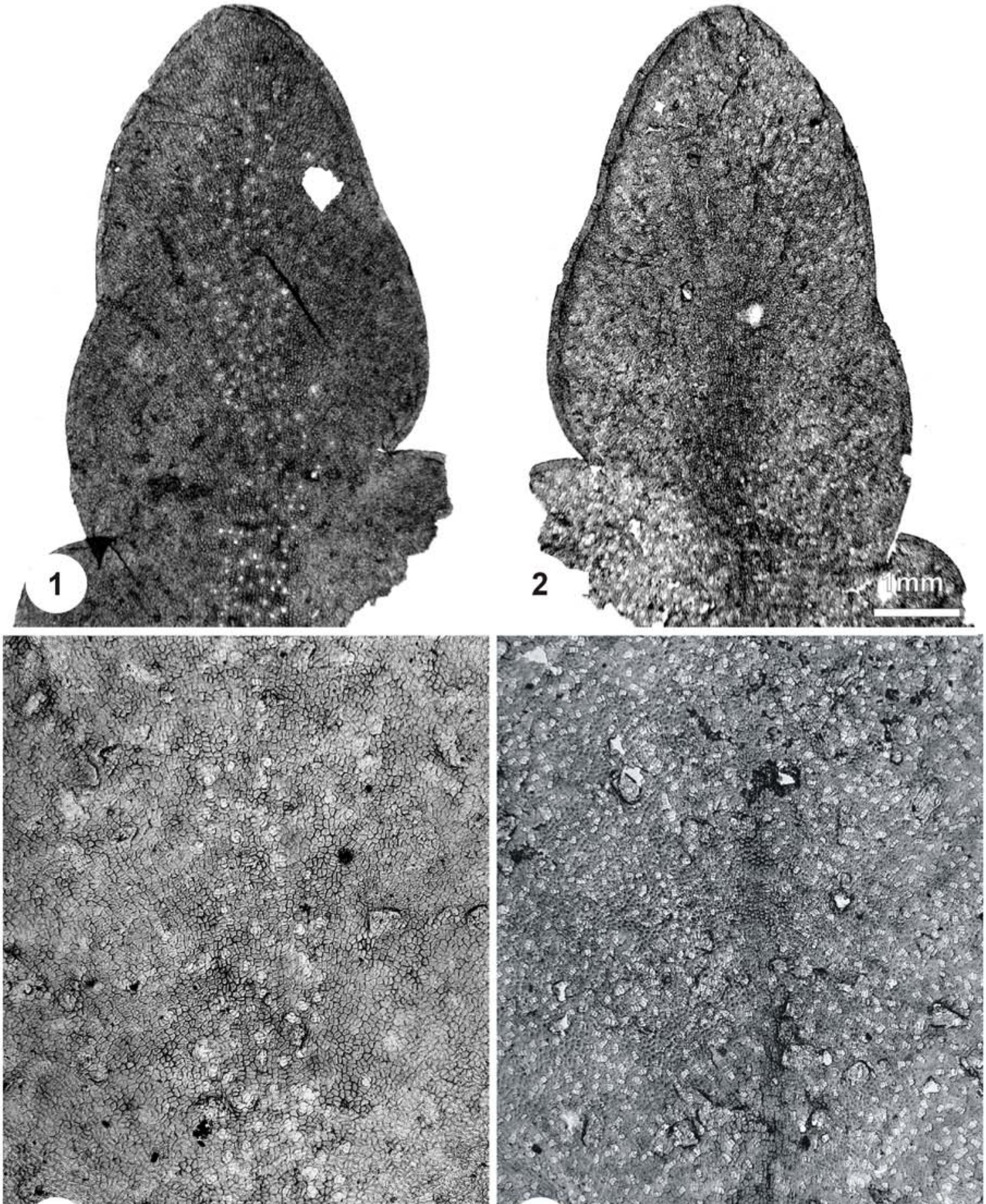


PLATE 5

Dicrodium irnensis nov. sp.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

1-4. Macerated pinnules showing the distribution of stomata within a single pinnule.

1 + 3.Upper pinnule surface with very few stomata, all in the area of the pinna axes and over the basal parts of the veins. 1. Slide S11U, X 16. 3. Slide S11U, X 40.

2 + 4. Lower pinule surface with many stomata on the pinnule lamina but hardly any over the pinna axis. 2. Slide S11L, X 16. 4. Slide S11L, X 40.

Plate 5

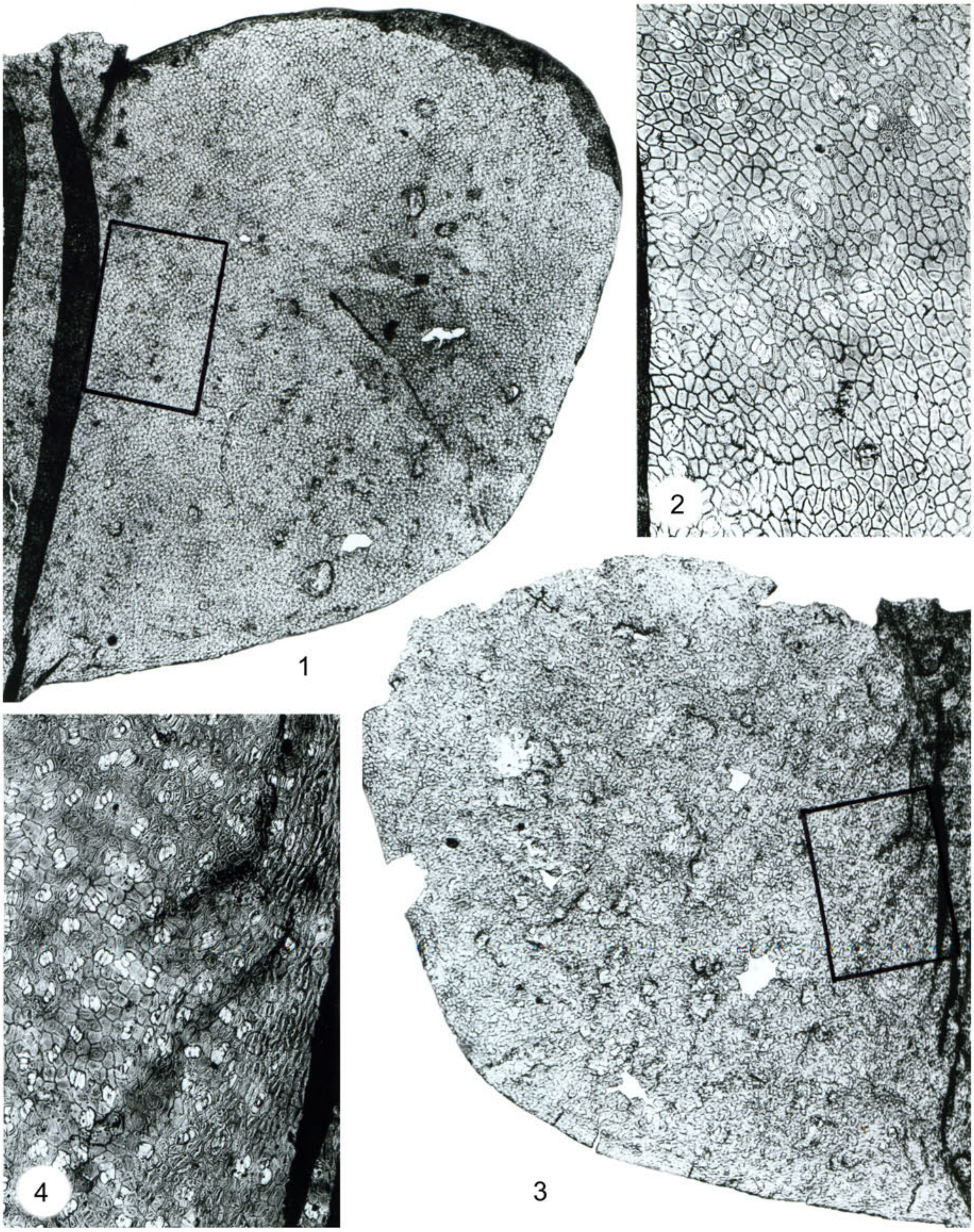


PLATE 6

Dicrodium irnensis nov. sp.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

1. Overview of the cuticle of the lower pinnule surface with numerous stomata. Scale bar = 100 µm. Slide HK001L.
2. Overview of the cuticle of the upper leaf surface lacking stomata. Scale bar = 100 µm. Slide HK001U
3. Detail of the specimen shown on Fig. 1. Scale bar = 25 µm.
4. Detail of the specimen shown on Fig. 1, showing the normal type of stomata with two weakly cutinised lateral subsidiary cells and normally cutinised polar subsidiary cells, and a stomatal complex with a ring of five normally cutinised subsidiary cells. Scale bar = 25 µm
5. Detail of Fig. 4 showing both types of stomata. Scale bar = 10 µm.

Plate 6

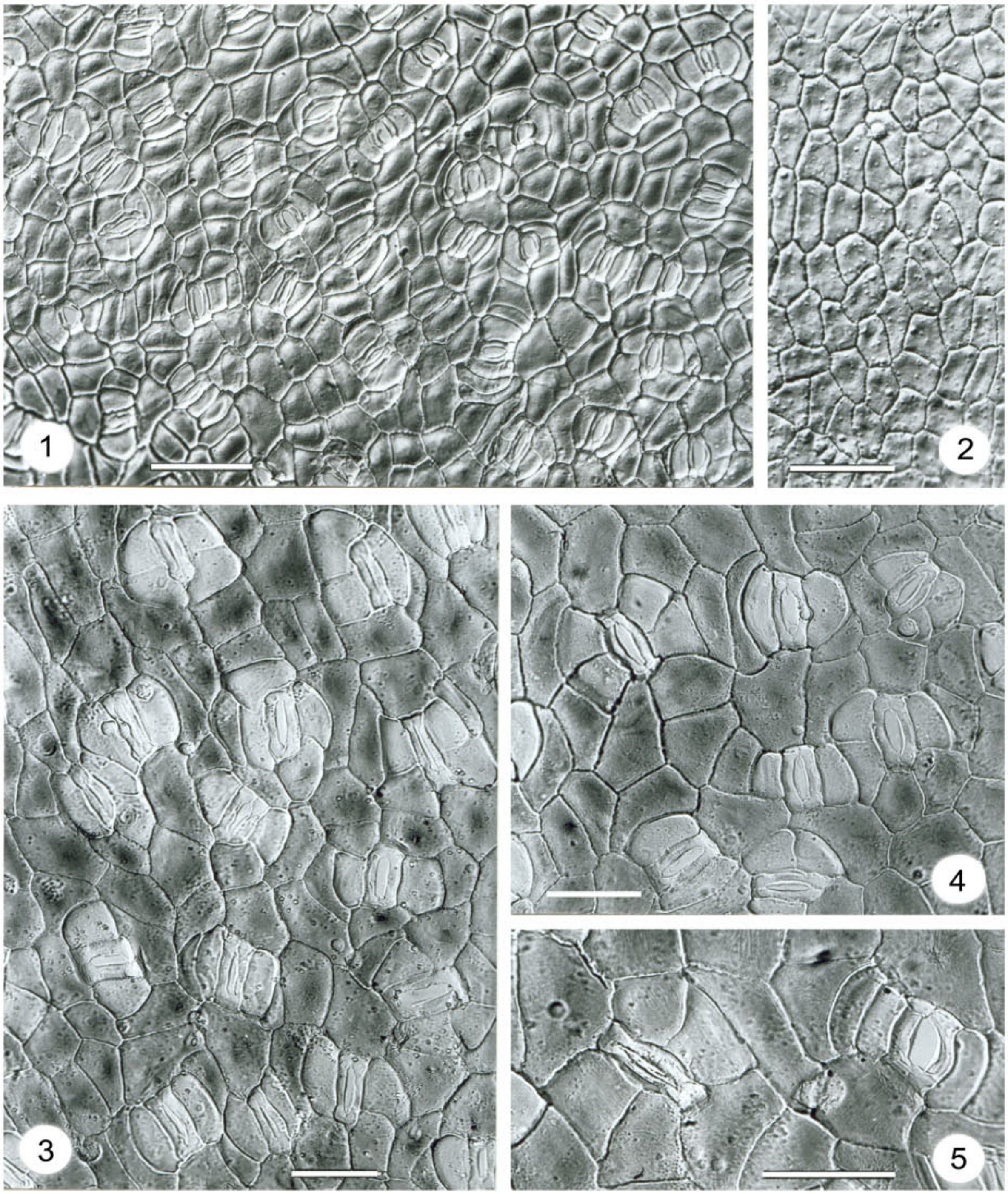


PLATE 7

Dicroidium jordanensis nov. sp. Holotype.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster. Coll. No. PbO UmIr 66.

1. Portion of a large frond showing the bifurcation in the basal part of the frond. Part of the right portion of the frond is missing because cuticles have detached. X 0.8.

Plate 7

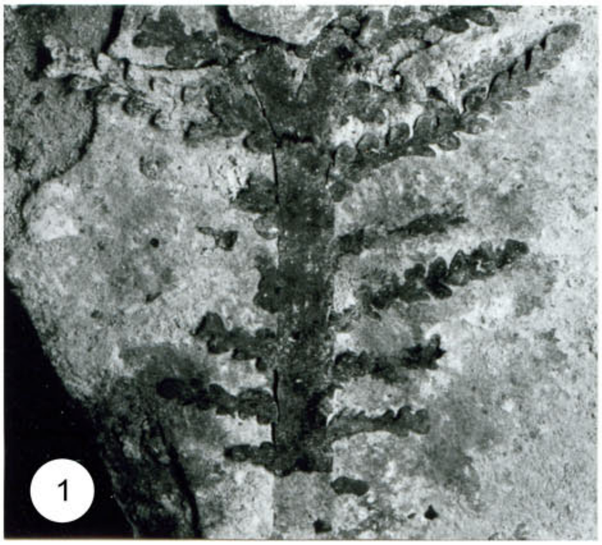
PLATE 8

Dicroidium jordanensis nov. sp. Holotype.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster. Coll. No. PbO UmIr 66.

1. Detail of the lower part of the frond with the bifurcation. X 1.
2. Detail of the upper left part of the frond with several pinnae. X 1.

Plate 8



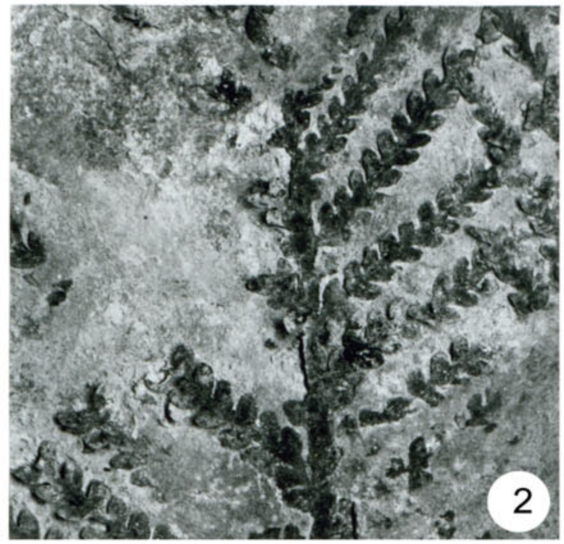


PLATE 9

Dicroidium jordanensis nov. sp.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

1. Portion of a large frond. Regarding the asymmetry it is a part of the right fork of the frond. X 1. Coll. No. PbO UmIr6.
2. Detail of Fig. 1. Note the presence of intercalary pinnules. X 2.
3. Pinna apex. X 2. Coll. No. PbO S38 .
4. Part of a macerated pinna with relatively narrow pinnules. X 2. Slide P/O152.
5. Part of a macerated pinna. X 4. Slide P/O150.

Plate 9

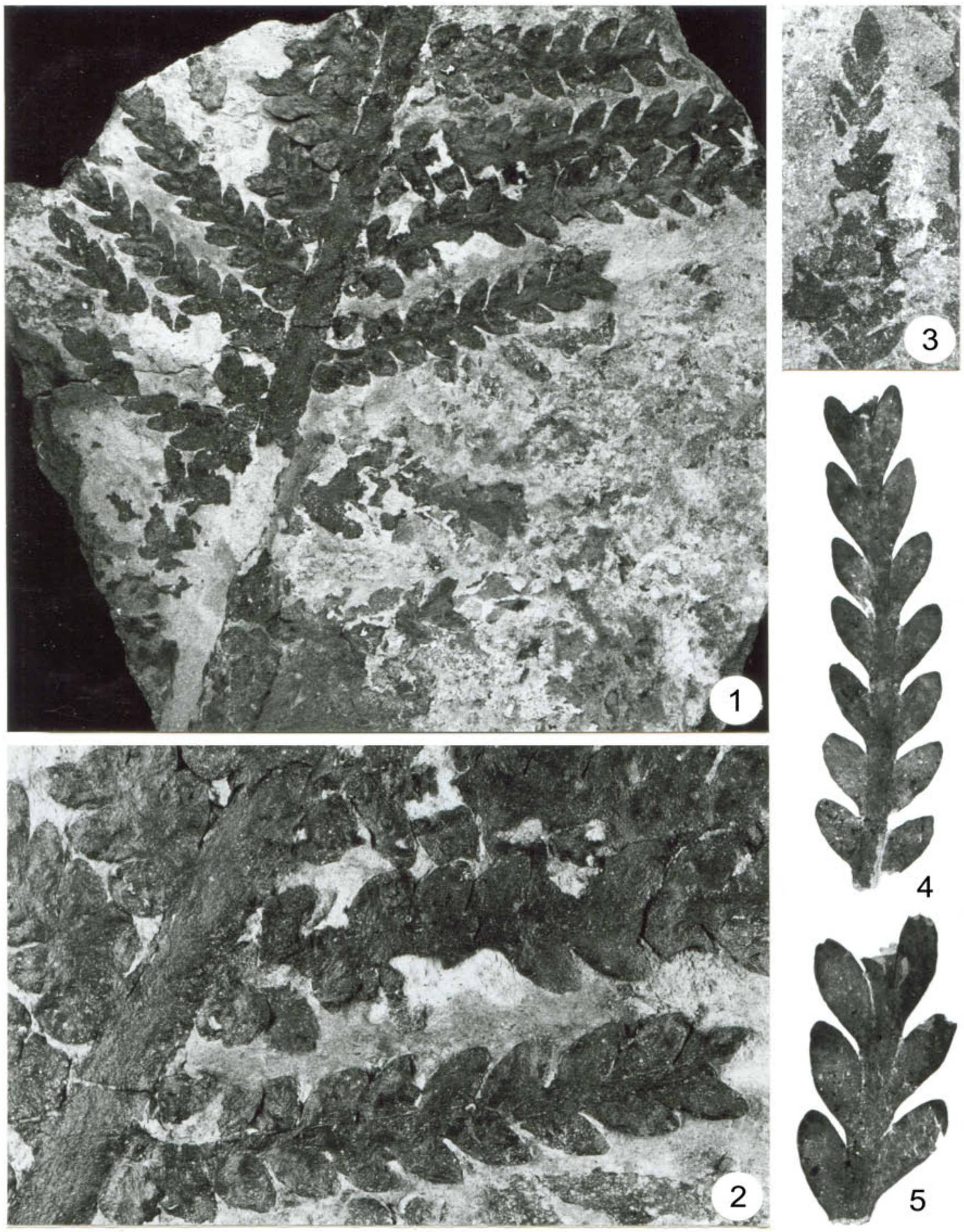


PLATE 10

Dicroidium jordanensis nov. sp.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

1. Part of a macerated frond showing the exterior (= left) and interior (= right) part. X 2. PbO LC20.

2-7. Pinna apices showing the strongly assymmetrical subapical pinnules and the narrow apical pinnules. All figures X 2; 2. PbO LC13; 3. PbO LC14; 4. PbO LC15; 5. PbO LC11; 6. PbO LC12; 7. PbO LC16.

Plate 10

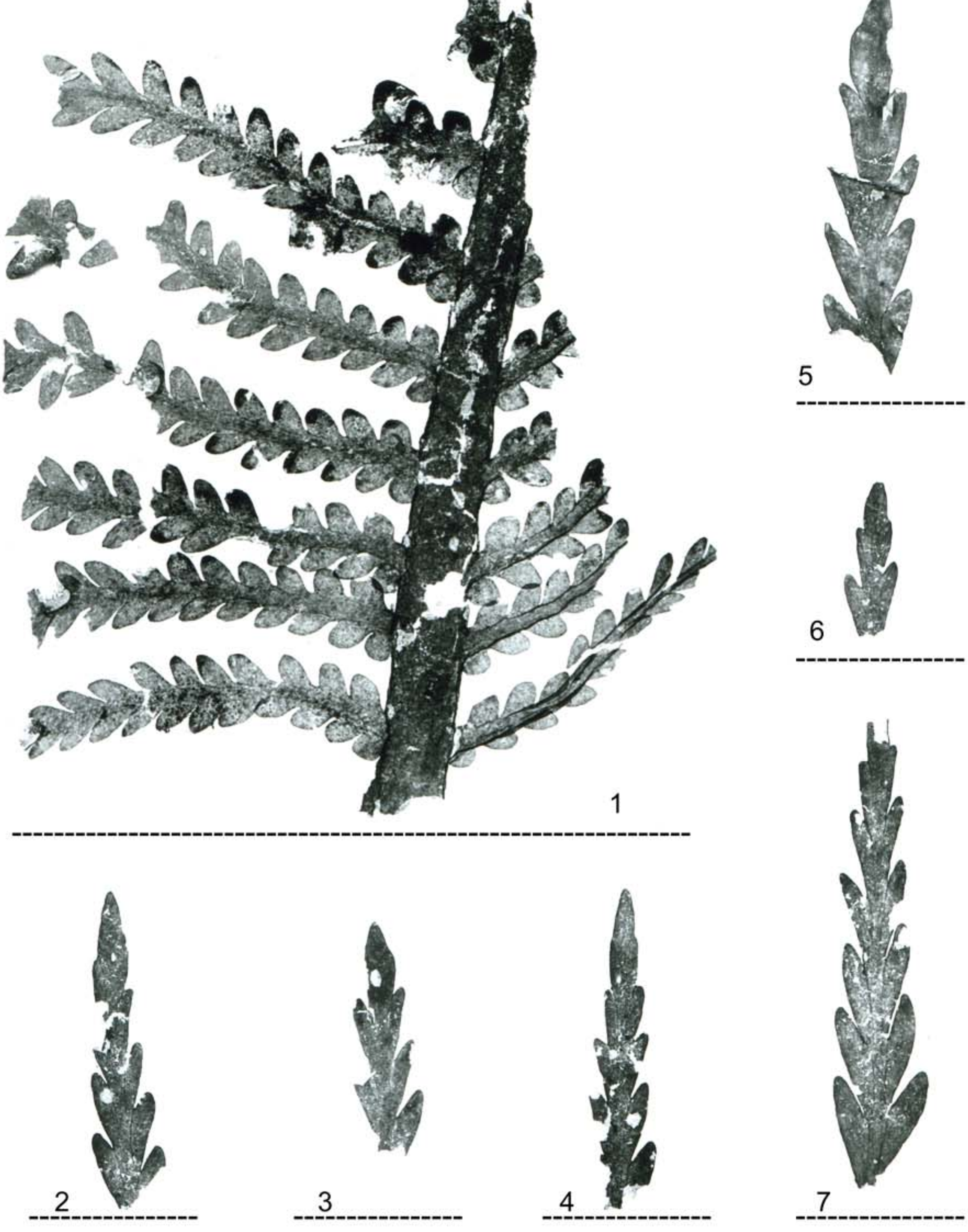


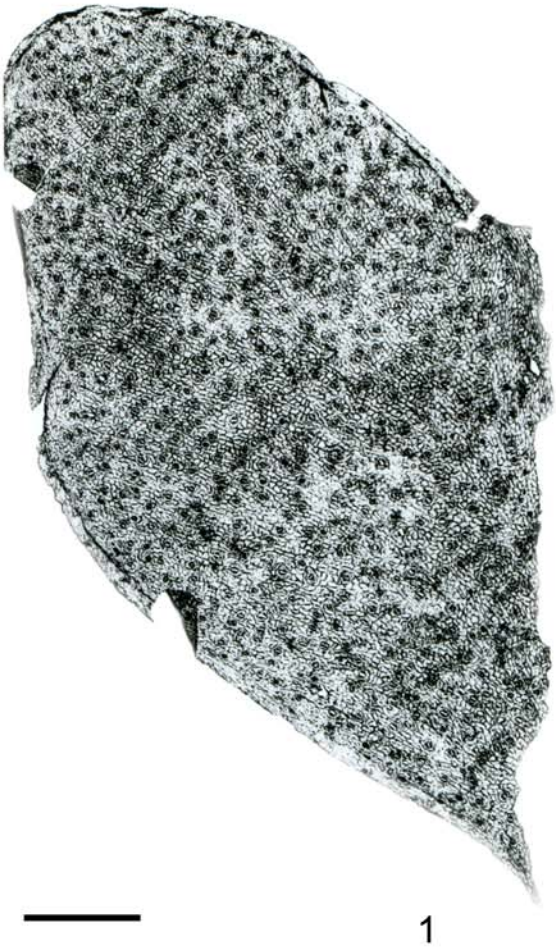
PLATE 11

Dicroidium jordanensis nov. sp.

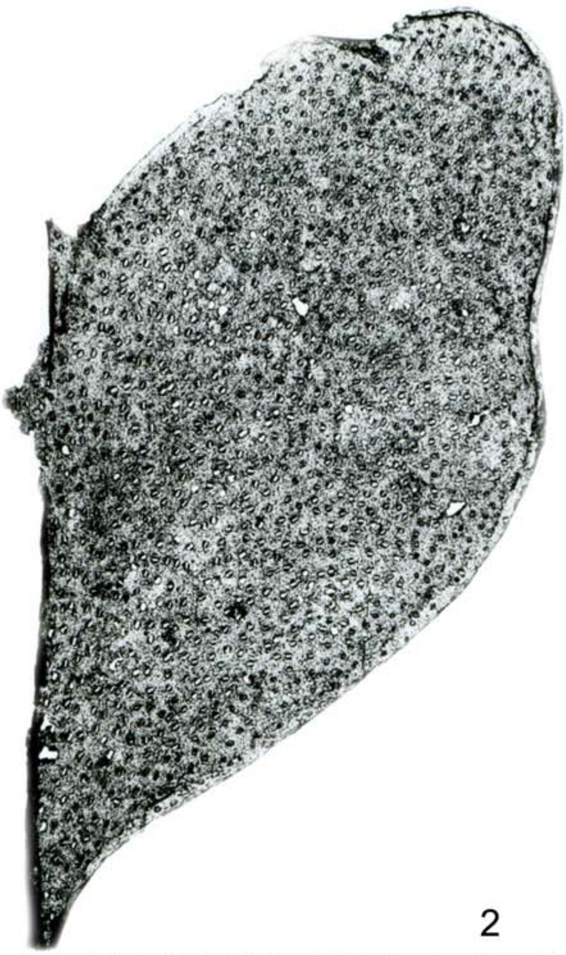
Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

1-2. Cuticles of the upper (1) and lower (2) surface of the same pinnule. Trapezoid pinnule from the basal part of a pinna. Note the difference in the stomatal frequency. Scale bar = 1 mm. 1. Slide S7U/007b; 2. Slide S7L/0007a.

Plate 11



1



2

PLATE 12

Dicroidium jordanensis nov. sp.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

1-2. Cuticles of the upper (1) and lower (2) surface of the same pinnule. Pinnule from the middle part of a pinna. Note the difference in cell size and the stomatal frequency. Scale bar = 0.5 mm. 1. Slide S31U/003b; 2. Slide S31L/003b.

Plate 12

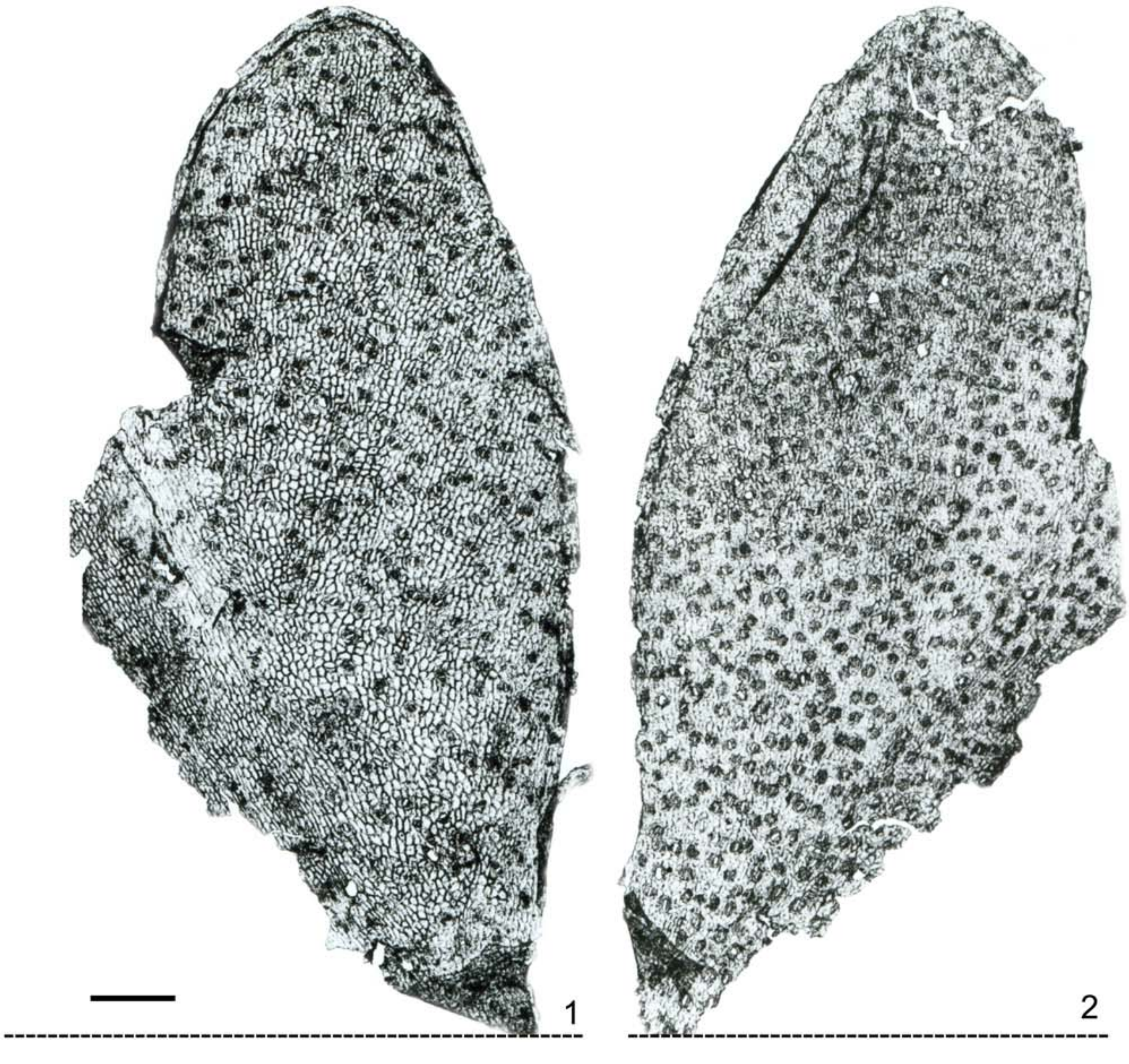


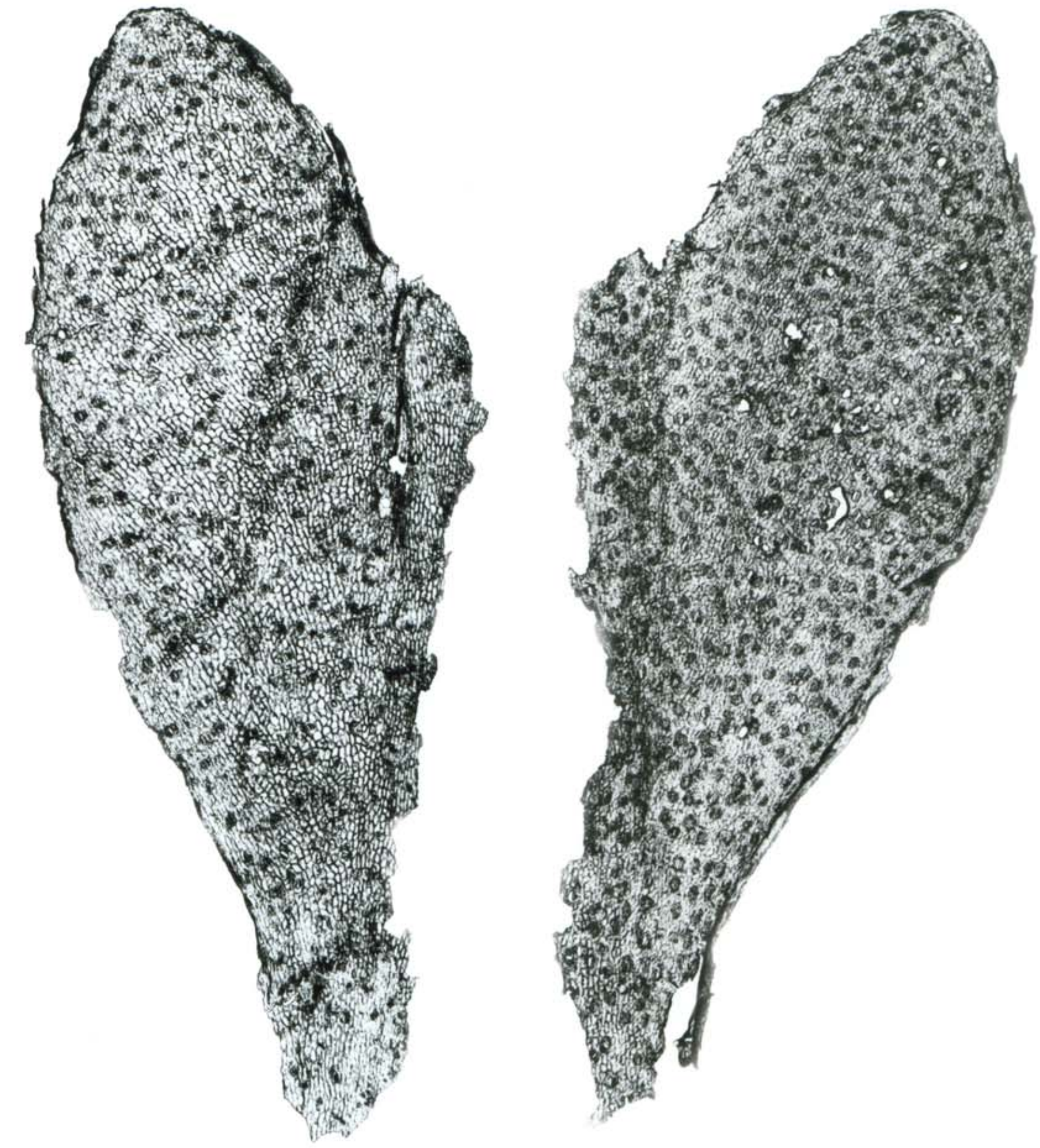
PLATE 13

Dicroidium jordanensis nov. sp.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster. Slide

1-2. Cuticles of the upper (1) and lower (2) surface of the same pinnule. Pinnule from the apical part of a pinna. Note the difference in cell size and the stomatal frequency. Scale bar = 0.5 mm. 1. Slide S31U/0002b; 2. Slide S31L/0002a.

Plate 13



1

2

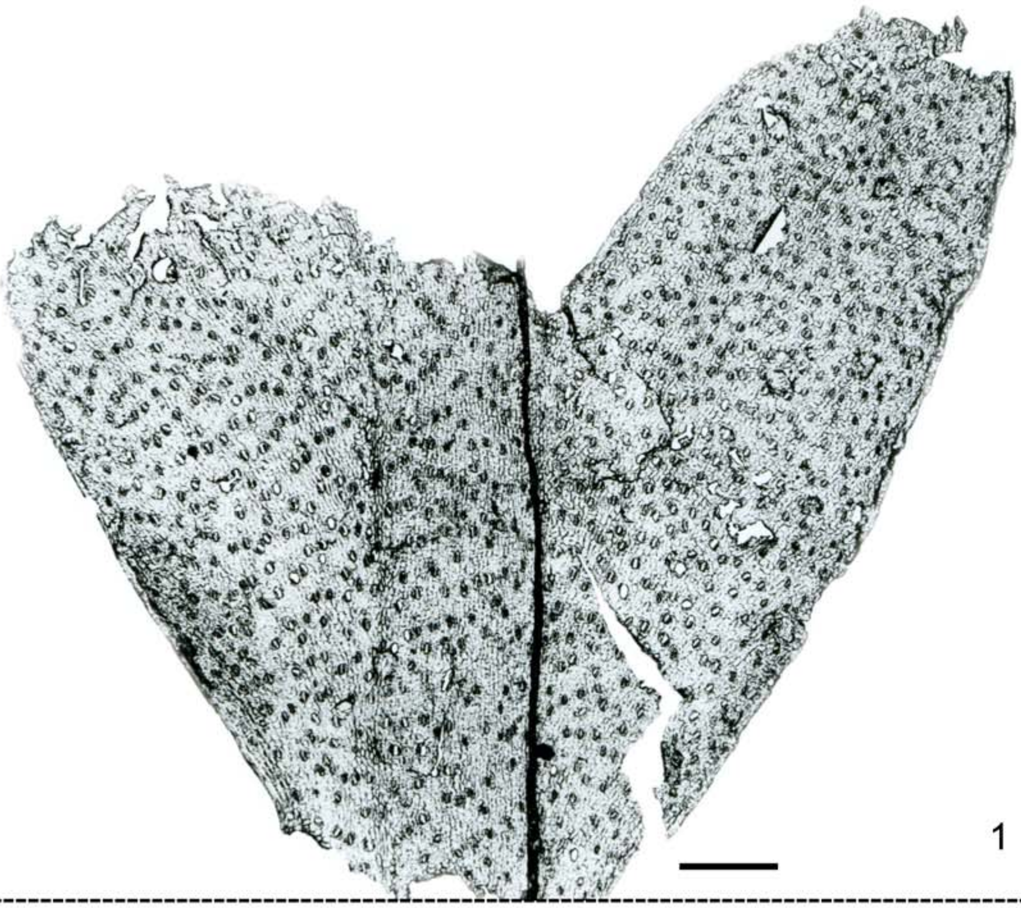
PLATE 14

Dicroidium jordanensis nov. sp.

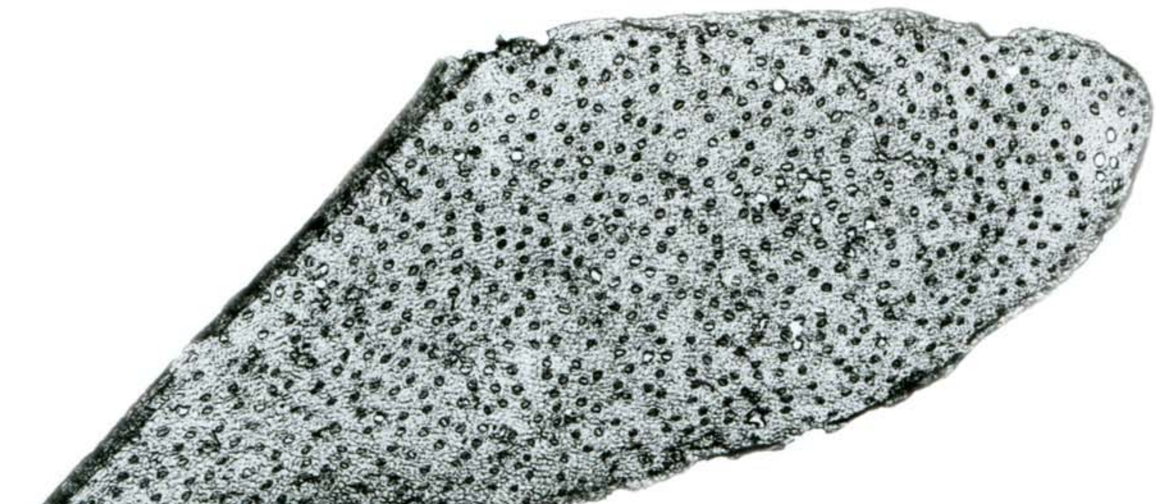
Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster. All figures at the same magnification.

1-2. Cuticles of the upper (1) and lower (2) leaf surfaces of the same pinnule. 1. Slide S31U; Slide S31L.

Plate 14



1



2

PLATE 15

Dicroidium jordanensis nov. sp.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster

1-2. Overviewof the upper (1) and lower (2) surfaceof the same pinnule. Note the difference in the stomatal frequency. 1. Slide S31U; 2. Slide S31L.

3-4. Overviewof the upper (3) and lower (4) surfaceof the same pinnule. Note the difference in the stomatal frequency. 3. Slide BN001U; 4. Slide BN001L.

Plate 15

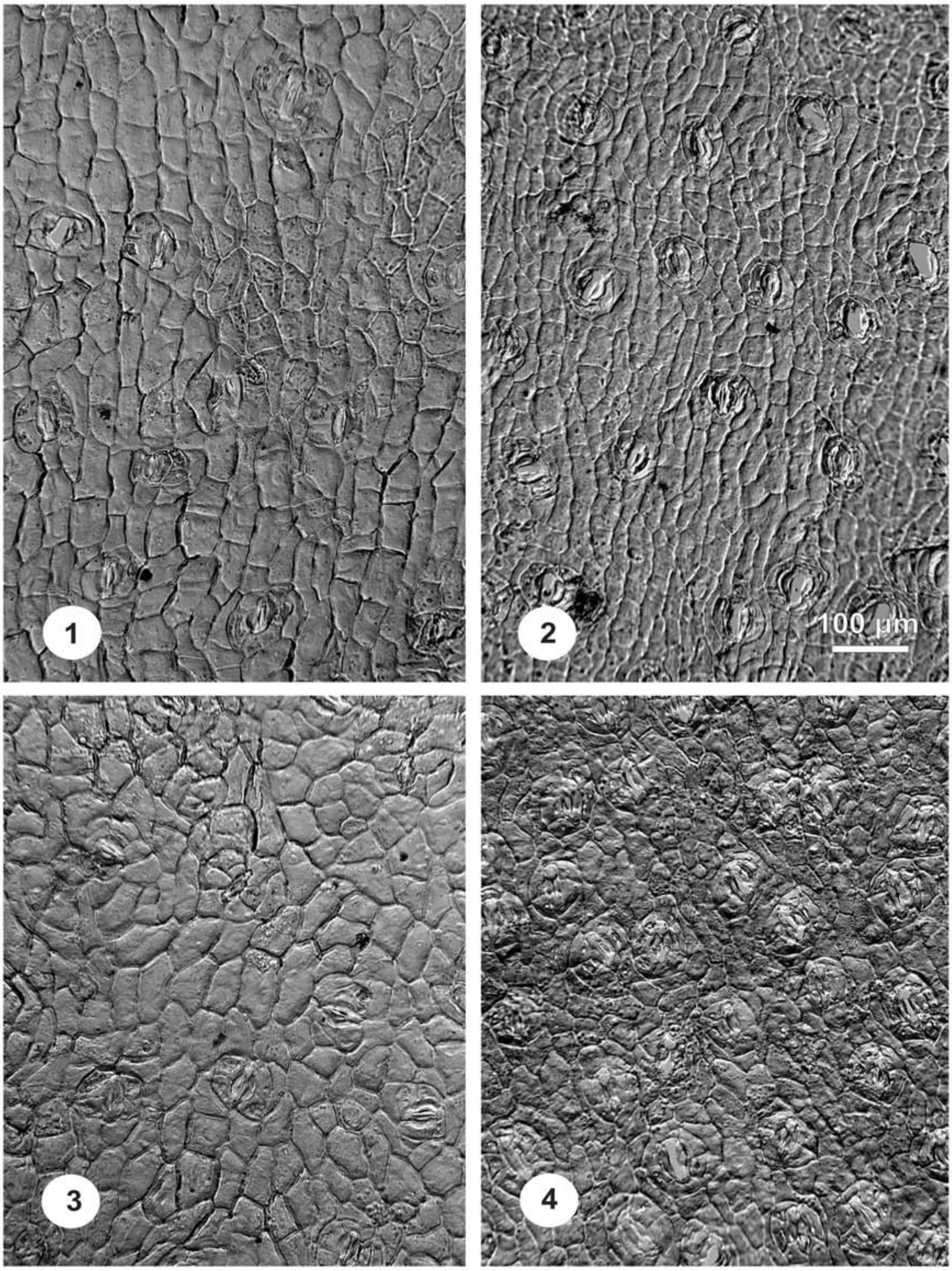


PLATE 16

Dicroidium jordanensis nov. sp.

Um Irna Formation, Upper Permian; Wadi Himara, Dead Sea Region, Jordan. Collection Forschungsstelle für Paläobotanik, Westfälische Wilhelms-Universität Münster.

1-2. Cuticles of the upper (1) and lower (2) leaf surfaces of the same pinnule. 1. Slide 009U; 2. Slide 009L.

3. Cuticle of the lower leaf surface showing stomata. Slide BN 001L.

4. Detail of Fig. 3 showing stomata.

5. Stoma of the upper leaf surface of the same pinnule as Figs. 3 + 4 showing a stomatal complex.

6. Stoma of the upper leaf surface with faintly visible

Plate 16

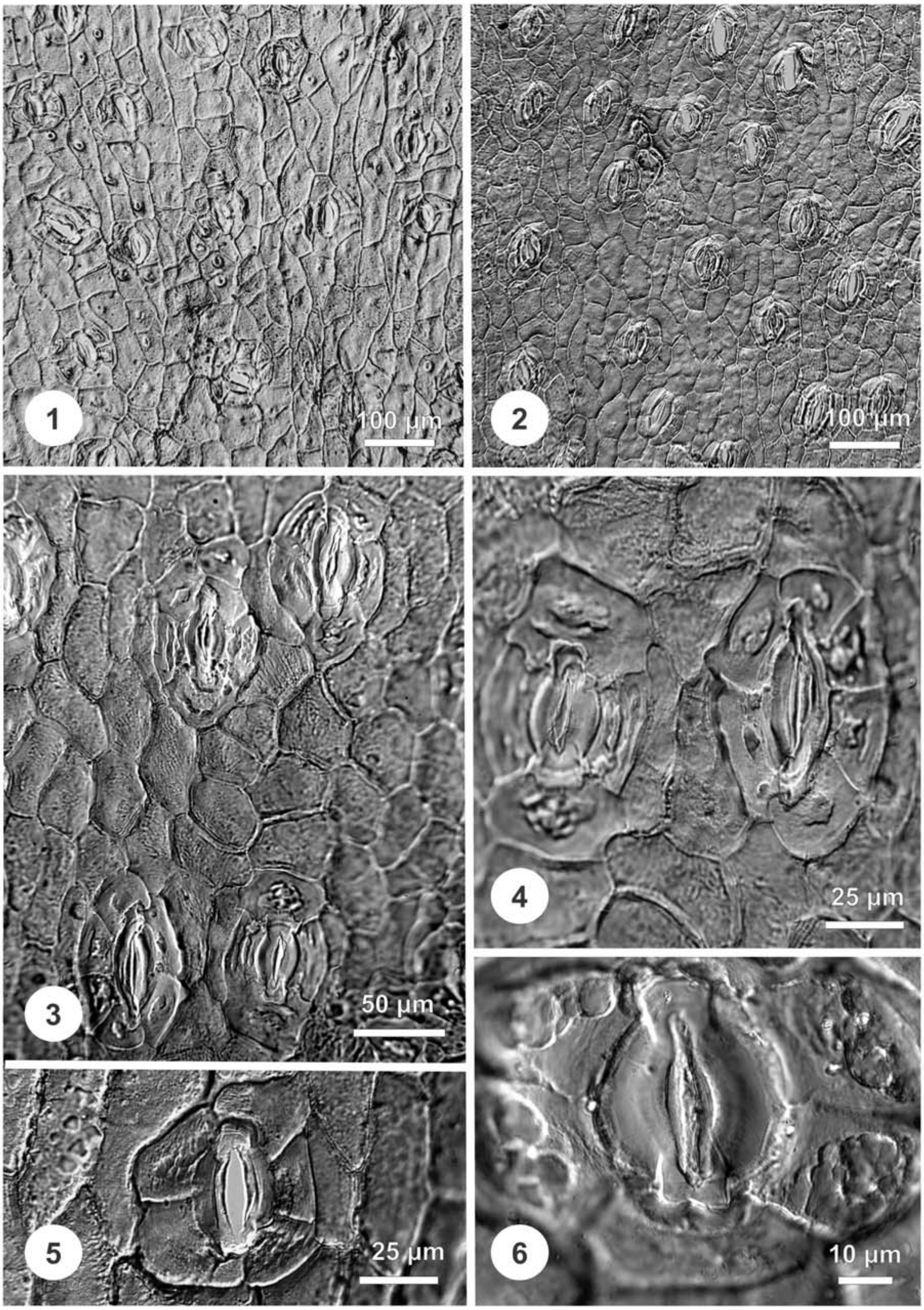


PLATE 17

Charcoal of *Dadoxylon*-type wood, Um Irna Formation, Late Permian, Jordan.

1. Tracheids in radial view with charred fungal hyphae; X 550.
2. Enlargement of 1, showing details of the branching patterns of the hyphae; X 1750.
3. Tracheids and wood rays in radial view; X 210.
4. Enlargement of 3, showing details of crossfield-pitting from the tracheid side; X 1100.
5. Tracheids in radial view with preserved tori in some of the pits; X 600.
6. Enlargement of 5, showing the preserved tori; X 1850.
7. Tracheids in radial view with bordered pits breaking away from the tracheidal walls; X 360.
8. Secondary xylem in transverse view; X 65.

Plate17

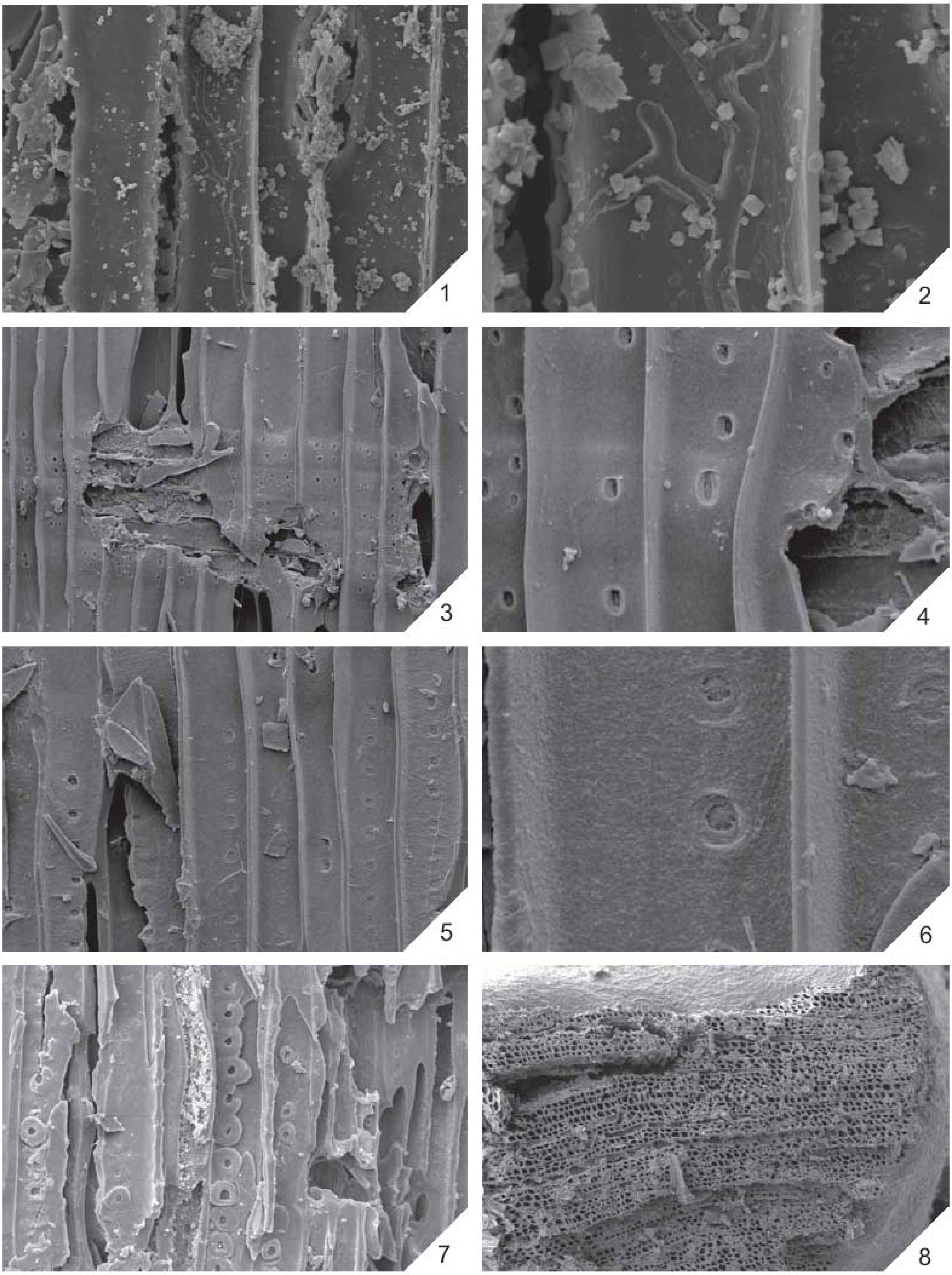


PLATE 18

Charcoal of potential corystospermalean affinity, Um Irna Formation, Late Permian, Jordan.

1. Secondary xylem in transverse view exhibiting ‘bogen-structures’; X 150.
2. Secondary wood in tangential view; X 80.
3. Enlargement of 2 showing details of rays; X 320.
4. Secondary wood in radial view; X 70.
5. Enlargement of 4 showing details of crossfield-pitting; X 175.
6. Enlargement of 4 showing details of araucariod pitting on the tracheid walls; X 310.
7. Secondary wood in tangential view with a pair of leaf traces and adjacent gap in the wood; X 35.
8. Enlargement of 7 showing details of a leaf trace; X 90.

Plate 18

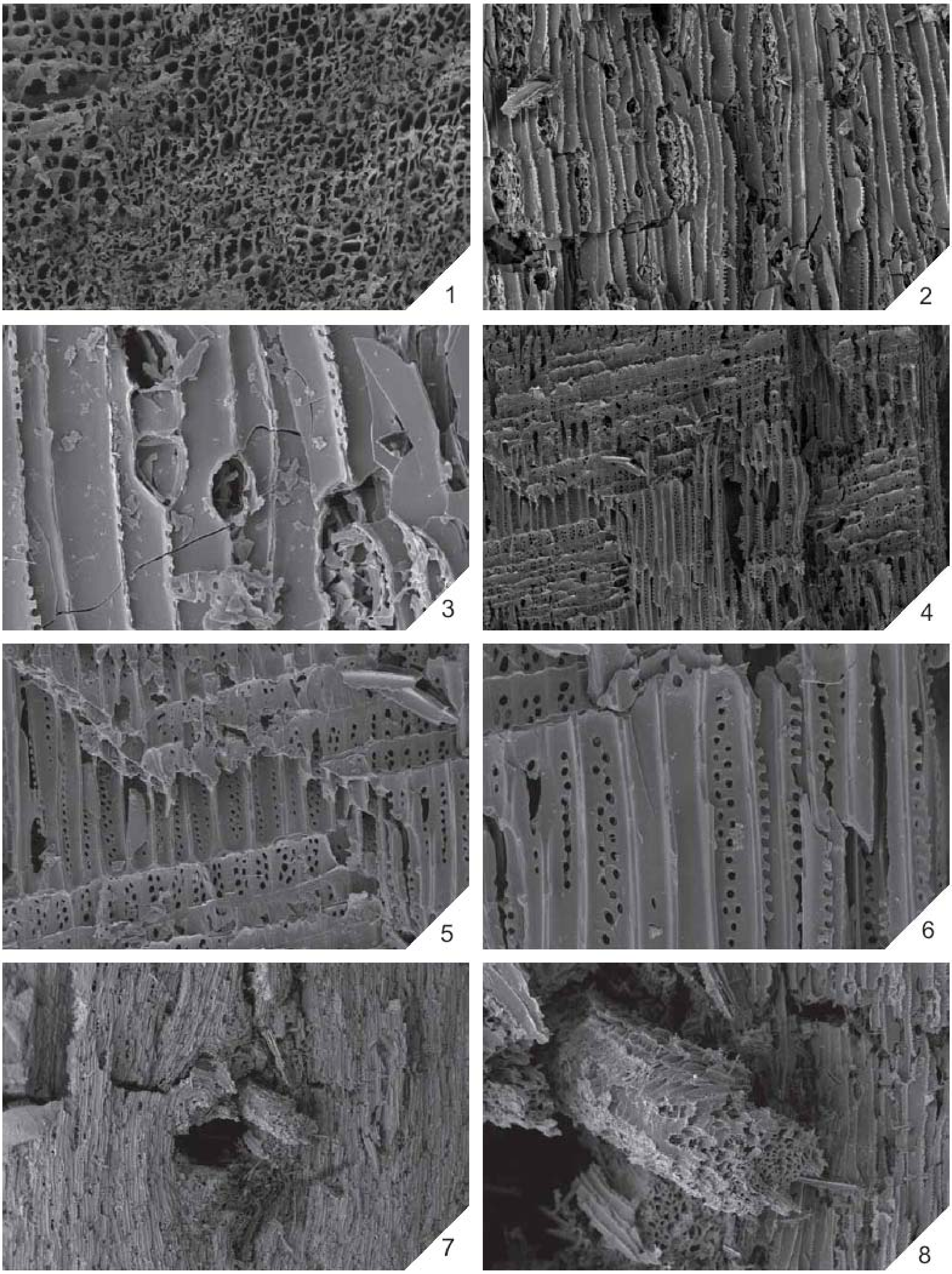


PLATE 19

1. *Leiotriletes* sp. (Naumova 1939) Potonie and Kremp 1954
X 1000, Um Irna Formation, Upper Permian, 11 UIR, S 1, EFC. B 185-186

2. *Triquitrites proratus* Balme 1970
X 1000, Um Irna Formation, Upper Permian, 8 UIR, S 1, EFC. B 22-23

3. *Leiotriletes* sp. (Naumova 1939) Potonie and Kremp 1954
X 400 Um Irna Formation, Upper Permian, 11 UIR, S 1, EFC. B 192-193

4. *Leiotriletes* sp. (Naumova 1939) Potonie and Kremp 1954
X400, Um Irna Formation, Upper Permian, 11 UIR, S 1, EFC. B 395

5. *Leiotriletes adnatus* (Kosanke) Ptonie and Kremp 1955
X 1000, Um Irna Formation, Upper Permian, 11 UIR, S 1, EFC.B 24-25

6. *Acanthotriletes tereteangulatus* Balme and Hennelly 1956
X 400, Um Irna Formation, Upper Permian, 10 UIR, S C3, EFC. B 192-193

7. *Camptotriletes warchianus* Balme 1970
X 400, Um Irna Formation, Upper Permian, 10 UIR, S B4, EFC. B 37

8. *Camptotriletes* sp.Potonie and Kremp 1954
X 400, Um Irna Formation, Upper Permian, 10 UIR, S A1, EFC. B 257

9. *Horriditriletes brevis* Bharadwaj and Salujha 1964
X 1000, Um Irna Formation, Upper Permian, 11UIR, S 1, EFC. B 348

10. *Verrucosisporites* sp. (Ibrahim 1933) emend. Smith and Butterworth 1967
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 802

11. *Foveotriletes* sp. Balme 1957
X 400, Um Irna Formation, Upper Permian, 10UIR, S C2, EFC.B 334

12. *Protohaploxypinus* sp. (Schaarschmidit 1963) Clarke 1965
X 400, Um Irna Formation, Upper Permian, 10UIR, S B2, EFC. B 711

Plate 19

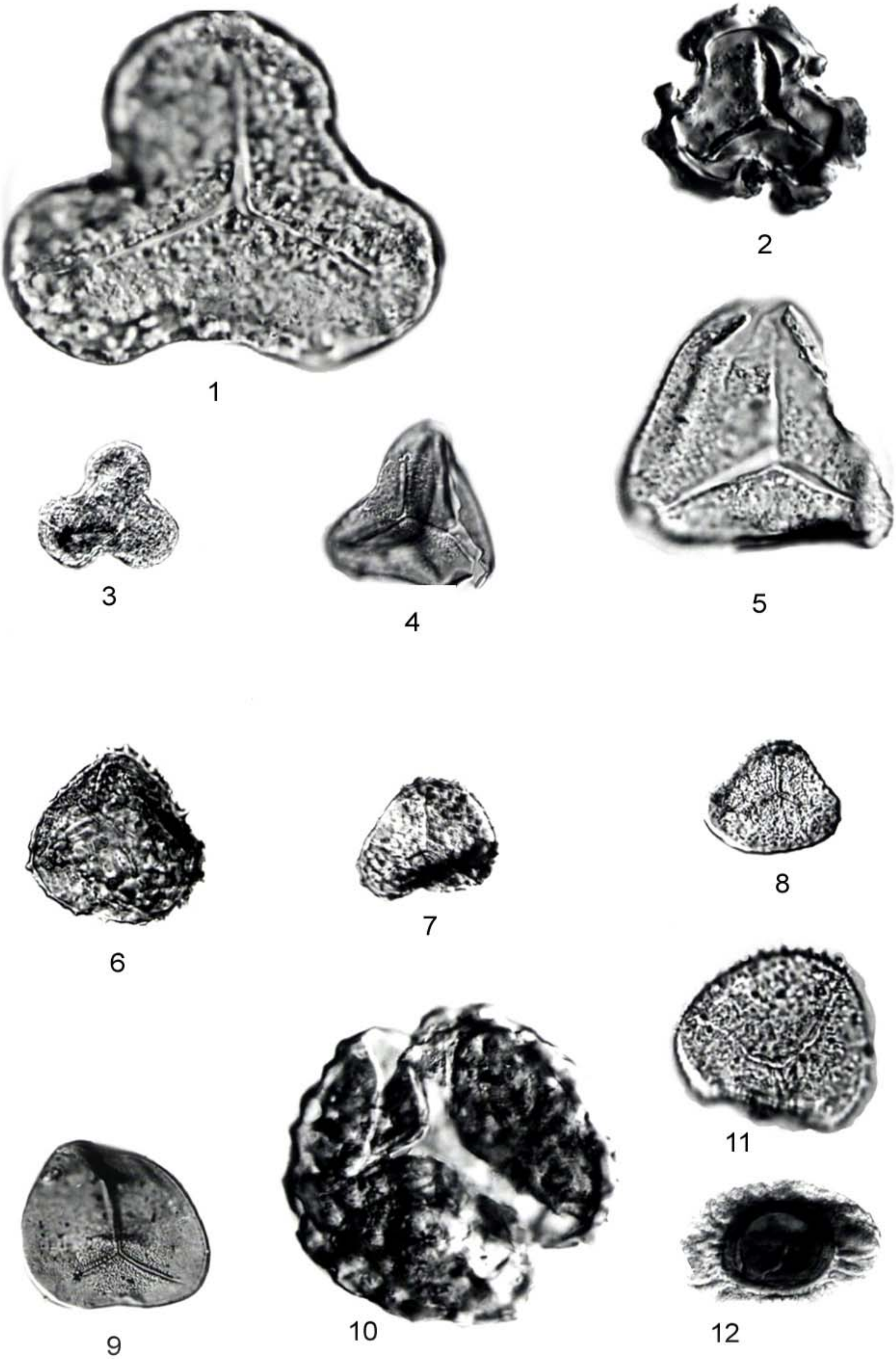


PLATE 20

1. *Protohaploxypinus microcorpus* (Schaarschmidit 1963) Clarke 1965
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. A 445

2. *Protohaploxypinus microcorpus*(Schaarschmidit 1963) Clarke 1965
X 400, Um Irna Formation, Upper Permian, 10UIR, S C1, EFC. B 276

3. *Protohaploxypinus microcorpus* (Schaarschmidit 1963) Clarke 1965
X 400, Um Irna Formation, Upper Permian, 10UIR, S C3, EFC. B 654

4. *Protohaploxypinus varius* (Bharadwaj 1962) Balma 1970
X 1000, Um Irna Formation, Upper Permian, 10UIR, S C1, EFC. B 832

5. *Protohaploxypinus limpidus* (Balme and Hennelly 1955) Balme and Hennelly 1958
X 1000, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 158

6. *Protohaploxypinus amplus* (Balme and Hennelly 1955) Hart 1964
X 400, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 73-74

7. *Protohaploxypinus* sp. (Schaarschmidit 1963) Klarke 1965
X 400, Um Irna Formation, Upper Permian, 11UIR, S C3, EFC. B73-74

8. *Protohaploxypinus* sp. Schaarschmidit 1963) Klarke 1965
X 400, Um Irna Formation, Upper Permian, 10UIR, S C1, EFC. B-678

9. *Protohaploxypinus* sp. (Schaarschmidit 1963) Klarke 1965
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 577

10. *Protohaploxypinus* cf. *limpidus* (Balme and Hennelly 1955) Balme and Hennelly 1958
X 400, Um Irna Formation, Upper Permian, 10UIR, S C4, EFC. B 128

11. *Lunatisporitres pellucidus* (Goubin 1965) Balme 1970
X 400, Um Irna Formation, Upper Permian, 10UIR, S B2, EFC. B 128

Plate 20

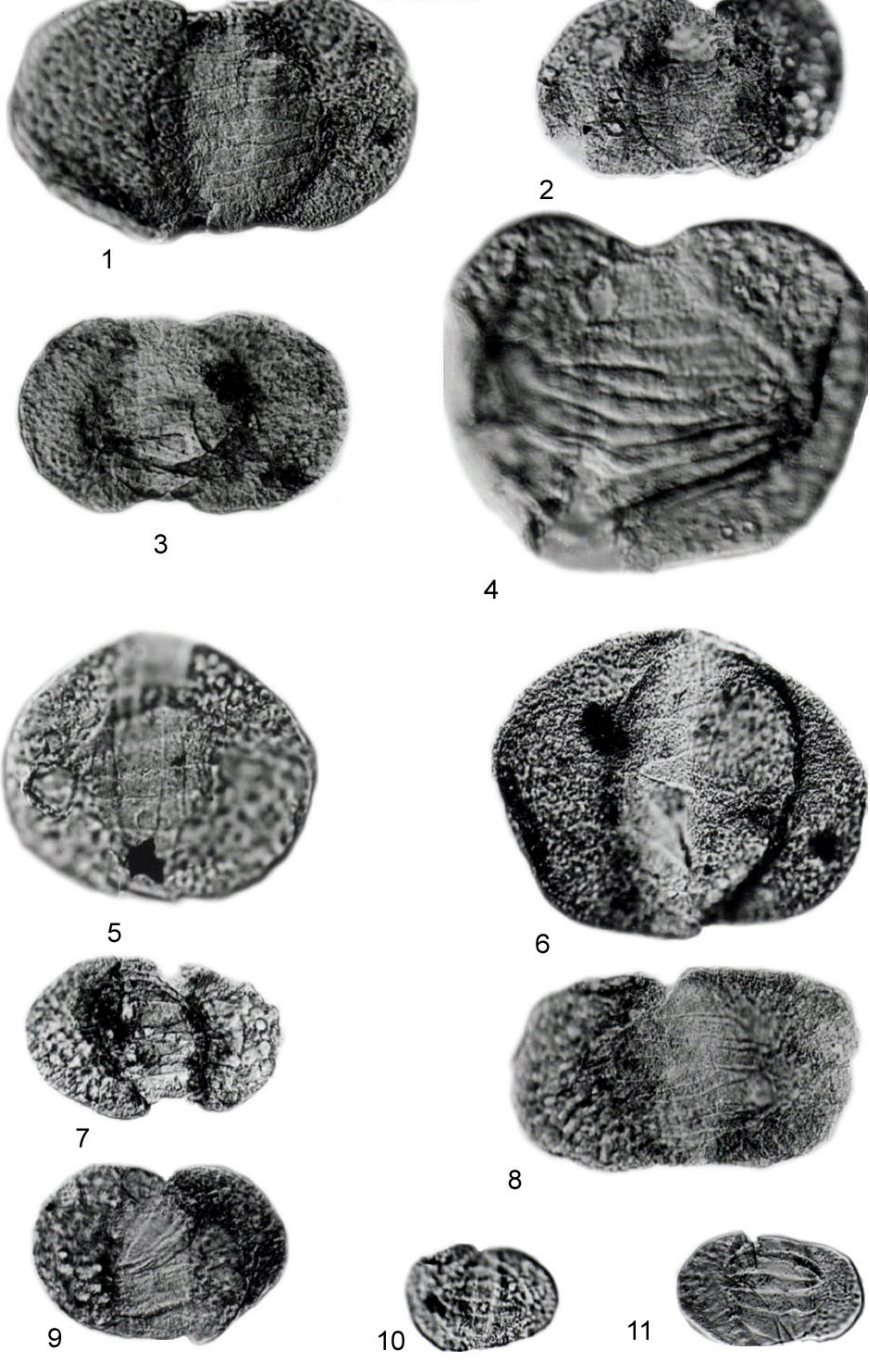


PLATE 21

1. *Lunatisporites pellucidus* (Goubin 1965) Balme 1970
X 400, Um Irna Formation, Upper Permian, 10UIR, S A3, EFC. B 143-144
2. *Lunatisporites fuscus* Bharadwaj and Salujha 1964
X 400, Um Irna Formation, Upper Permian, 10UIR, S A2, EFC. B 70-71
3. *Hamiapollenites insolitus* Bharadwaj and Salujha 1964
X 400, Um Irna Formation, Upper Permian, 10UIR, S A3, EFC. B 91-92
4. *Jugasporites delasaccei* (Potonie and Klaus) Leschik 1956
X 400, Um Irna Formation, Upper Permian, 10UIR, S B1, EFC. A 597-598
5. *Jugasporites delasaucei* (Potonie and Klaus) Leschik 1956
X 400, Um Irna Formation, Upper Permian, 10UIR, S B 2, EFC. B 362
6. *Jugasporites delasaucei*(Potonie and Klaus) Leschik 1956
X 400, Um Irna Formation, Upper Permian, 10UIR, S A3, EFC. B 739
7. *Illinites spectabilis* Leschik 1956
X 400, Um Irna Formation, Upper Permian, 10UIR, S C3, EFC. B 529
8. *Illinites tectus* (Leschik 1956) Clarke 1965
X 400, Um Irna Formation, Upper Permian, 10UIR, S B 2, CFC. B 643-644
9. *Gardenasporites moroderi* Klaus 1963
X 400, Um Irna Formation, Upper Permian, 10UIR, S A3, EFC. B 331-332
10 *Vestigisporites* sp. (Balme and Hennelly 1955) emend. Hart 1960
X 400, Um Irna Formation, Upper Permian, 10UIR, S C1, EFC. B 223-224
11. *Illinites parvus* Leschik 1956
X 400, Um Irna Formation, Upper Permian, 10UIR, S A2, EFC. B 535
12. *Jugasporites delasaucei* (Potonie and Klaus) Leschik 1956
X 400, Um Irna Formation, Upper Permian, 10UIR, S C3, EFC. B 701
13. *Lueckisporites virkkiae* Potonie and Klaus 1954
X 400, Um Irna Formation, Upper Permian, 10UIR, S B2, EFC. B 282
14. *Lueckisporites virkkiae* Potonie and Klaus 1954
X 400, Um Irna Formation, Upper Permian, 10UIR, S A2, EFC. B 70-71
15. *Lueckisporites virkkiae* Potonie and Klaus 1954
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 437
16. *Lueckisporites virkkiae* Potonie and Klaus 1954
X 400, Um Irna Formation, Upper Permian, 10UIR, S C1, EFC. B 581
17. *Klausipollenites schaubergeri* (Potonie and Klaus1954) Jansonius 1962
X 400, Um Irna Formation, Upper Permian, 10UIR, S A5, EFC. B 519
18. *Klausipollenites schaubergeri* (Potonie and Klaus1954) Jansonius 1962
X 400, Um Irna Formation, Upper Permian, 10UIR, S C1, EFC. B 638-639
19. *Klausipollenites schaubergeri* (Potonie and Klaus1954) Jansonius 1962
X 400, Um Irna Formation, Upper Permian, 10UIR, S B 1, EFC. B 68-69
20. *Klausipollenites schaubergeri* (Potonie and Klaus1954) Jansonius 1962
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 84.
21. *Pinuspollenites thoracatus* Balme 1970
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 621

Plate 21

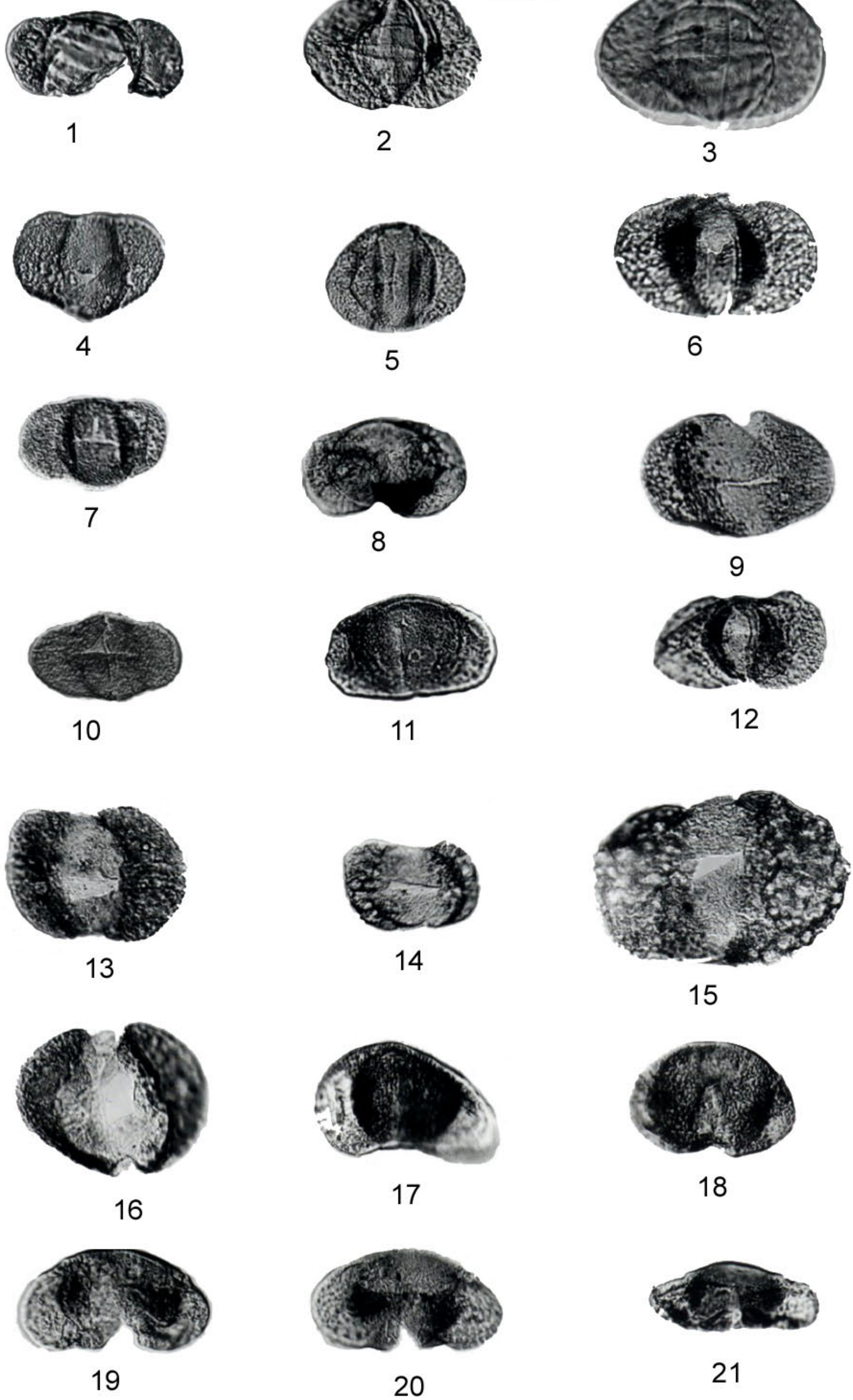


PLATE 22

1. *Falcisporites stabilis* Balme 1970
X 400, Um Irna Formation, Upper Permian, 10UIR, S B1, EFC. B 344-345
2. *Falcisporites stabilis* Balme 1970
X 400, Um Irna Formation, Upper Permian, 10UIR, S C1, EFC. B 372
3. *Falcisporites stabilis* Balme 1970
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. A 147-148
4. *Falcisporites stabilis* Balme 1970
X 400, Um Irna Formation, Upper Permian, 10UIR, SA1, EFC.B 177-178
5. *Falcisporites zapfei* Potonie and Klaus 1954
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 49-50
6. *Falcisporites zapfei* Potonie and Klaus 1954
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 683
7. *Falcisporites nuthallensis* (Clarke 1965) Balme 1970
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1,EFC. B 671-672
8. *Falcisporites nuthallensis* (Clarke 1965) Balme 1970
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 84
9. *Falcisporites* sp. (Leschik 1956) emend. Klaus 1963
X 400, Um Irna Formation, Upper Permian, 10UIR, S C1, EFC. B 354-355
10. *Falcisporites* sp. (Leschik 1956) emend. Klaus 1963
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 781
11. *Falcisporites* sp. (Leschik 1956) emend. Klaus 1963
X 400, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 331-332
12. *Striatopodocarpites* sp. (Zoricheva and Sedova 1954, Sedova 1956) emend. Hart 1964
X 400, Um Irna Formation, Upper Permian, 11UIR, S 1, EFC. B 613
13. *Striatopodocarpites* sp. (Zoricheva and Sedova 1954, ex Sedova 1956) emend. Hart 1964
X 400, Um Irna Formation, Upper Permian, 10UIR, S C3, EFC. B 864
14. *Striatopodocarpites fusus* (Balme and Hennelly) Potonie 1958
X 400, Um Irna Formation, Upper Permian, 10UIR, S B1, EFC. B 131-132
15. *Striatopodocarpites fusus* (Balme and Hennelly) Potonie 1958
X 400, Um Irna Formation, Upper Permian, 10UIR, S B1, EFC, B 219
16. *Platysaccus fimbriatus* Potonie and Klaus 1954
X 400, Um Irna Formation, Upper Permian, 10UIR, S B3, B 739-740
17. *Platysaccus* sp. (Naumova 1937) Potonie and Klaus 1954
X 1000, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 297

Plate 22

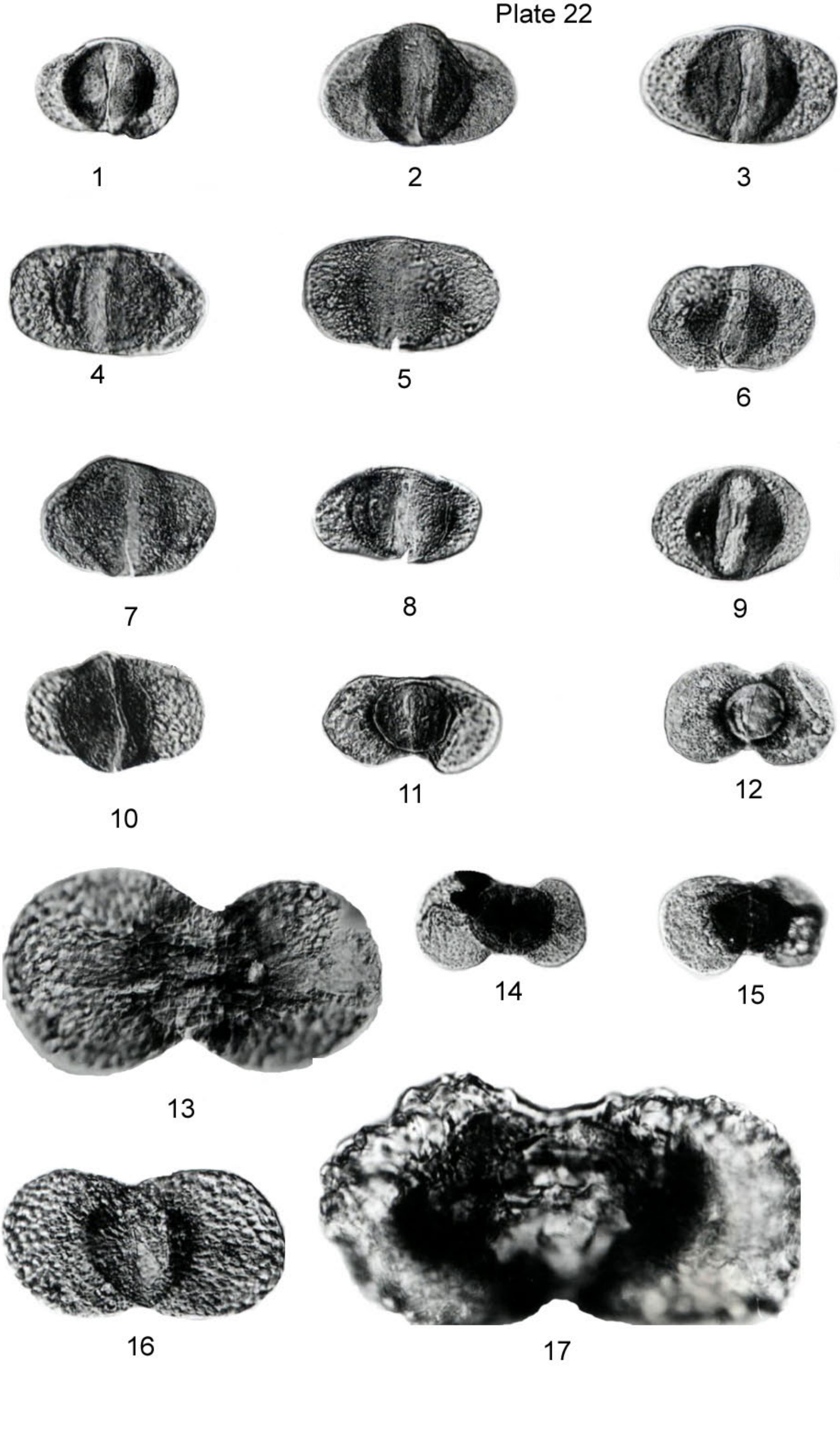


PLATE 23

1. *Guthoerlisporites cancellsus* Playford and Dettmann 1965
X 400, Um Irna Formation, Upper Permian, 10UIR, S C4; EFC. B 486

2. *Guthoerlisporites cancellsus* Playford and Dettmann 1965
X 400, Um Irna Formation, Upper Permian, 10UIR, S C2a, EFC. B 83-84

3. *Nuskoisporites klausii* Grebe 1957
X 400, Um Irna Formation, Upper Permian, 10UIR, S B3, EFC, B 626

4. *Potonieisporites novices* Bharadwaj 1954
X 400, Um Irna Formation, Upper Permian, 10UIR, S C3, EFC. C 636

5. *Potonieisporites novices* Bharadwaj 1954
X 400, Um Irna Formation, Upper Permian, 11UIR, S 1, EFC.B 854

6. *Nuskoisporites klausii* Grebe 1957
X 400, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 344

7. *Nuskoisporites klausii* Grebe 1957
X 400, Um Irna Formation, Upper Permian, 10UIR, S B3, EFC. B 605

8. *Plicatipollenites indicus* (Lele 1964) emend. Srivastava 1970
X 400, Um Irna Formation, Upper Permian, 10UIR, S C3, EFC. B 617

9. *Nuskoisporites klausii* Grebe 1957
X 1000, Um Irna Formation, Upper Permian, 10UIR, S A3, EFC. B 618

10. *Crustaesporites globosus* Leschik 1956
X 400, Um Irna Formation, Upper Permian, 10UIR, S A2, EFC. B 864

11. *Cordaitina* sp. (Samoilovich 1953) Hart 1963
X 400, Um Irna Formation, Upper Permian, 10UIR, S B2, EFC. B 427

Plate 23

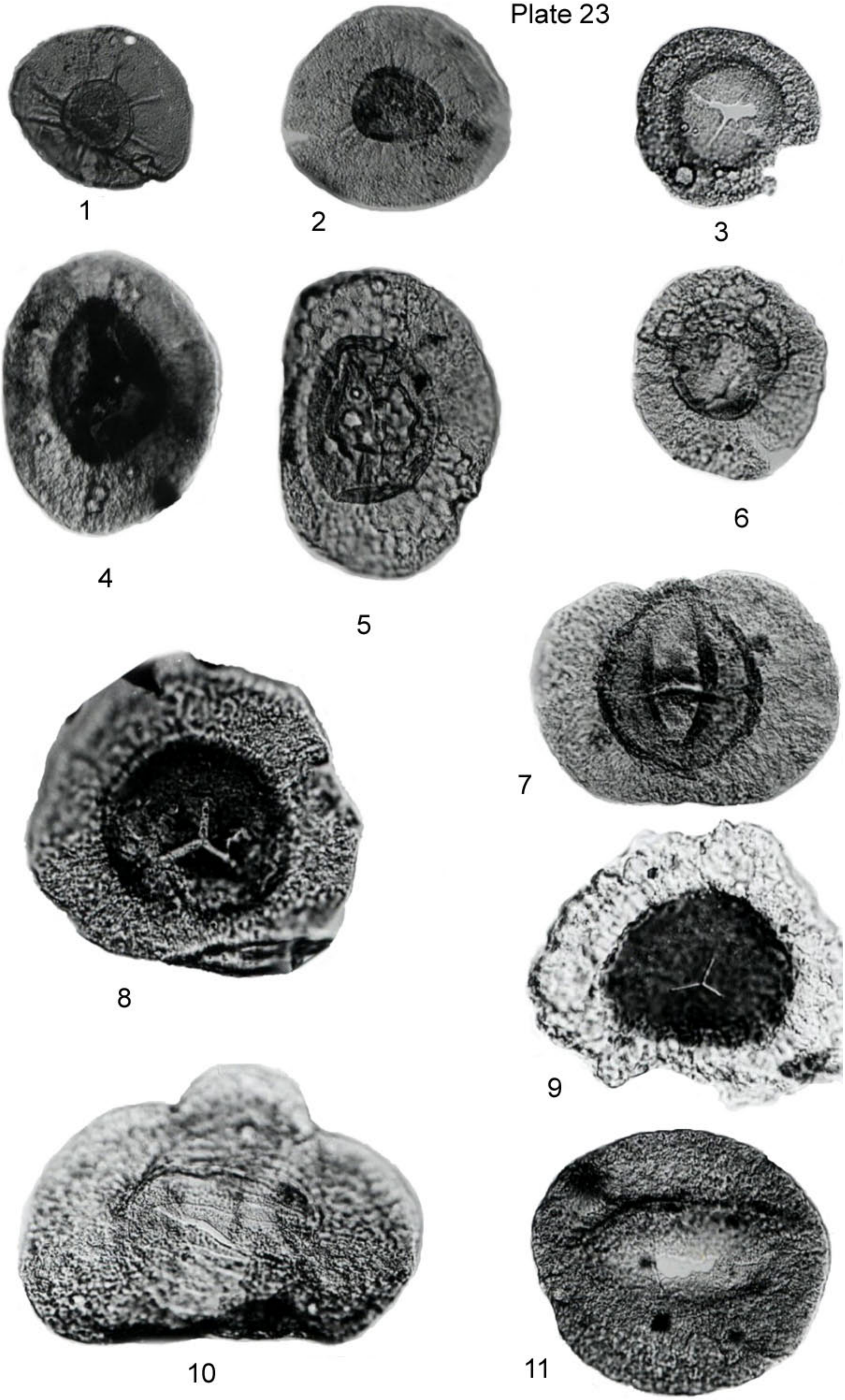


PLATE 24

1. *Potonieisporites novicus* Bharadwaj 1954
X 400, Um Irna Formation, Upper Permian, 10UIR, S C1a, EFC. B623

2. *Potonieisporites* sp. Bharadwaj 1954
X 1000, Um Irna Formation, Upper Permian, 8UIR, S 2, EFC. B 895

3. *Triplexisporites* sp. De Jersey and Hamilton 1967
X 1000, Um Irna Formation, Upper Permian, 8UIR, S 2, EFC. B 641

4. *Cedripites* sp. Wodehouse 1933
X 1000, Um Irna Formation, Upper Permian, 10UIR, S A1, EFC. B 296-297

5. *Punctatisporites minutes* (Ibrahim 1933) Potonie and Kremp 1956
X 1000, Um Irna Formation, Upper Permian, 10UIR, S B1, EFC. B 37

6. *Nuskoisporites klausii* Grebe 1957
X 400, Um Irna Formation, Upper Permian, 11UIR, S1, EFC. B 70

7. *Anaplanisporites stipulates* Jansonius 1962
X 400, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 107

8. *Anaplanisporites stipulates* Jansonius 1962
X 1000, Um Irna Formation, Upper Permian, 11UIR, S1, EFC. B 602

9. *Guttulapollenites hannonicus* Goubin 1965
X 1000, Um Irna Formation, Upper Permian, 10UIR, S B1, EFC. B 591

10. *Anapiculatisporites* sp. Potonie and Kremp 1954
X 1000, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 167-168

11. *Anapiculatisporites spiniger* (Leschik 1956a) Reinhardt 1961
X 1000, Um Irna Formation, Upper Permian, 10UIR, S C3a, EFC. B 737

Plate 24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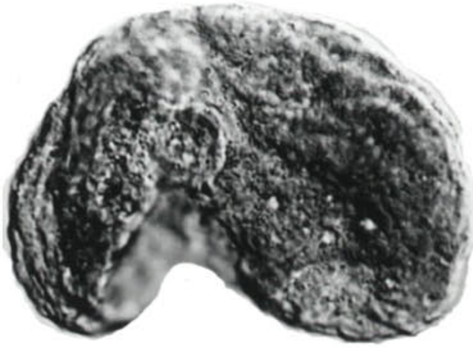
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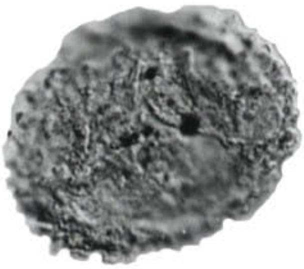
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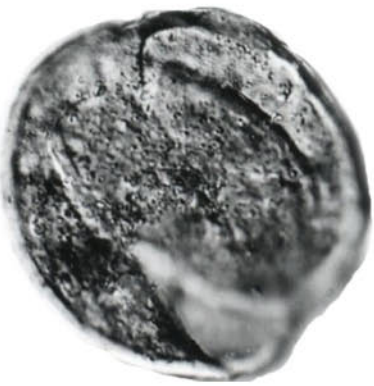
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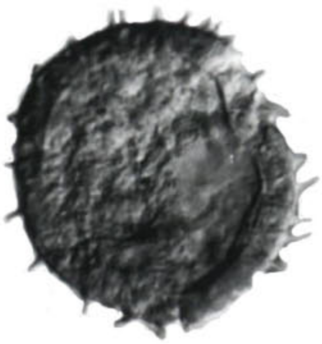
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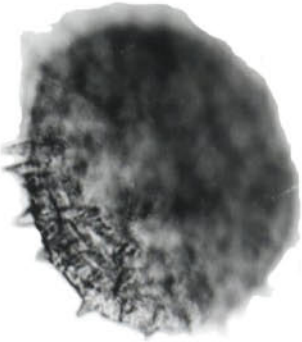
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PLATE 25

1. *Polypodiidites* sp. Ross 1949
X 1000, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 627-628

2. *Polypodiidites* sp. Ross 1949
X 1000, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 629

3. *Leiotriletes* sp. (Naumova 1939) Potonie and Kremp 1954
X 1000, Um Irna Formation, Upper Permian, 11UIR, S1, EFC. B 482-483

4. *Foveotriletes* sp. Potonie 1956
X 1000, Um Irna Formation, Upper Permian, 10UIR, S C2, EFC. B 761-762

5. *Retusotriletes* sp. (Naumova 1953) emend. Streel 1964
X 1000, Um Irna Formation, Upper Permian, 10UIR, S C3a, EFC. B 35

6. *Retusotriletes* sp. (Naumova 1953) emend. Streel 1964
X 400, Um Irna Formation, Upper Permian, 10UIR, S C2, EFC. B 694

7. *Punctatisporites gretensis* Balme and Hennelly 1956
X 400, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 566

8. *Panctatisporites* sp. (Ibrahim 1933) Potonie and Kremp 1954
X 400, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 515-516

9. *Punctatisporites.* sp. (Ibrahim 1933) Potonie and Kremp 1954
X 400, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 270

10. *Calamospora diversiformis* Balme and Hennelly 1956
X 400, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 275-276

11. *Kraeuselisporites echinatus*. Reinhardt and Schön 1967
X 400, Um Irna Formation, Upper Permian, 11UIR, S B1, EFC. A 627-628

12. *Kraeuselisporites* sp. Leschik 1956, emend. Jansonius 1962
X 400, Um Irna Formation, Upper Permian, 10UIR, S C3, EFC. B 318-319

13. *Calamospora* sp. Schopf, Wilson and Bentall 1944
X 400, Um Irna Formation, Upper Permian, 10UIR, S C2, EFC. B 256

14. *Laevigatosporites vulgaris* (Ibrahim 1932) Loose 1934
X 400, Um Irna Formation, Upper Permian, 11UIR, S 2, EFC. B 515-516

15. *Laevigatosporites vulgaris* (Ibrahim 1932) Loose 1934
X 400, Um Irna Formation, Upper Permian, 10UIR, S C3a, EFC. B101

Plate 25

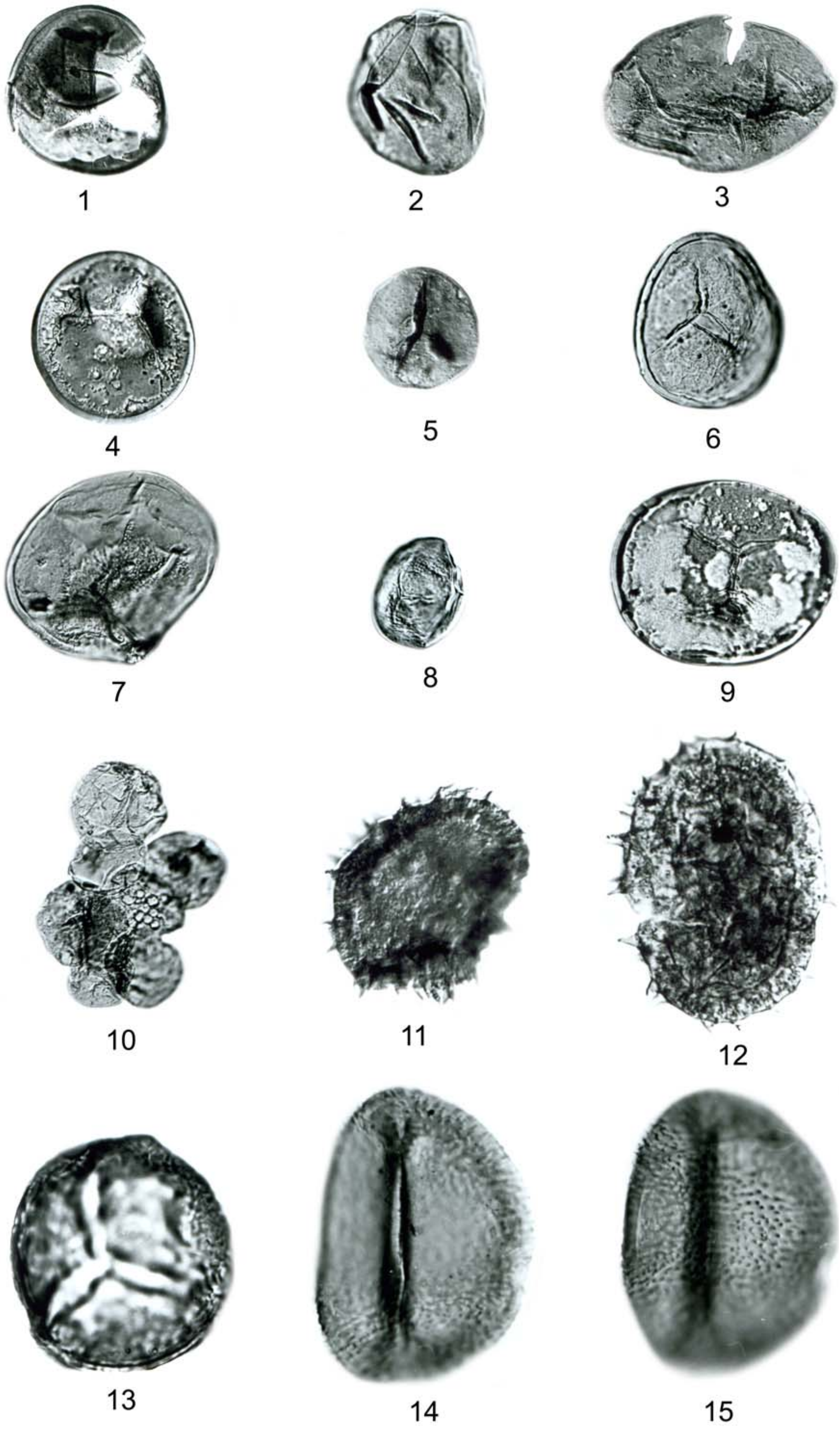

PLATE 26

1. Unidentified grain
   X 1000, Um Irna Formation, Upper Permian, 10UIR, S C3, EFC. C 304

2. *Vittatina* sp. (Luber 1941) Wilson 1962
   X 1000, Um Irna Formation, Upper Permian, 10UIR, S C1, EFC. B 584-585
3. *Vittatina* sp. (Luber 1941) Wilson 1962
   X 1000, Um Irna Formation, Upper Permian, 10UIR, S 2, EFC. B 725

4. *Vittatina* sp. (Luber 1941) Wilson 1962
   X 400, Um Irna Formation, Upper Permian, 10UIR, S B 1, EFC. B671

5. *Tympanicysta stochiana* Balme 1980
   X 400, Um Irna Formation, Upper Permian, 10UIR, S B1, EFC. B 586-587

6. *Tympanicysta stochiana* Balme 1980
   X 400, Um Irna Formation, Upper Permian, 10UIR, S C3, EFC. B 610

7. *Tympanicysta stoschiana* Balme 1980
   X 1000, Um Irna Formation, Upper Permian, 10UIR, S A6, EFC. B 644-645

8. *Cycadopites* sp. (Woodhouse 1935) Wilson and Webster 1946
   X 400, Um Irna Formation, Upper Permian, 10UIR, S B2, EFC. B 821

9. *Cycadopites* sp. (Woodhouse 1935) Wilson and Webster 1946
   X 400, Um Irna Formation, Upper Permian, 10UIR, SA1, EFC. B49-50

10. *Vittatina* sp. (Luber 1941) Wilson 1962
    X 1000, Um Irna Formation, Upper Permian, 10UIR, S B2, EFC. B 566

11. Organic facies
    X 10, Um Irna Formation, Upper Permian, 10UIR, S C4

Plate 26


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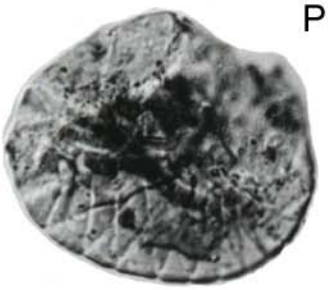
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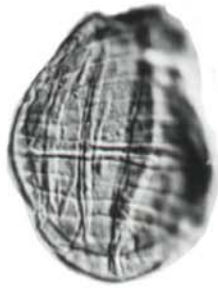
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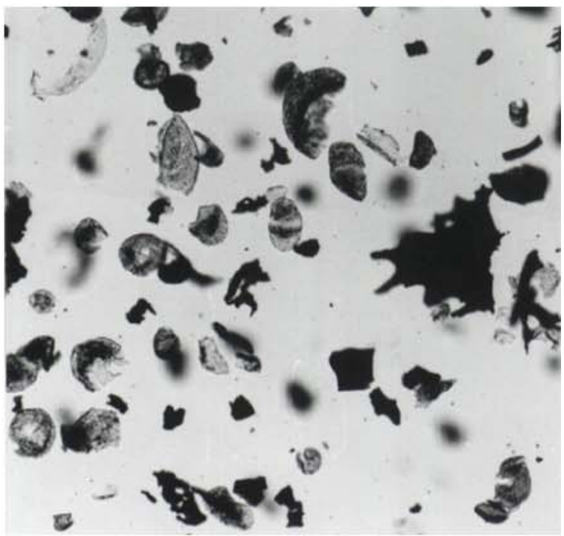
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PLATE 27

1. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 127

2. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 600, Ma'in Formation, Lower Triassic, 6MAI, S 6, EFC. B 725

3. *Aratrisporites paenulatus* Playford and Dettmann 1965
X 600, Ma'in Formation, Lower Triassic, 10DAR, S 1, EFC. B 561

4. *Aratrisporites* sp (Leschik 1955) emend. Playford and Dettmann 1965
X 600, Ma'in Formation, Lower Triassic, 6MAI, S 4, EFC. B 213

5. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 600, Ma'in Formation, Lower Triassic, 6MAI, S 2, EFC. B 487

6. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 600, Ma'in Formation, Lower Triassic, 6MAI, S 10, EFC. B 731

7. *Endosporites papillatus* Jansonius 1962
X 1000, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 732

8. *Endosporites papillatus* Jansonius 1962
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 1, EFC. B 302

9. *Endosporites papillatus* Jansonius 1962
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 6, EFC. B 424-425

10. *Spinotriletes* sp. Mädler 1964
X 1500, Ma'in Formation, Lower Triassic, 5MAI, S 3, EFC. B 309

11. *Spinotriletes* sp. Mädler 1964
X 1500, Ma'in Formation, Lower Triassic, 5MAI, S 1, EFC. B 442

12. *Cyclotriletes pustulatus* Mädler 1964
X 1500, Ma'in Formation, Lower Triassic, 5MAI, S 1, EFC. B 185

Plate 27

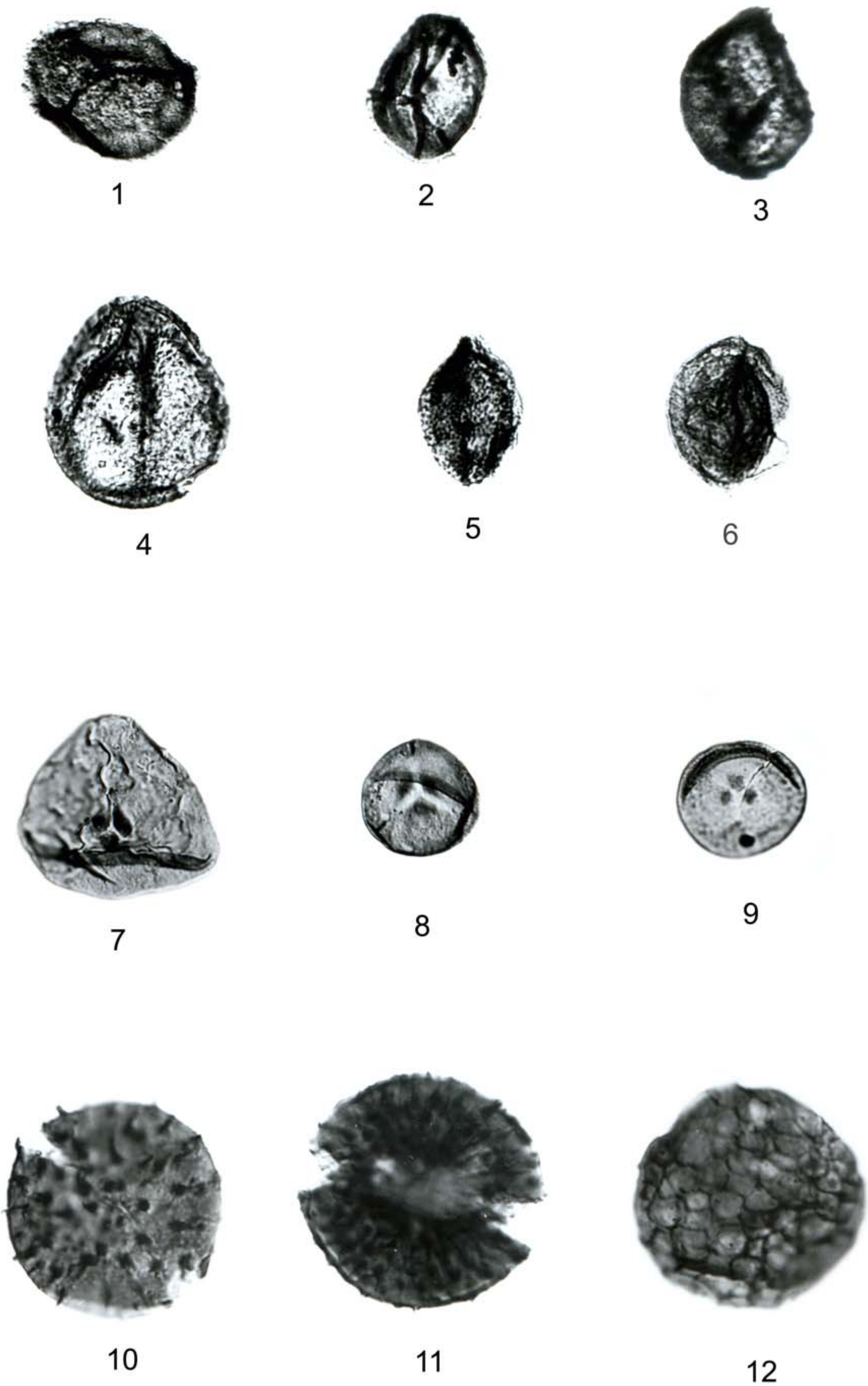

PLATE 28

1. *Lundbladispora obsoleta* Balme 1970
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 2, EFC. B 625

2. *Lundbladispora obsoleta* Balme 1970
X 600, Ma'in Formation, Lower Triassic, 6MAI, S 3, EFC. B 490-491

3. *Lundbladispora obsoleta* Balme 1970
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 6, EFC. B 440

4. *Lundbladispora obsoleta* Balme 1970
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 3, EFC. B 890

5. *Kraeuselisporites echinatus* Reinhardt and Schön 1967
X 600, Ma'in Formation, Lower Triassic, 5MAI, S1, EFC. B 781-782

6. *Kraeuselisporites varius* Ouyang and Norris 1999
X 600, Ma'in Formation, Lower Triassic, 5MAI, S1, EFC. B 765

7. *Kraeuselisporites* sp. Leschik 1956, emend. Jansonius 1962
X 600, Dardur Formation, Lower Triassic, 1DAR, S 1, EFC. B 240

8. *Kraeuselisporites apiculatus* Jansonius 1962
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 6, EFC. B 717

9. *Cyclogranisporites arenosus* Mädler 1964
X 600, Dardur Formation, Lower Triassic, 2DAR, S 1, EFC. B 599

10. *Cyclogranisporites* sp. Potonie and Kremp 1954
X 600, Dardur Formation, Lower Triassic, 10DAR, S 1, EFC. B 171

11. *Cyclogranisporites arenosus* Mädler 1964
X 600, Ain Musa Formation, Lower Triassic, 9AMU, S 1, EFC. B 172

12. *Cyclogranisporites* sp. Potonie and Kremp 1954
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 6, EFC. B 856

Plate 28

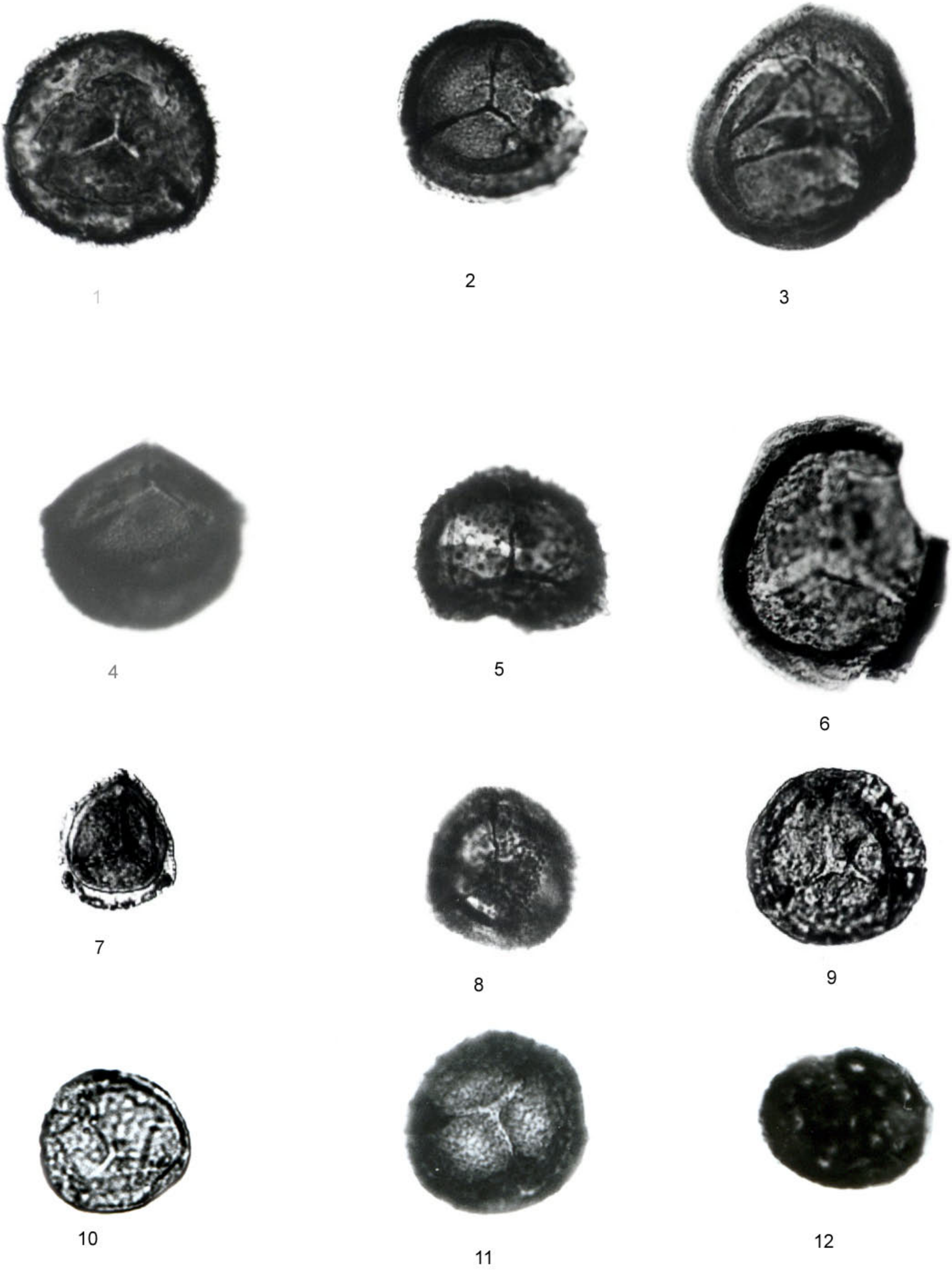

PLATE 29

1. *Lunatisporites pellucidus* (Goubin 1965) Balme 1970
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 2, EFC. B 45
2. *Lunatisporites pellucidus* (Goubin 1965) Balme 1970
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 5, EFC. B 398
3. Unidentified disaccate grain.
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 3, EFC. B 861
4. *Distriatites insolitus* Bharadwaj and Salujha 1964
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 5, EFC. B 448
5. *Striatoabieitites* sp. (Sedova 1956) Hart 1964
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 433
6. *Lunatisporites noviaulensis* (Leschik 1956) Foster 1979
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 5, EFC. B 324
7. *Falcisporites stabilis* Balme 1970
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 105
8. *Falcisporites stabilis* Balme 1970
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 1, EFC. A 89-90
9. *Alisporites* sp. (Daugherty 1941) emend. Jansonius 1971
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 1, EFC. B 224
10. *Falcisporites nuthalensis*. (Klarke 1965) Balme 1970
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 582-583
11. Unidentified disaccate grain
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 2, EFC. B 630
12. *Punctatisporites uniformis* (Ibrahim 1933) Tiwari 1968
X 400, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 432
13. *Monosulcites minimus* (Cookson 1947) emend. Couper 1953
X 1000, Ma'in Formation, Lower Triassic, 5MAI, S 5, EFC. B 16
14. *Aulisporites* sp.Leschik 1955
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 6, EFC. B 855-856
15. *Punctatisporites fungosus* Balme 1963
X 400, Ma'in Formation, Lower Triassic, 5MAI, S 1, EFC. B 118

Plate 29

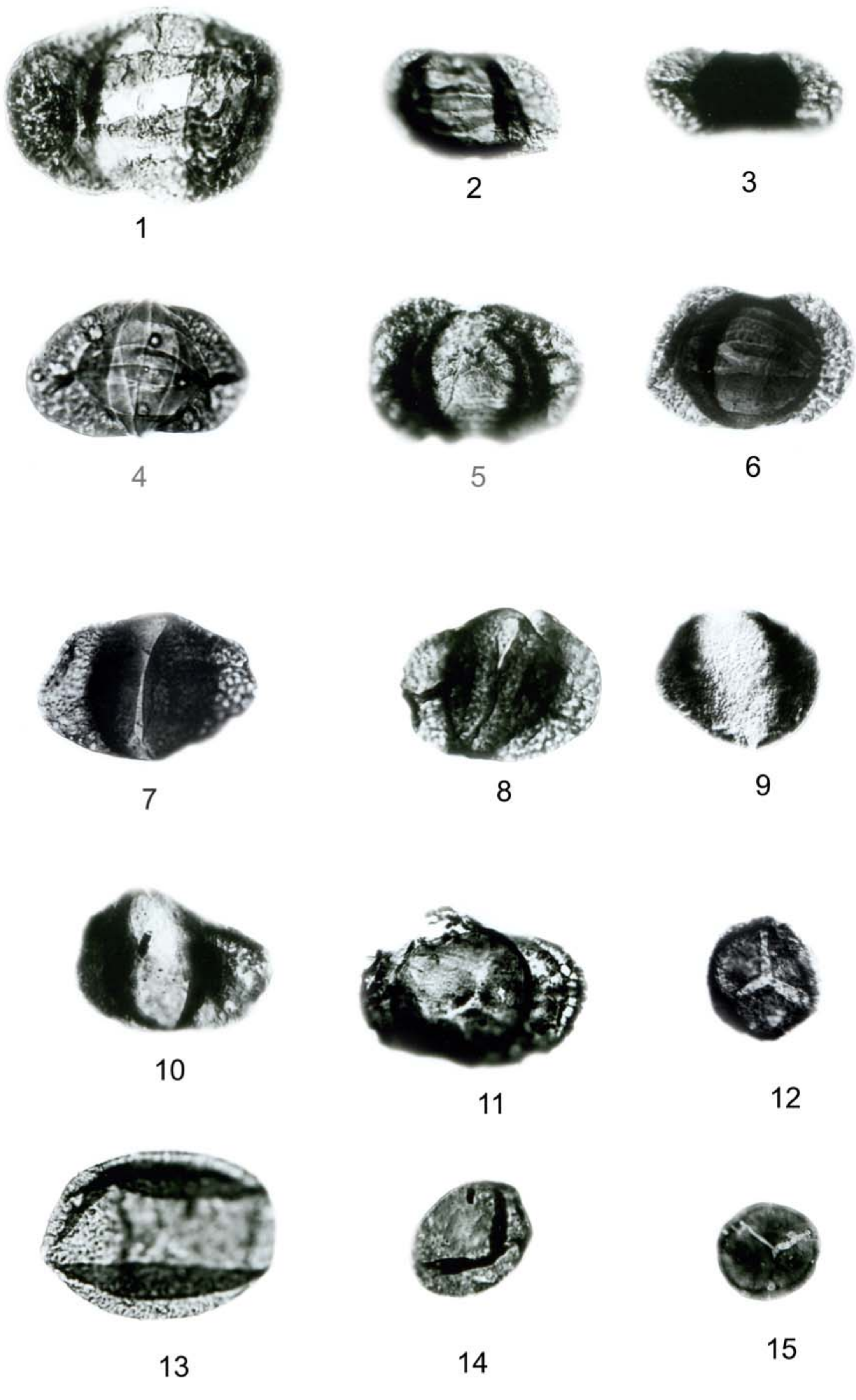

PLATE 30

1. *Platysaccus papilionis* Potonie and Klaus 1954
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 779

2. *Platysaccus papilionis* Potonie and Klaus 1954
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 2, EFC. B 780

3. *Voltziaceaesporites heteromorphus* Klaus 1964
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 1, EFC. B 124

4. *Striatoabieitites* sp. (Sedova 1956) Hart 1964
X 1000, Ma'in Formation, Lower Triassic, 5MAI, S 1, EFC. B 881

5. *Lapposisporites echinatus* Ouyang and Norris 1999
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 2, EFC. B 44

6. *Lapposisporites echinatus* Ouyang and Norris 1999
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 127

7. *Lapposisporites echinatus* Ouyang and Norris 1999
X 400, Ma'in Formation, Lower Triassic, 5MAI, S 1, EFC. B 428

8. *Inaperturopollenites nebulosus* Balme 1970
X 600, Ain Musa Formation, Lower Triassic, 9AMU, S 2, EFC. B 109

9. Unidentified grain
X 600, Ma'in Formation, Lower Triassic, 6MAI, S 5, EFC. B 777

10.Unidentified grain
X 600, Ma'in Formation, Lower Triassic, 6MAI, S 5, EFC. B 138

11. *Stereisporites* sp. Pflug in Thomson and Pflug 1953
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 551

12. *Aulisporites astigmosus* Klaus 1960
X 600, Ma'in Formation, Lower Triassic, 5MAI, S 1, EFC. B 468

Plate 30

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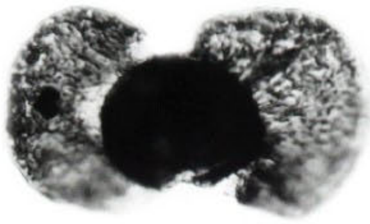

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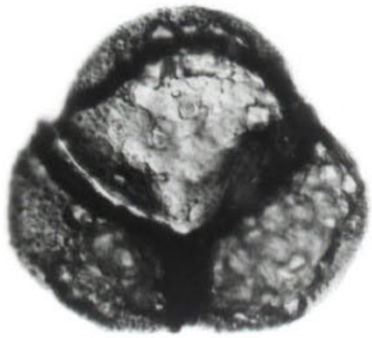

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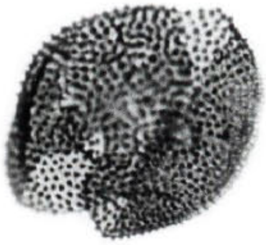

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PLATE 31

1. *Densoisporites playfordii* Balme 1963
   X 1000, Ma'in Formation, Lower Triassic, 5MAI, S 3, EFC. B 551

2. *Densoisporites playfordii* Balme 1963
   X 600, Ma'in Formation, Lower Triassic, 6MAI, S 1, EFC. B 578

3. *Densoisporites playfordii* Balme 1963
   X 600, Ma'in Formation, Lower Triassic, 6MAI, S 1, EFC. B 859

4. *Densoisporites* sp. (Weyland and Krieger 1953) emend. Dettmann 1963
   X 600, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 318

5. *Densoisporites playfordii* Balme 1963
   X 600, Ma'in Formation, Lower Triassic, 5MAI, S 3, EFC. B 748

6. *Densoisporites playfordii* Balme 1963
   X 600, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 314

7. *Densoisporites nejburgii* (Schulz 1964) Balme 1970
   X 600, Ma'in Formation, Lower Triassic, 6MAI, S 5, EFC. B 843

8. *Densoisporites nejburgii* (Schulz 1964) Balme 1970
   X 600, Ma'in Formation, Lower Triassic, 5MAI, S 3, EFC. B 800

9. *Apiculatisporites spiniger* (Leschik 1955) Qu 1980
   X 1500, Ma'in Formation, Lower Triassic, 5MAI, S 3, EFC. B 737

10. *Leiosphaeridia* sp. (Eisenack 1938) Dovnie, Evitt and Sarjeant 1963
    X 400, Ma'in Formation, Lower Triassic, 5MAI, S 6, EFC. B 359

11. *Retitriletes* sp. Pierce 1961
    X 600, Ma'in Formation, Lower Triassic, 5MAI, S 3, EFC. B 225

12. *Foraminifera remains*
    X 600, Ain Musa Formation, Lower Triassic, 5AMU, S 1, EFC. B 47

13. *Veryhachium* sp. (Deunff 1954) emend. Loebil and Tappan 1976
    X 600, Ain Musa Formation, Lower Triassic, 9AMU, S 1, EFC. B 401

14. *Micrhystridium* sp. (Deflandre 1937) Sarjeant 1967
    X 600, Ma'in Formation, Lower Triassic, 5MAI, S 3, EFC. B 209

15. *Micrhystridium* sp. (Deflandre 1937) Sarjeant 1967
    X 600, Ma'in Formation, Lower Triassic, 5MAI, S 4, EFC. B 519

16. *Micrhystridium* sp. (Deflandre 1937) Sarjeant 1967
    X 600, Ma'in Formation, Lower Triassic, 5MAI, S 6, EFC. B 641-642

17. *Concavisporites* sp. Pflug in Thomson and Pflug 1953
    X 400, Ma'in Formation, Lower Triassic, 5MAI, S 1, EFC. B 856

Plate 31

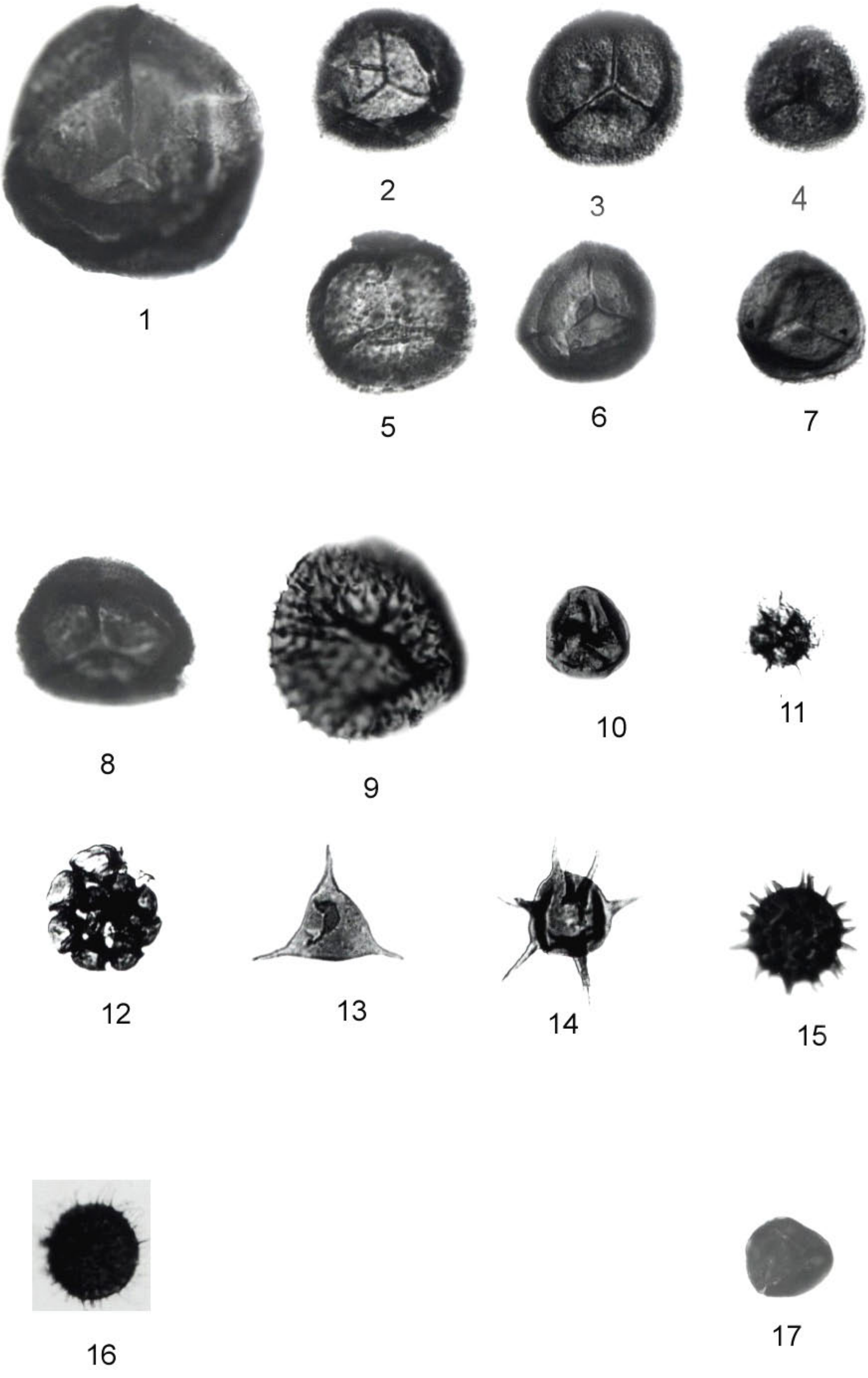

PLATE 32

1. *Microfoveolatispora* sp. Bharadwaj 1962
X 1000, Hisban Formation, Anisian, 2HIS, S 3, EFC. B 301
2. *Microfoveolatispora* sp. Bharadwaj 1962
X 1000, Hisban Formation, Anisian, 2HIS, S 1, EFC. B 532

3. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 1000, Hisban Formation, Anisian, 2HIS, S 5, EFC. B 286

4. *Osmundacidites* sp. Couper 1953
X 1000, Hisban Formation, Anisian, 2HIS, S 1, EFC. B 304

5. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Hisban Formation, Anisian, 2HIS, S 2, EFC. B 516

6. *Cyclotriletes pustulatus* Mädler 1964
X 400, Mukheiris Formation, Anisian, 8MUK, S 2, EFC. B 674

7. *Cyclotriletes margaritatus* Mädler 1964
X 400, Mukheiris Formation, Anisian, 6MUK, S 1, EFC. B 733

8. *Cyclotriletes microgranifer* Mädler 1964
X 400, Mukheiris Formation, Anisian, 5MUK, S 2, EFC. B 318

9. *Brachysaccus ovalis* Mädler 1964
X 400, Mukheiris Formation, Anisian, 15MUK, S 1, EFC. B 327

10. *Osmundacidites* sp. Couper 1953
X 400, Mukheiris Formation, Anisian, 15MUK, S 1, EFC. B 855

11. *Echinitosporites iliacoides* Schulz and Krutzsch 1961
X 400, Mukheiris Formation, Anisian, 16MUK, S 1, EFC. B 762

12. *Cyclotriletes oligogranifer* Mädler 1964
X 1000, Mukheiris Formation, Anisian, 16MUK, S 1, EFC. B 892

Plate 32

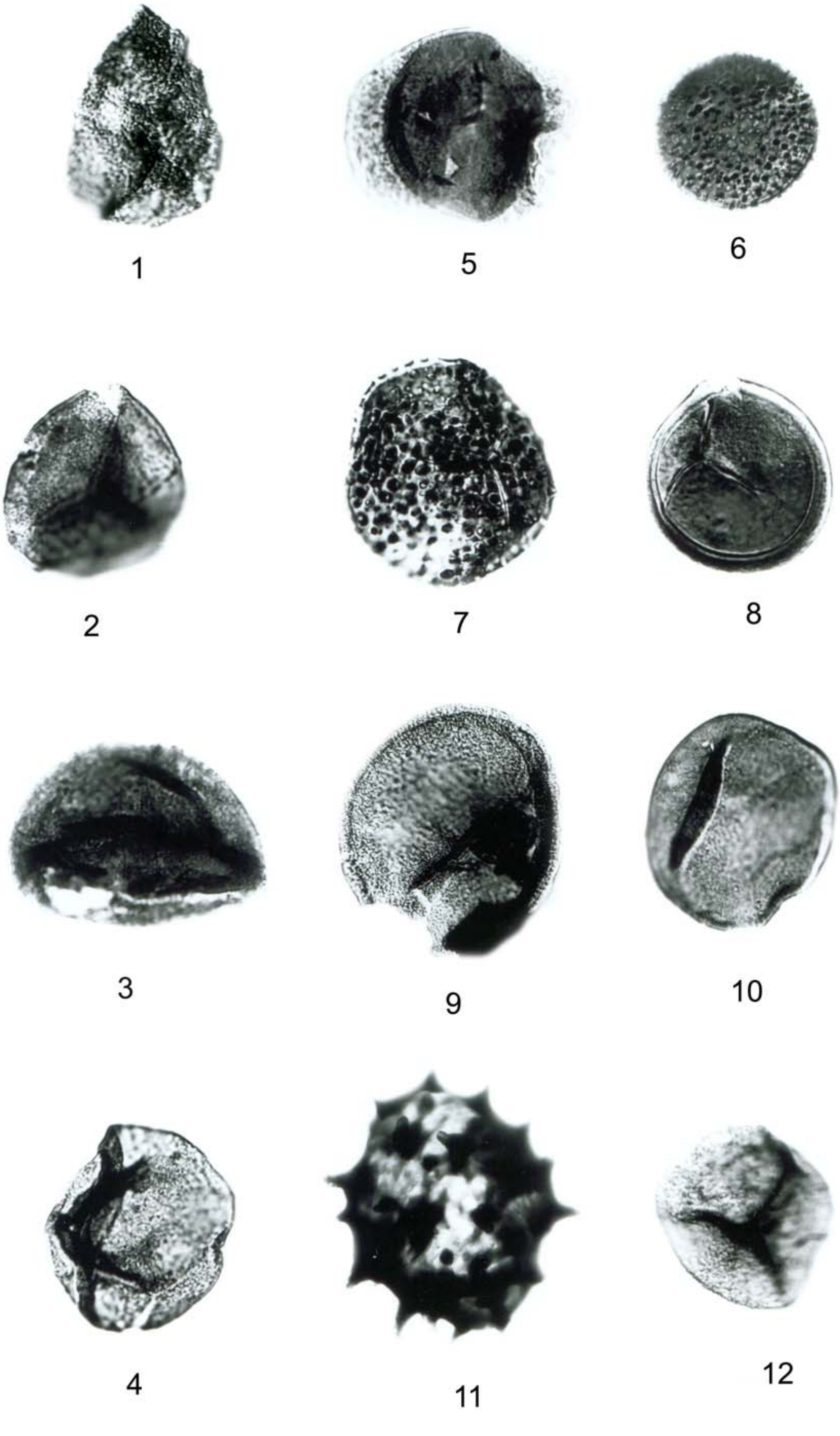

PLATE 33

1. *Verrucosisporites remyanus* Mädler 1964
X 1000, Mukheiris Formation, Anisian, 8MUK, S 2, EFC. B 142

2. *Cyclotriletes granulatus* Mädler 1964
X 1000, Mukheiris Formation, Anisian, 1MUK, S 1, EFC. B 754

3. *Cyclotriletes granulatus* Mädler 1964
X 1000, Mukheiris Formation, Anisian, 1MUK, S 1, EFC. B 20

4. *Microreticulatisporites* sp. (Knox) Potonie and Kremp 1954
X 1000, Mukheiris Formation, Anisian, 1MUK, S 1, EFC. B 450

5. *Uvaesporites gadensis* Praehauser- Enzenberg 1970
X 1000, Mukheiris Formation, Anisian, 6MUK, S 1, EFC. B 630

6. Unidentified grain
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 469

Plate 33

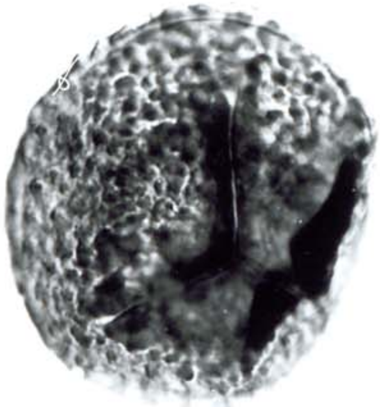

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PLATE 34

1. *Punctatisporites* sp. (Ibrahim 1933) Potonie and Kremp 1954
X 1000, Mukheiris Formation, Anisian, 5MUK, S 2, EFC. B 585

2. *Punctatisporites* sp. (Ibrahim 1933) Potonie and Kremp 1954
X 1000, Mukheiris Formation, Anisian, 8MUK, S 2, EFC. B 320

3. *Punctatisporites* sp. (Ibrahim 1933) Potonie and Kremp 1954
X 1000, Mukheiris Formation, Anisian, 9MUK, S 1, EFC. B 802

4. *Verrucosisporites jenensis* Reinhardt and Schmitz 1965
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 265

5. Unidentified grain
X 1000, Mukheiris Formation, Anisian14, MUK, S 2, EFC. B 552

6. Unidentified grain
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 173

Plate 34

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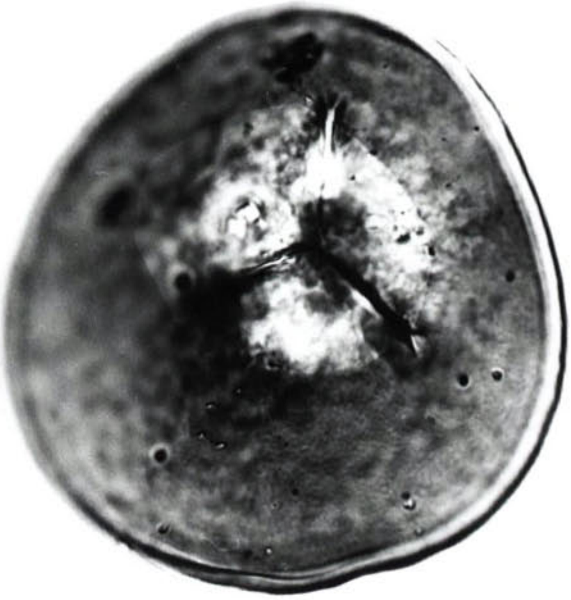

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PLATE 35

1. *Verrucosisporites krempii* Mädler 1964
X 400, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 465

2. *Verrucosisporites krempii* Mädler 1964
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 465

3. Unidentified grain
X 400, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 56

4. Unidentified grain
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 56

5. *Punctatisporites crassexinis* Mädler 1964
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 827

6. *Todisporites cinctus* (Maljavkina 1949) Orlowska-Zwolinska 1971
X 400, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 546

7. *Deltoidospora* sp. (Miner 1935) Potonie 1956
X 1000, Mukheiris Formation, Anisian, 15MUK, S 1, EFC. B 550

8. *Kraeuselisporites* sp. Leschik 1956, emend. Jansonius 1962
X 1000, Mukheiris Formation, Anisian, 18MUK, S 1, EFC. B 209

Plate 35

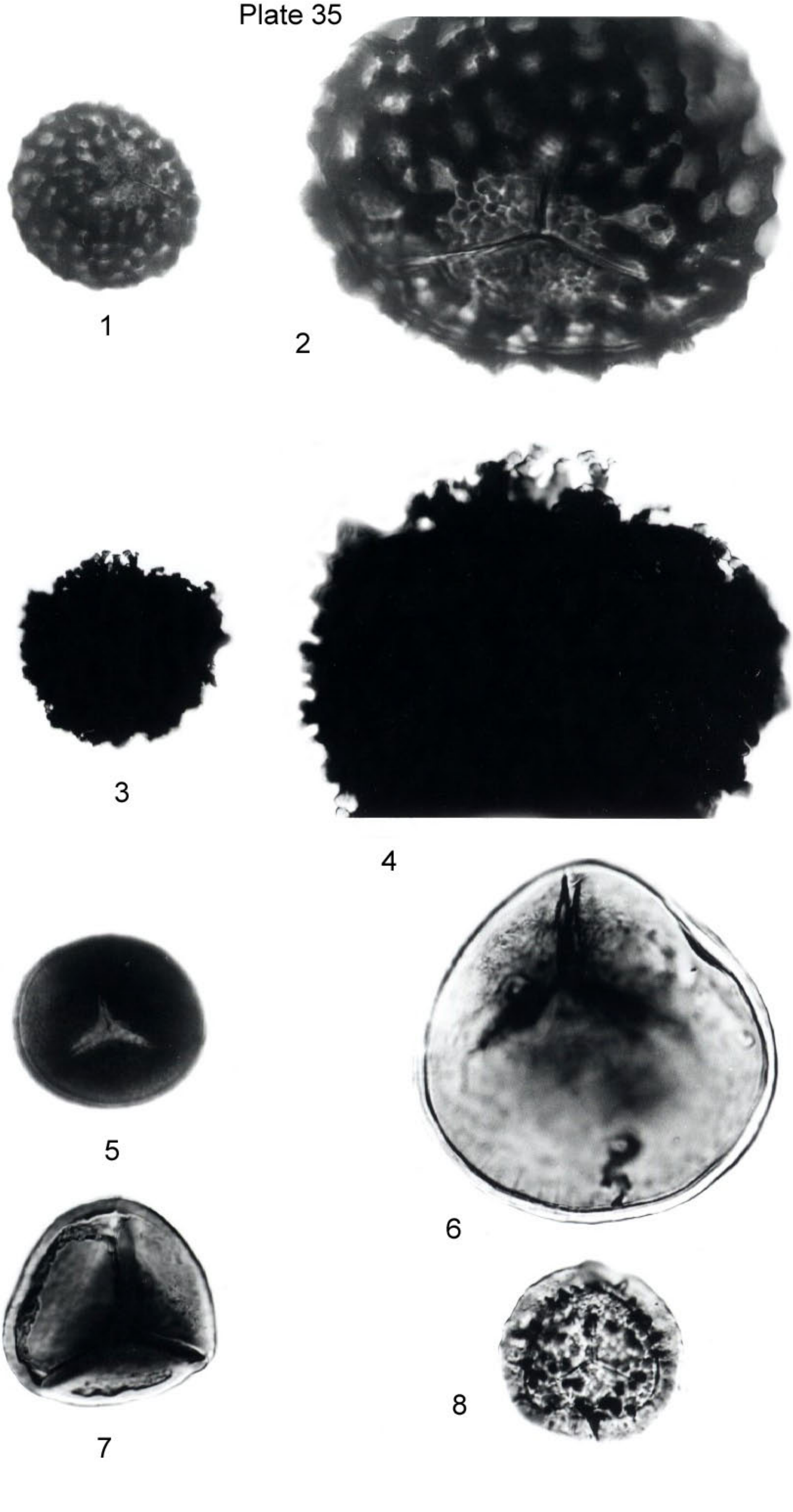


PLATE 36

1. *Cyclotriletes granulatus* Mädler 1964
X 1000, Mukheiris Formation, Anisian, 18MUK, S 1, EFC. B 515

2. *Sellaspora* sp. Van Der Eem 1983
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 732

3. *Cyclogranisporites arenosus* Mädler 1964
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 482

4. *Punctatisporites uniformis* (Ibrahim 1933) Tiwari 1968
X 400, Mukheiris Formation, Anisian, 8MUK, S 2, EFC. B 744

5. *Verrucosisporites reinhardtii* Visscher 1966.
X 1000, Mukheiris Formation, Anisian, 8MUK, S 2, EFC. B 234

6. *Sellaspora rugoverrucata* Van der Eem 1983
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 460

7.*Triplexisporites playfordii* (De Jersey and Hamilton 1967) Foster 1979
X 1000, Mukheiris Formation, Anisian, 18MUK, S 2, EFC. B 272

8. Unidentified grain
X 1000, Mukheiris Formation, Anisian, 1MUK, S 1, EFC. B 555

9. *Hexasaccites muelleri* Reinhardt and Schmitz 1965
X 400, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 337

10. *Triadispora crassa* Klaus 1964 emend. Brugman 1979
X 1000, Mukheiris Formation, Anisian, 12MUK, S 2, EFC. B 572

11. *Triadispora muelleri* (Reinhardt and Schmitz 1965) Visscher 1966
X 1000, Mukheiris Formation, Anisian, 12MUK, S 1, EFC. B 766

Plate 36

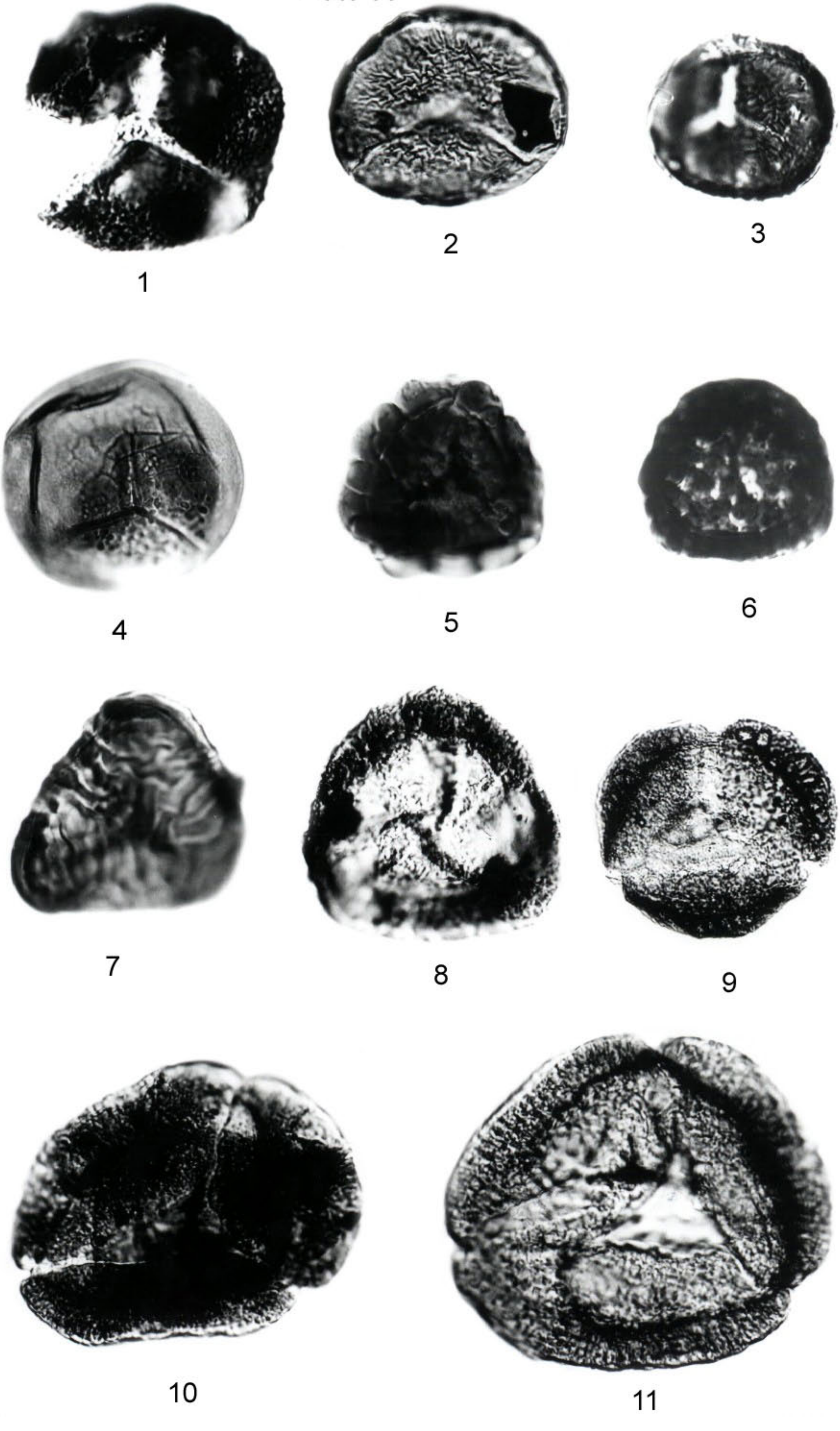


PLATE 37

1. *Hexasaccites muelleri* Reinhardt and Schmitz 1965
X 400, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 464

2. *Hexasaccites muelleri* Reinhardt and Schmitz 1965
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 464

3.*Crustaesporites* sp. Leschik 1956
X 400, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 691

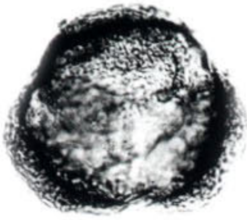
4. *Crustaesporites* sp. Leschik 1956
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 691

5. *Stellapolenites thiergartii* (Mädler 1964) Clement-Westerhof et. al. 1974, emend. Brugman 1983
X 400, Mukheiris Formation, Anisian, 15MUK, S 1, EFC. B 330

6. *Stellapollenites thiergartii* (Mädler 1964) Clement-Westerhof et. al. 1974, emend. Brugman 1983
X 400, Mukheiris Formation, Anisian, 16MUK, S 1, EFC. B 111

7. *Kuglerina meieri* Scheuring 1978
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 102

Plate 37



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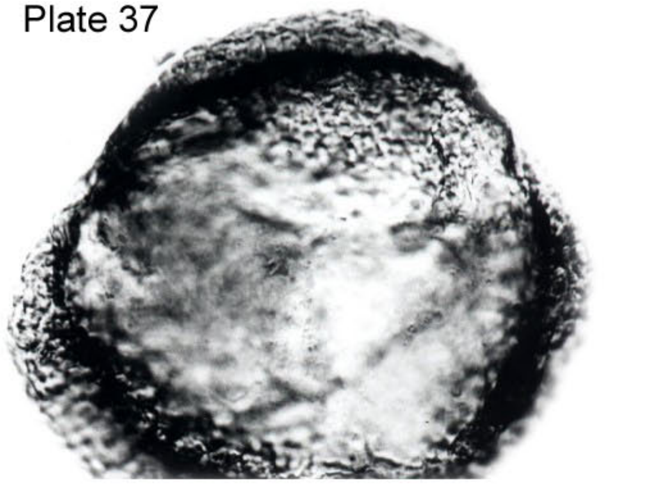

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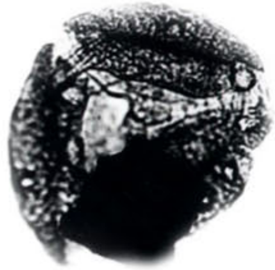

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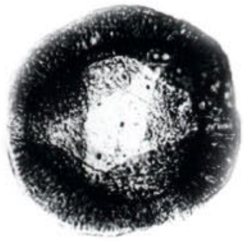

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PLATE 38

1. *Convolutispora* sp. Hoffmeister, Staplin and Malloy 1955
X 1000, Mukheiris Formation, Anisian, 1MUK, S 1, EFC. B 123-124

2. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 15MUK, S 1, EFC. B 527

3. *Vestigisporites* sp. (Balme and Hennelly 1955) emend. Hart 1960
X 1000, Mukheiris Formation, Anisian, 15MUK, S 2, EFC. B 893

4. *Saccizonati* sp. Bharadwaj 1957
X 1000, Mukheiris Formation, Anisian, 16MUK, S 1, EFC. B 309

5. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 1MUK, S 1, EFC. B 781

6. *Triadispora crassa* Klaus 1964 emend. Brugman 1979
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 42

Plate 38

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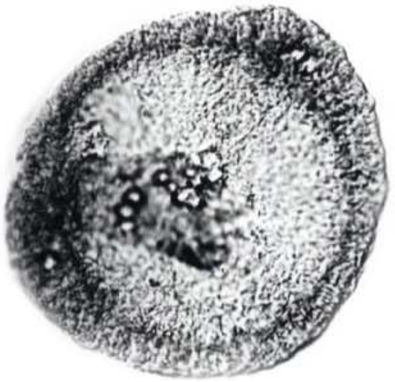

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PLATE 39

1. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 12MUK, S 1, EFC. B 812

2. *Triadispora stabilis* Scheuring 1970
X 1000, Mukheiris Formation, Anisian, 7MUK, S 1, EFC. B 87

3. *Triadispora stabilis* Scheuring 1970
X 1000, Mukheiris Formation, Anisian, 1MUK, S 1, EFC. A 478

4. *Triadispora crassa* .(Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 44

5. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 15MUK, S 2, EFC. B 452

6. *Triadispora crassa* (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 896

7. *Triadispora crassa*.(Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 15MUK, S 1, EFC. B 527

8. *Triadispora obscura* Scheuring 1970
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 68

Plate 39

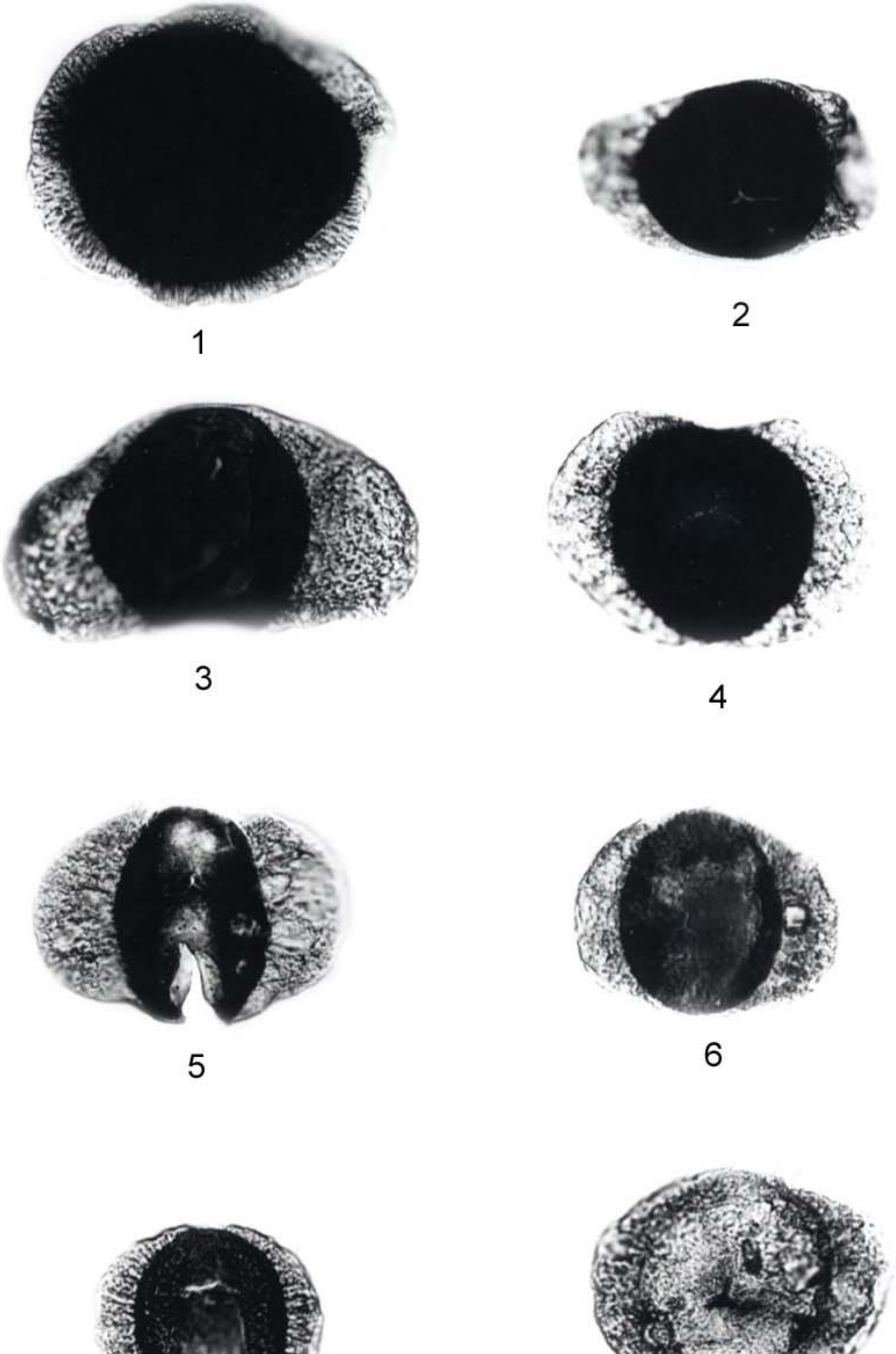

PLATE 40

1. *Triadispora crassa*.(Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 18MUK, S 1, EFC. B 172

2. *Triadispora crassa* (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 15MUK, S 2, EFC. B 798

3. *Triadispora modesta* Scheuring 1970
X 1000, Mukheiris Formation, Anisian, 14MUK, S 1, EFC. B 896

4. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 9MUK, S 1, EFC. B 818

5. *Voltziaceaesporites heteromorphus* Klaus 1964
X 400, Mukheiris Formation, Anisian, 16MUK, S 1, EFC. B 608

6. *Triadispora crassa* (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 365

7. Internal corpus of 6
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 365

8. *Triadispora obscura* Scheuring 1970
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 895

9. Internal corpus of 8
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 895

10. *Triadispora suspecta* Scheuring 1970
X 1000, Mukheiris Formation, Anisian, 18MUK, S 1, EFC. B 754

Plate 40

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PLATE 41

1. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 1MUK, S 1, EFC. B 257

2. *Triadispora suspecta* Scheuring 1970
X 1000, Mukheiris Formation, Anisian, 15MUK, S 1, EFC. B 377

3. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 225

4. *Triadispora falcata* Klaus 1964
X 1000, Mukheiris Formation, Anisian, 13MUK, S 1, EFC. B 517

5. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 13MUK, S 1, EFC. B 654

6. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Mukheiris Formation, Anisian, 12MUK, S 2, EFC. B 601

7. *Platysaccus* sp. Potonie and Klaus 1954
X 400, Mukheiris Formation, Anisian, 9MUK, S 2, EFC. B 546

8. *Triadispora sulcata* Scheuring 1978
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 789

Plate 41

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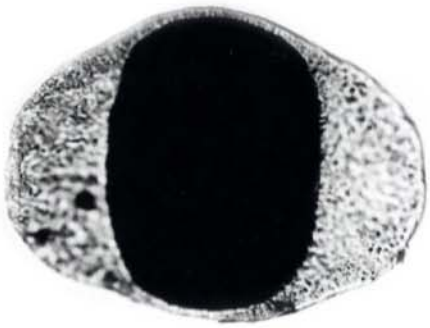

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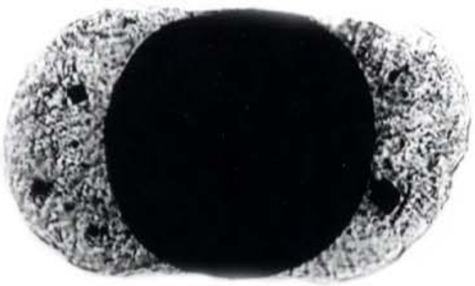

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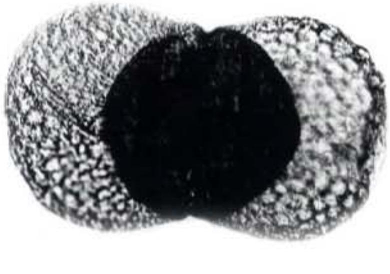

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PLATE 42

1. *Alisporites magnus* Jain 1968
X 400, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 602

2. *Alisporites magnus* Jain 1968
X 400, Mukheiris Formation, Anisian, 15MUK, S 1, EFC. B 884

3. *Alisporites magnus* Jain 1968
X 400, Mukheiris Formation, Anisian, 9MUK, S 2, EFC. B 123

4. *Alisporites* sp. (Daugherty 1941) emend. Nilsson 1958
X 400, Mukheiris Formation, Anisian, 9MUK, S 1, EFC. B 791

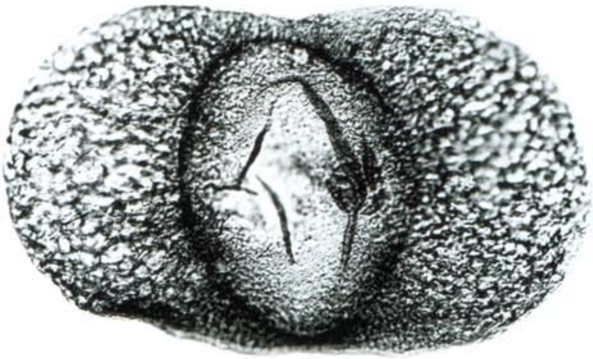
5. *Triadispora sulcata* Scheuring 1978
X 1000, Mukheiris Formation, Anisian, 18MUK, S 1, EFC. B 758

6. *Alisporites progrediens* Klaus 1964
X 400, Mukheiris Formation, Anisian, 9MUK, S 2, EFC. B 867

7. *Alisporites grauvogelii* Klaus 1964
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 245

8. *Guthoerlisporites cancellosus* Playford and Dettmann 1965
X 400, Mukheiris Formation, Anisian, 5MUK, S 1, EFC. B 641

Plate 42



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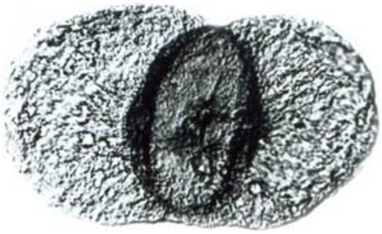

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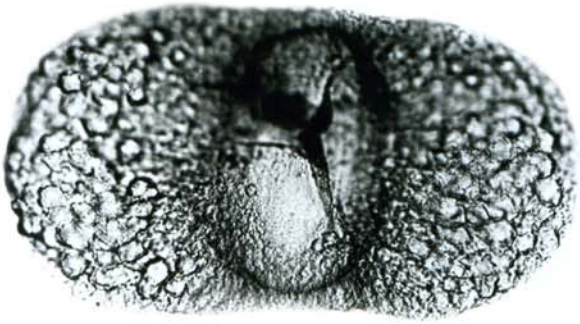

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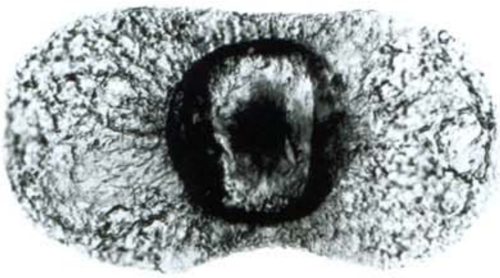

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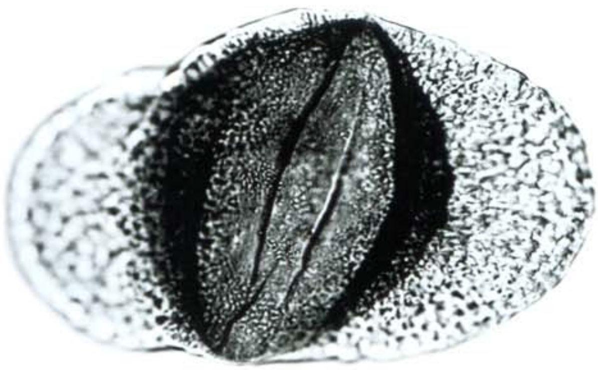

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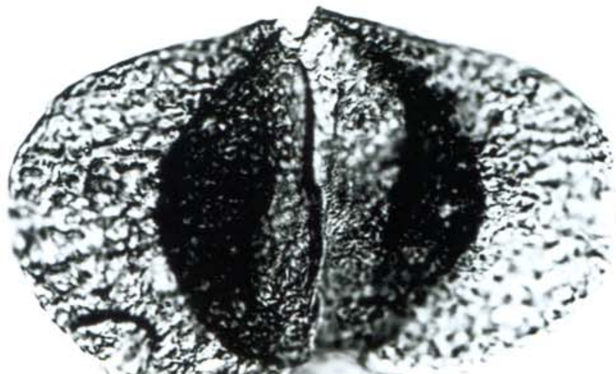

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PLATE 43

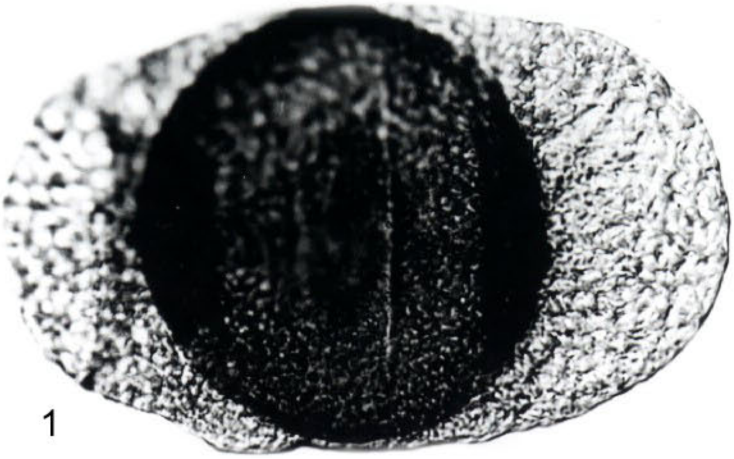
1. *Falcisporites stabilis* Balme1970
X 1000, Mukheiris Formation, Anisian, 18MUK, S 1, EFC. B 191

2. *Falcisporites stabilis* Balme1970
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 760

3. *Alisporites townrorii* Helby 1966
X 1000, Mukheiris Formation, Anisian, 16MUK, S 1, EFC. B 738

4. *Rimaesporites potoniei* Leschik 1955
X 1000, Mukheiris Formation, Anisian, 1MUK, S 1, EFC. B 199

Plate 43



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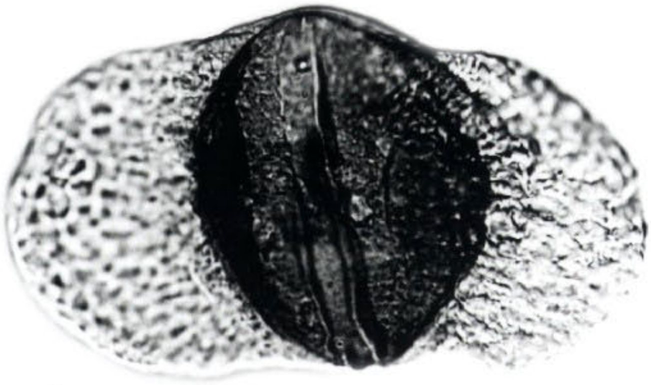

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PLATE 44

1. *Platysaccus* sp. Potonie and Klaus 1954
X 400, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 563

2. *Platysaccus* sp. Potonie and Klaus 1954
X 400, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 234

3. *Platysaccus* sp. Potonie and Klaus 1954
X 400, Mukheiris Formation, Anisian, 9MUK, S 2, EFC. B 817

4. *Platysaccus* sp. Potonie and Klaus 1954
X 400, Mukheiris Formation, Anisian, 9MUK, S 1, EFC. B 643

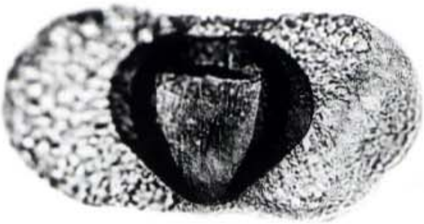
5. *Platysaccus papilionis* Potonie and Klaus 1954
X 400, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 646

6. *Platysaccus* sp. Potonie and Klaus 1954
X 400, Mukheiris Formation, Anisian, 4MUK, S 2, EFC. B 497

7. *Platysaccus* sp. Potonie and Klaus 1954
X 400, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 428

8. *Platysacuss Queenslandi* De Jersy 1962
X 400, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 623

Plate 44



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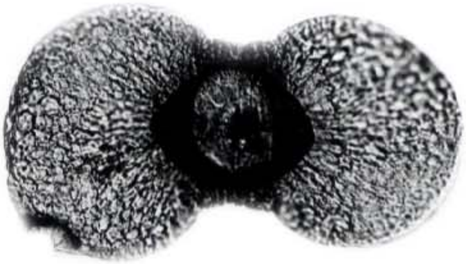

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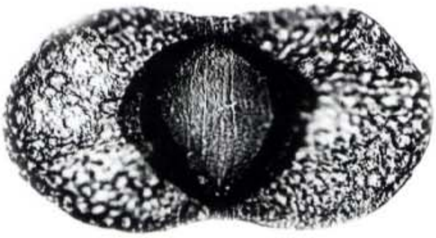

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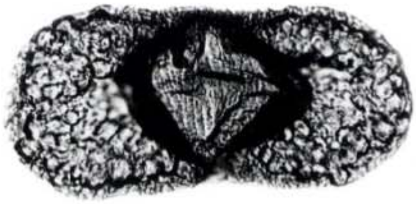

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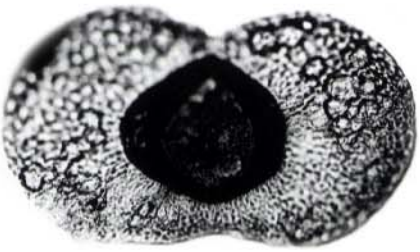

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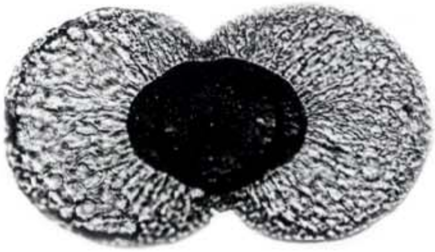

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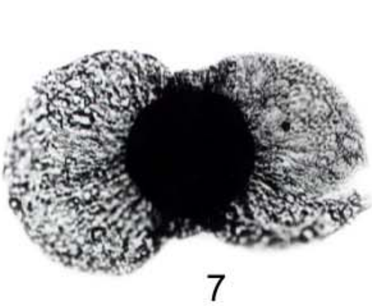

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PLATE 45

1. *Platysaccus leschikii* Hart 1960
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 403

2. *Platysaccus queenslandi* De Jersy 1962
X 1000, Mukheiris Formation, Anisian, 15MUK, S 1, EFC. B 601

3. *Platysaccus* sp. Potonie and Klaus 1954
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 34

4. *Ovalipollis* sp Krutzsch 1955
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 503

5. *Microcachryidites daubingeri* Klaus 1964
X 1000, Mukheiris Formation, Anisian, 9MUK, S 1, EFC. B 589

6. *Microcachryidites daubingeri* Klaus 1964
X 1000, Mukheiris Formation, Anisian, 15MUK, S 2, EFC. B 798

7. *Angustisulcites klausii* (Freudenthal 1964) emend. Visscher 1966
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 35

8. *Angustisulcites klausii* (Freudenthal 1964) emend. Visscher 1966
X 1000, Mukheiris Formation, Anisian, 13MUK, S 1, EFC. B 136

Plate 45

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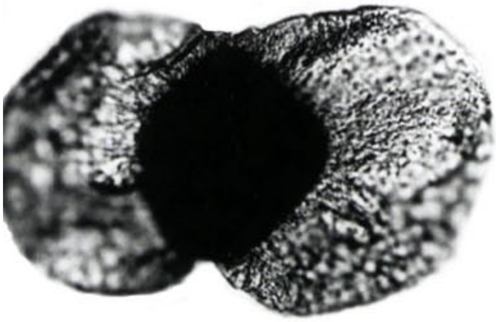

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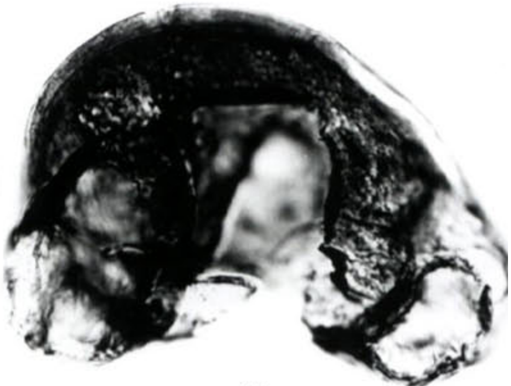

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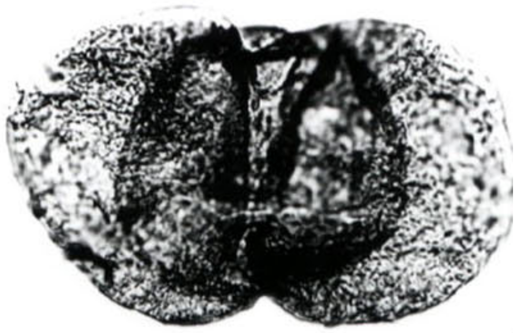

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PLATE 46

1. *Angustisulcites klausii* (Freudenthal 1964) emend. Visscher 1966
X 1000, Mukheiris Formation, Anisian, 13MUK, S 1, EFC. B 842

2. *Vestigisporites* sp. (Balme and Hennelly 1955) emend. Hart 1960
X 1000, Mukheiris Formation, Anisian, 18MUK, S 2, EFC. B 277

3. *Vestigisporites* sp. (Balme and Hennelly 1955) emend. Hart 1960
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 626

4. *Vestigisporites* sp. (Balme and Hennelly 1955) emend. Hart 1960
X 1000, Mukheiris Formation, Anisian, 15MUK, S 2, EFC. B 229

5. *Lunatisporites acutus* Leschik 1955
X 1000, Mukheiris Formation, Anisian, 18MUK, S 1, EFC. B 368

6. *Lunatisporites* sp. Leschik 1955
X 1000, Mukheiris Formation, Anisian, 6MUK, S 1, EFC. B 519

7. *Lunatisporites acutus* Leschik 1955
X 1000, Mukheiris Formation, Anisian, 18MUK, S 1, EFC. B 866

8. *Lunatisporites* sp. Leschik 1955
X 1000, Mukheiris Formation, Anisian, 13MUK, S 1, EFC. B 661

Plate 46

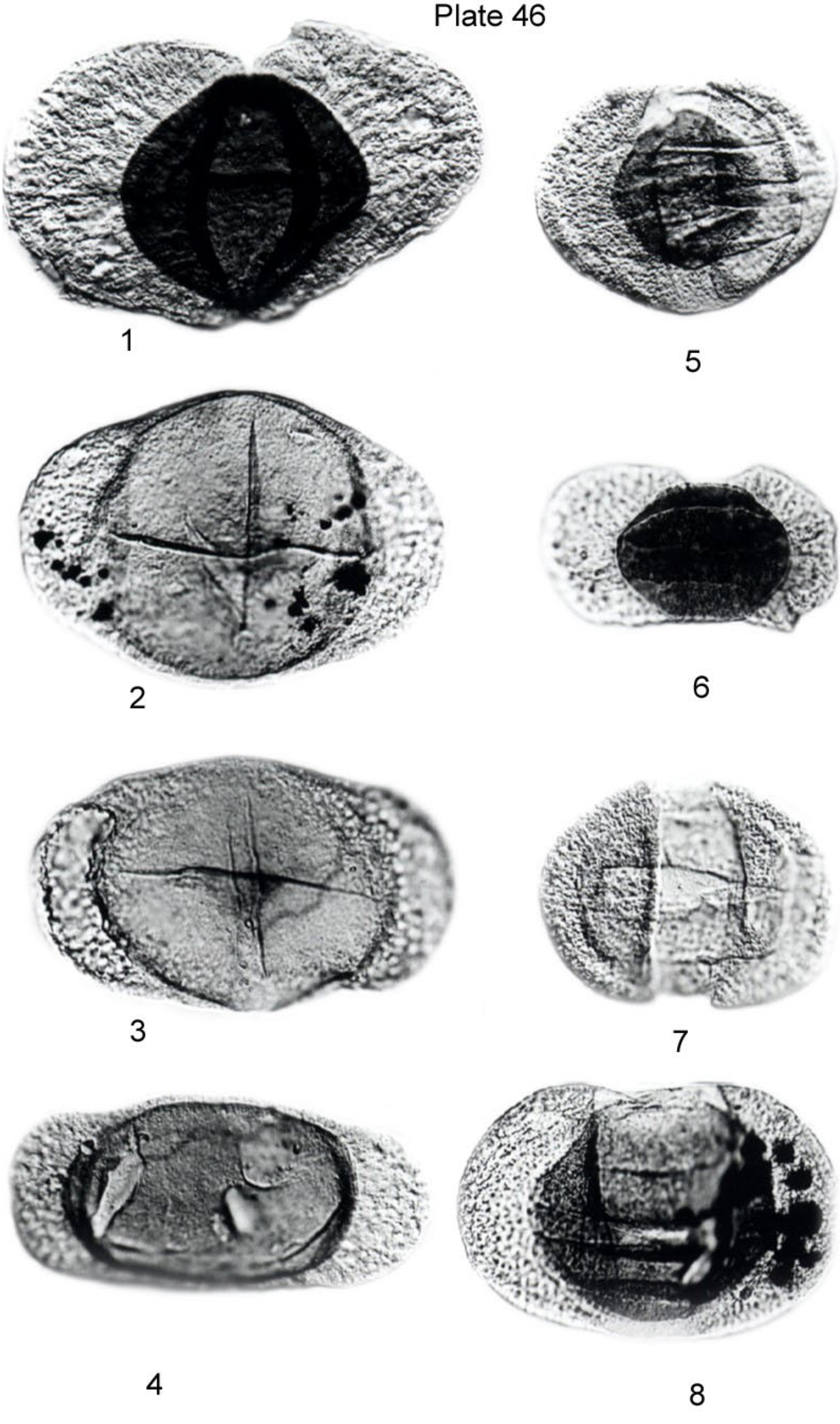

PLATE 47

1. *Lunatisporites acutus* Leschik 1955
X 1000, Mukheiris Formation, Anisian, 15MUK, S 2, EFC. B 428

2. *Lunatisporites noviaulensis* Leschik (1956) Foster 1979
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 566

3. *Lunatisporites pellucidus* (Goubin1965) emend. Balme 1970
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 601-602

4. *Lunatisporites acutus* Leschik 1955
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 6

5. *Lunatisporites* sp. Leschik 1955
X 1000, Mukheiris Formation, Anisian, 15MUK, S 1, EFC. B 810

6. *Lunatisporites* sp. Leschik 1955
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 635

7. *Infernopollenites salcatus* (Putsch 1958) Scheuring 1970
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 115

8. *Veryhachium* sp. (Deunff 1954) emend. Loebil and Tappan 1976
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 340

Plate 47

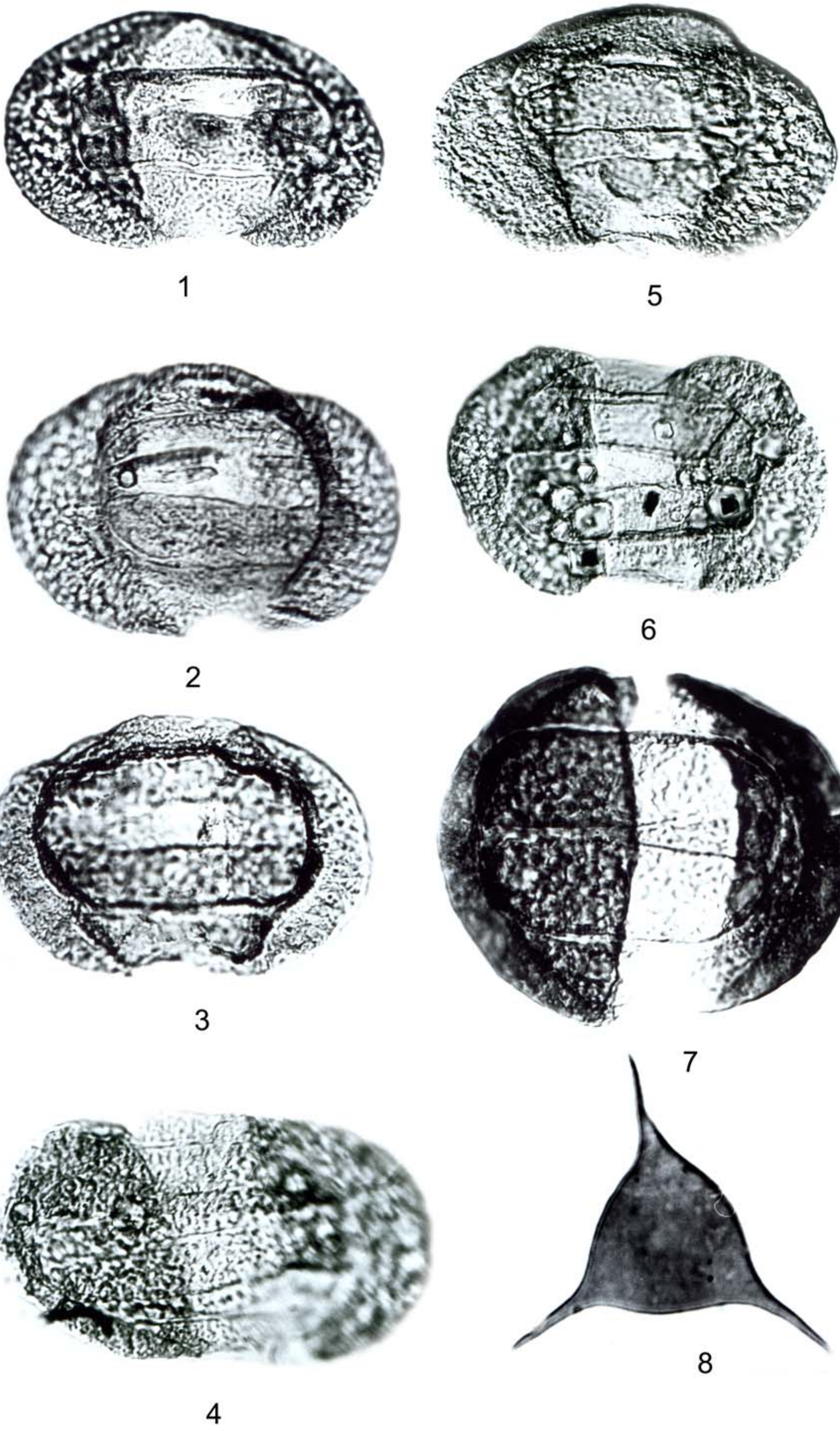

PLATE 48

1. *Lunatisporites pellucidus* (Goubin1965) emend. Balme 1970
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 536

2. *Lunatisporites pellucidus* (Goubin1965) emend. Balme 1970
X 1000, Mukheiris Formation, Anisian, 15MUK, S 1, EFC. B 358

3 *Striatoabieites aytugii* Visscher 1966
X 1000, Mukheiris Formation, Anisian, 6MUK, S 1, EFC. B 566

4. *Aratrisporites saturnii* (Thiergardt 1949) emend. Mädler 1964a
X 1000, Mukheiris Formation, Anisian, 8MUK, S 2, EFC. B 236

5. *Aratrisporites parvispinosus* (Leschik 1956a) emend. Playford 1965
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 681

6. *Aratrisporitesv saturnii* (Thiergardt 1949) emend. Mädler 1964a
X 1000, Mukheiris Formation, Anisian, 16MUK, S 1, EFC. B 459

7. *Aratrisporites saturnii* (Thiergardt 1949) emend. Mädler 1964a
X 1000, Mukheiris Formation, Anisian, 18MUK, S 1, EFC. B 98

8. *Aratrisporites saturnii* (Thiergardt 1949) emend. Mädler 1964a
X 1000, Mukheiris Formation, Anisian, 18MUK, S 2, EFC. B 517

Plate 48

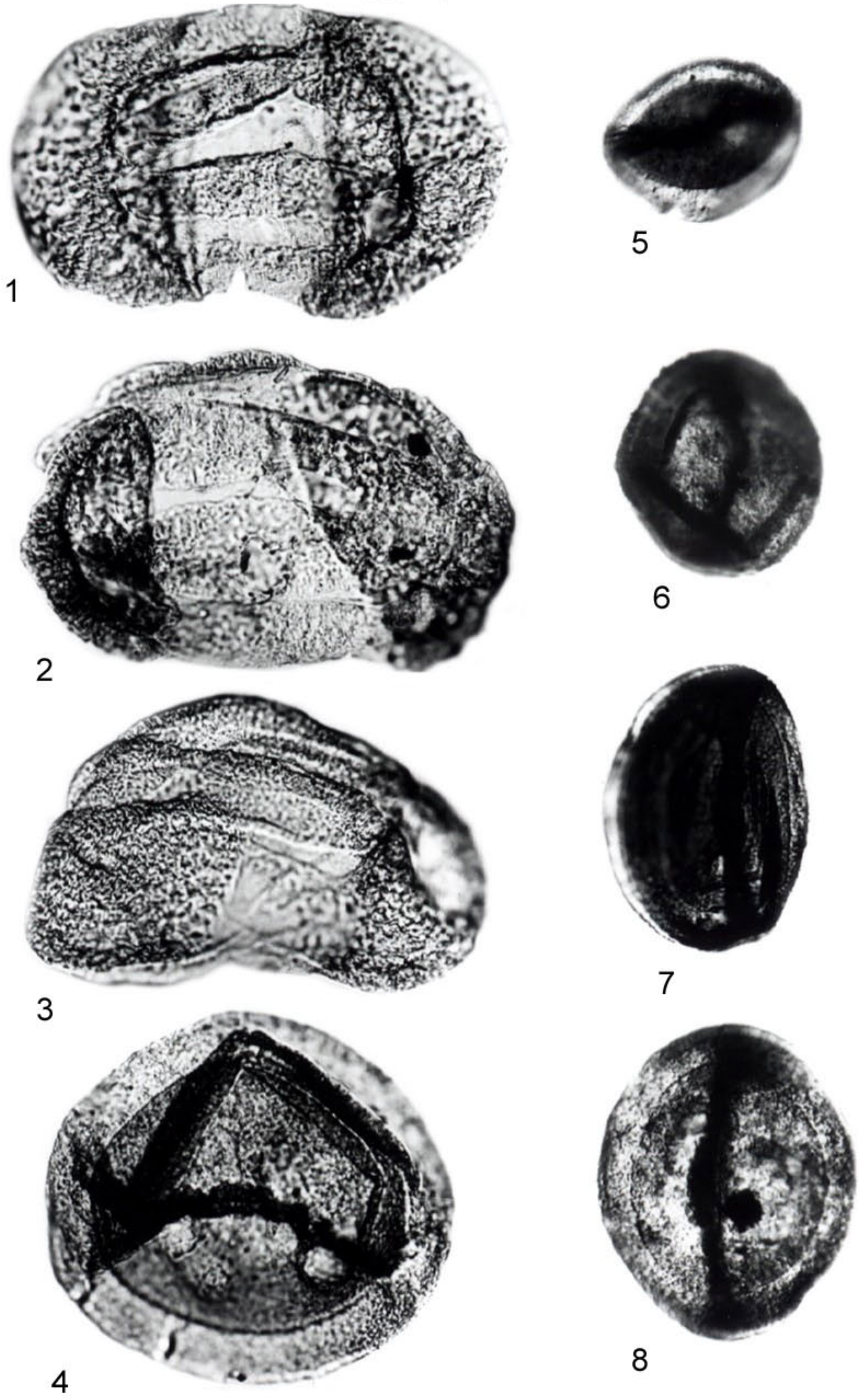

PLATE 49

1. *Aratrisporites paenulatus* Playford and Dettmann 1965
X 1000, Mukheiris Formation, Anisian, 18MUK, S 1, EFC. B 464

2. *Aratrisporites paenulatus* Playford and Dettmann 1965
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 516

3. *Aratrisporites fischeri* (Klaus 1960) emend. Playford and Dettmann 1965
X 1000, Mukheiris Formation, Anisian, 8MUK, S 2, EFC. B 35

4. *Aratrisporites parvispinosus* (Leschik 1955) emend. Playford 1965
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 224

5. *Aratrisporites strigosus* Playford and Dettmann 1965
X 1000, Mukheiris Formation, Anisian, 18MUK, S 2, EFC. B 182

6. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 561

7. *Aratrisporites saturnii* (Thiergardt 1949) emend. Mädler 1964a
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 141-142

8. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 1000, Mukheiris Formation, Anisian, 18MUK, S 1, EFC. B 396

Plate 49

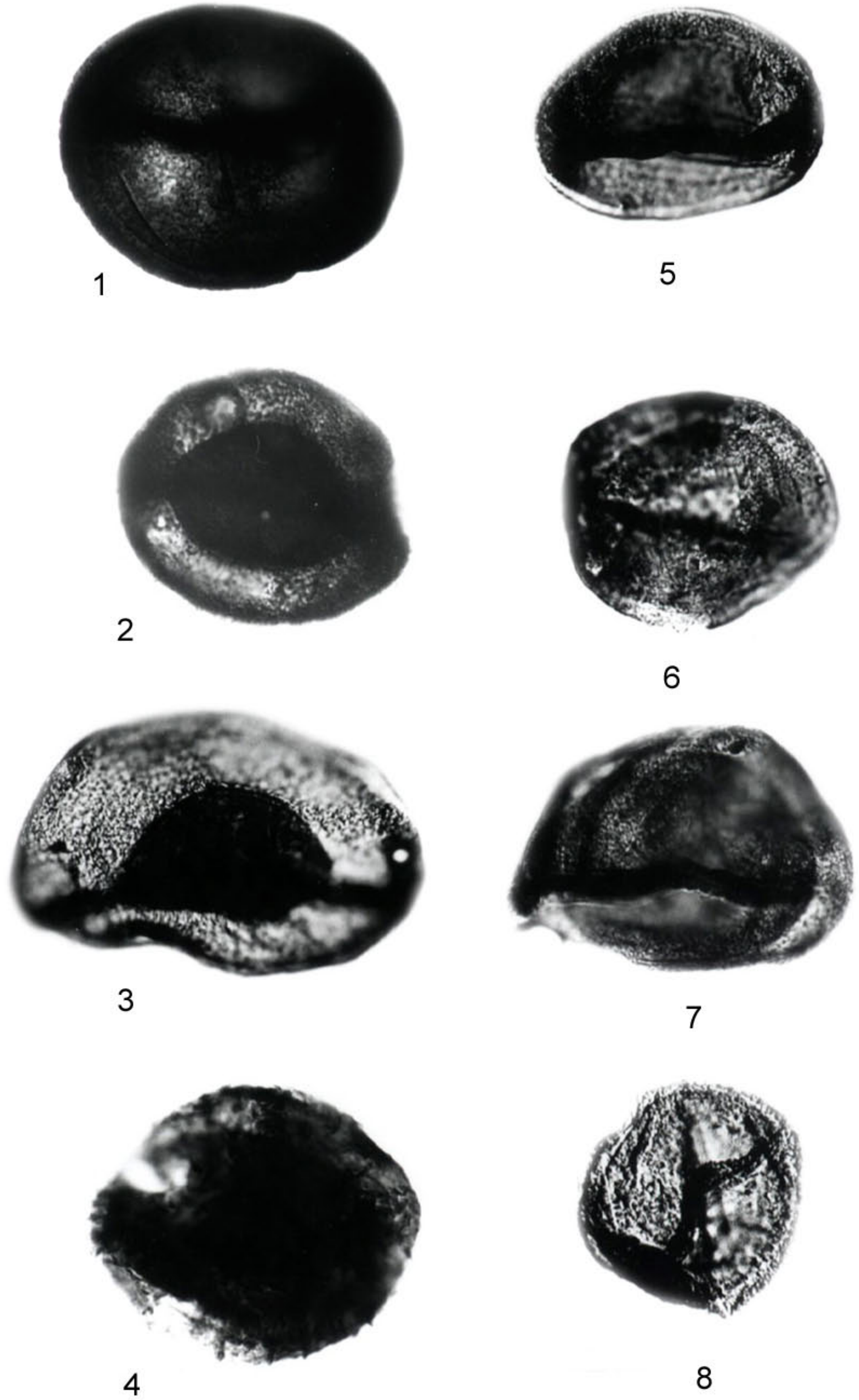

PLATE 50

1. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 1000, Mukheiris Formation, Anisian, 8MUK, S 1, EFC. B 895

2. *Aratrisporites strigosus* Playford and Dettmann 1965
X 1000, Mukheiris Formation, Anisian, 8MUK, S 2, EFC. B 41

3. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 516

4. *Aratrisporites saturnii* (Thiergardt 1949) emend. Mädler 1964a
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 141-142

5. *Aratrisporites saturnii* (Thiergardt 1949) emend. Mädler 1964a
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 491

6. *Aratrisporites fimbriatus* (Klaus 1960) emend Mädler 1964
X 1000, Mukheiris Formation, Anisian, 4MUK, S 1, EFC. B 222

7. *Aratrisporites saturnii* (Thiergardt 1949) emend. Mädler 1964a
X 1000, Mukheiris Formation, Anisian, 1MUK, S 2, EFC. B 856

8. *Carnisporites* cf. *mesozoicus* (Klaus 1960) emend. Mädler 1964
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 1, EFC. B 304

Plate 50

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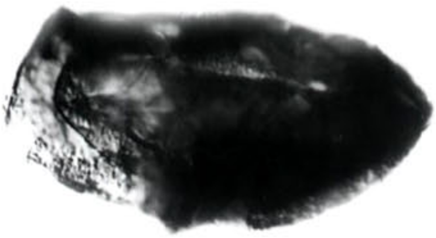

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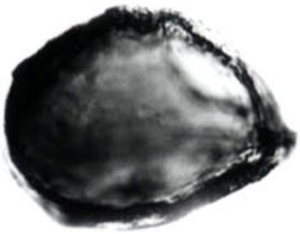

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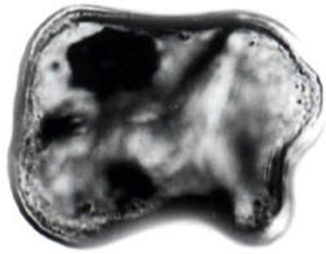

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PLATE 51

1. *Verrucosisporites thuringiacus* Mädler 1964
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 2, EFC. B 707

2. *Hexasaccites muelleri* Reinhardt and Schmitz 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 2, EFC. B 896-897

3. *Cyclotriletes microgranifer* Mädler 1964
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 1, EFC. B 727-728

4. *Cyclotriletes microgranifer* Mädler 1964
X 1000, Iraq Al-Amir Formation, Ladinian, 1IRA, S 1, EFC. B 830

5. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 287

6. P*olypodiisporites crassus* Dolby and Balme 1975
X 400, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 500

7. *Keuperisporites baculatus* Schulz 1965
X 400, Iraq Al-Amir Formation, Ladinian, 2IRA, S 2, EFC. B 319

8. *Echinitosporites iliacoides* Schulz and Krutzsch 1961
X 400, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 444

9. *Punctatisporites* sp. (Ibrahim 1933) Potonie and Kremp 1954
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 591

10. *Triplexisporites playfordii* (De Jersey and Hamilton 1967)emend. Foster 1979
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 849

11. *Guttatisporites* cf. *elegans* Visscher 1966
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 773

Plate 51

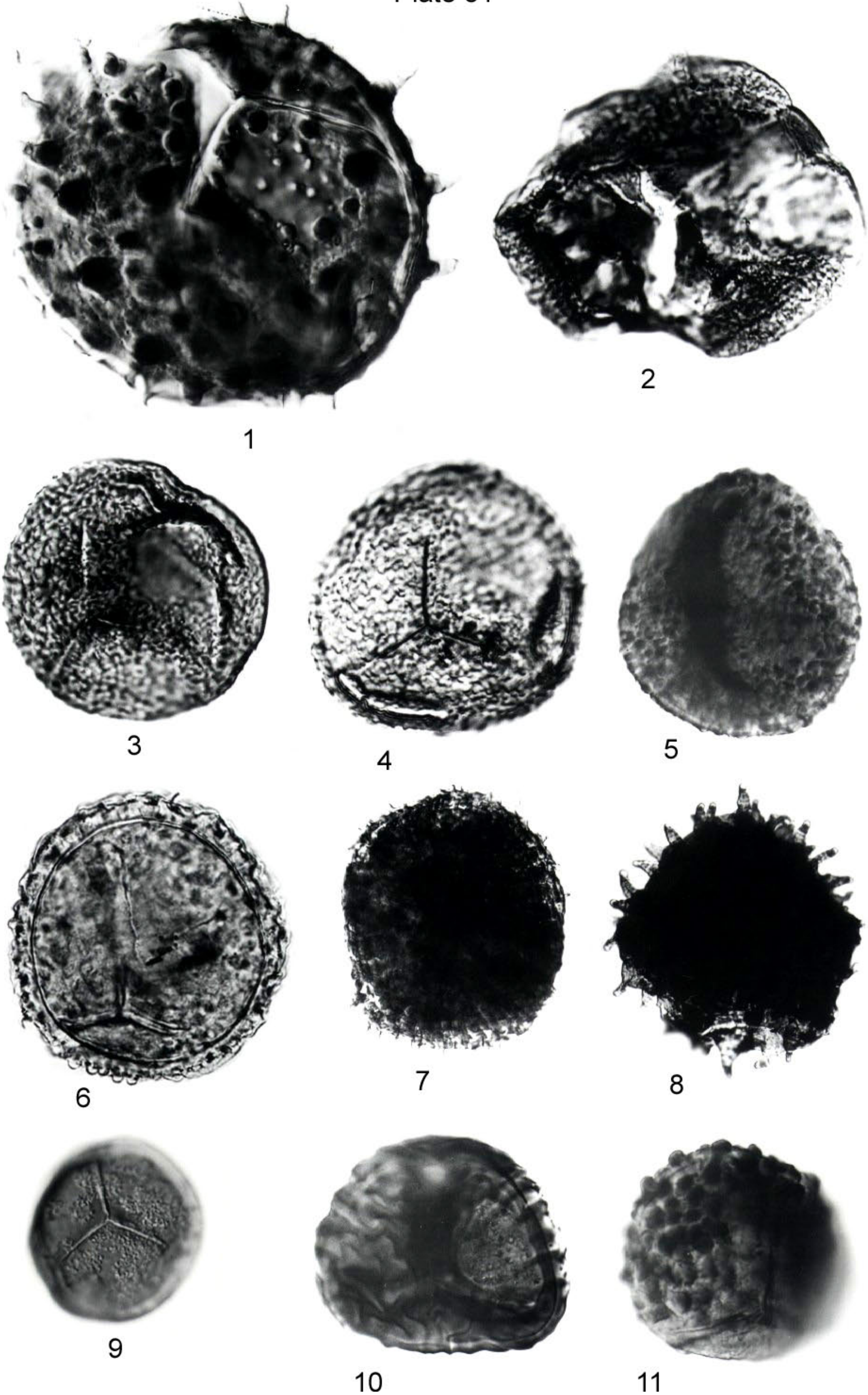


PLATE 52

1. *Heliosaccus dimorphus* Mädler 1964
X 1000, Iraq Al-Amir Formation, Ladinian, 5IRA, S 2, EFC. B 362

2. *Heliosaccus dimorphus* Mädler 1964
X 1000, Iraq Al-Amir Formation, Ladinian, 5IRA, S 2, EFC. B 473

3. *Punctatisporites* sp. (Ibrahim 1933) Potonie and Kremp 1954
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 674

4. *Punctatisporites* sp. (Ibrahim 1933) Potonie and Kremp 1954
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 674

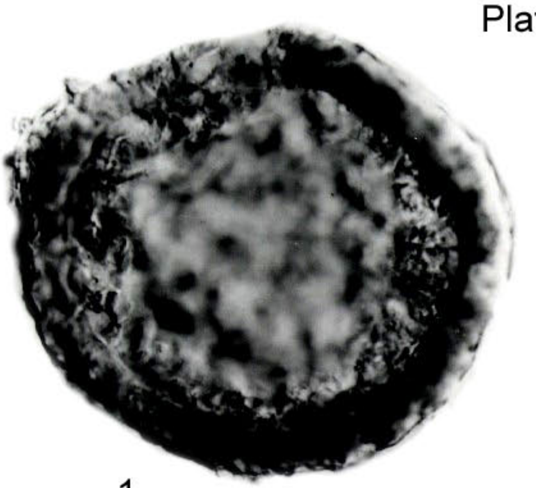
5. *Vitreisporites pallidus* (Reissinger 1938) emend. Nilsson 1958
X 1000, Iraq al Amir Formation, Ladinian, 4IRA, S 1, EFC. B 111

6. *Vitreisporites pallidus* (Reissinger 1938) emend. Nilsson 1958
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 868

7. *Vitreisporites pallidus* (Reissinger 1938) emend. Nilsson 1958
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 390

8. *Reticulatisporites muricatus* Kosanke 1950
X 400, Iraq Al-Amir Formation, Ladinian, 2IRA, S 1, EFC. B 417

Plate 52



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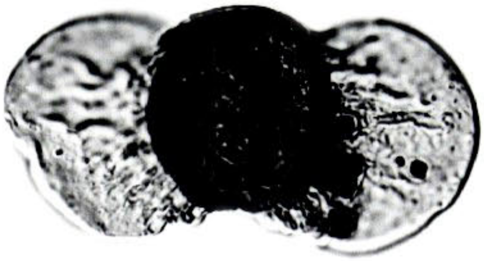

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PLATE 53

1. *Triadispora sulcata* Scheuring 1978
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 390

2. *Triadispora sulcata* Scheuring 1978
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 811-812

3. *Triadispora sulcata* Scheuring 1978
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 793

4. *Triadispora crassa* (Klaus 1964) sensu Brugman 1979
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 814

5. *Triadispora crassa* (Klaus 1964) sensu Brugman 1979
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 876

6. *Triadispora crassa* (Klaus 1964) sensu Brugman 1979
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 82

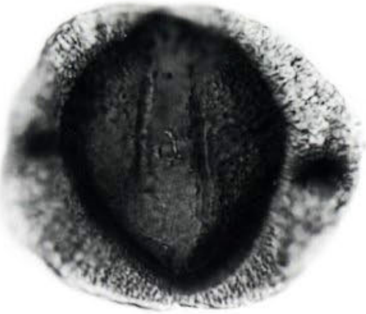
7. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 442-443

8. *Staurosaccites quadrifidus* Dolby in Dolby and Balme 1976
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. A 27

9. Unidentified grain
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 4, EFC. B 101

10. *Fuldaesporites* sp. Leschik 1956
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 743

Plate 53



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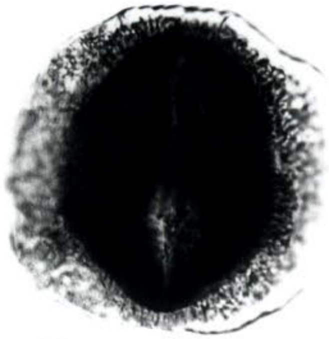

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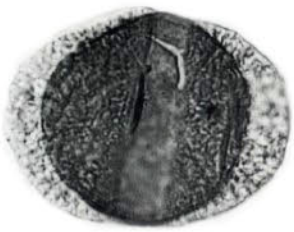

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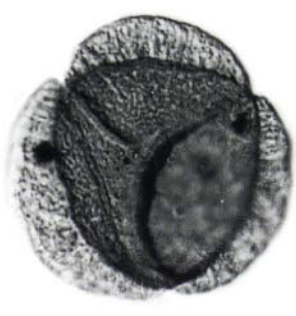

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PLATE 54

1. *Hexasaccites muelleri* Reinhardt and Schmitz 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 1, EFC. A 900

2. *Hexasaccites muelleri* Reinhardt and Schmitz 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 2, EFC. A 447

3. *Hexasaccites muelleri* Reinhardt and Schmitz 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 5IRA, S 1, EFC. B 92-93

4. *Lunatisporites* sp. Leschik 1955
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 736-737

5. *Lunatisporites acutus* Leschik 1955
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 2, EFC. B 876

6. *Lunatisporites acutus* Leschik 1955
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 678

7. *Lunatisporites* sp. Leschik 1955
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 2, EFC. B 815-816

8. *Lunatisporites pellucidus* (Goubin1965) emend. Balme 1970
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 697-698

9. *Lunatisporites noviaulensis* Leschik 1956
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. A 329

10. *Lueckisporites singhii* Balme 1970
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 2, EFC. B 770

Plate 54

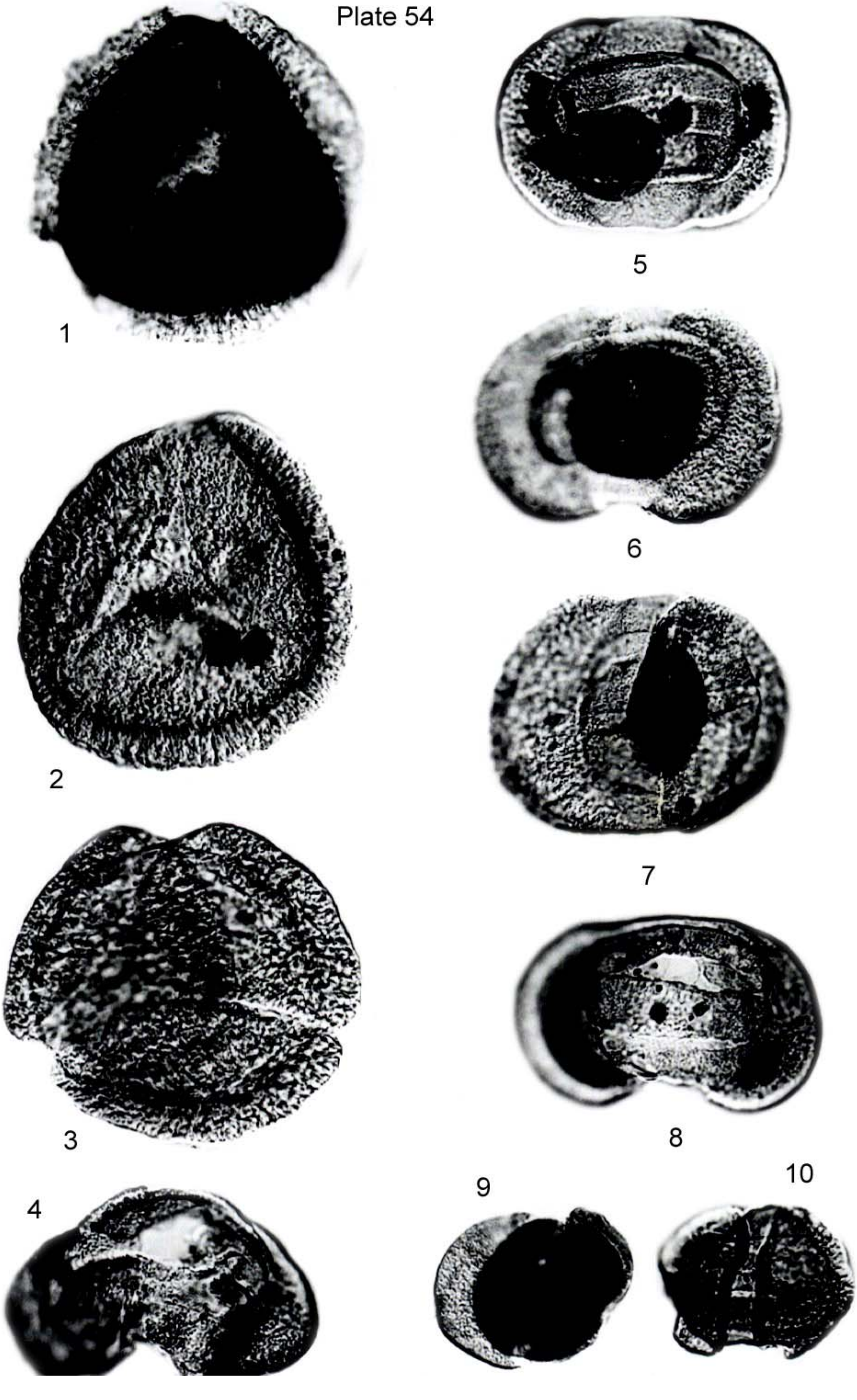

PLATE 55

1. *Eucommiidites microgranulatus* Scheuring 1970
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 3, EFC. B 122-123

2. *Rimaesporites* sp. Leschik 1955
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 1, EFC. A 451

3. *Alisporites microretculatus* Reinhardt 1964
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. A 479

4. *Alisporites* sp. (Daugherty 1941) emend. Nilsson 1958
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 2, EFC. B 770

5. Unidentified grain
X 1000, Iraq Al-Amir Formation, Ladinian, 5IRA, S 1, EFC. B 18

6. *Pityosporites neomundanus* Leschik 1955
X 1000, Iraq al-Amir Formation, Ladinian, 5IRA, S 1, EFC. B 495

7. *Angustisulcites klausii* (Freudenthal 1964) emend. Visscher 1966
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 80

8. *Angustisulcites klausii* (Freudenthal 1964) emend. Visscher 1966
X 1000, Iraq Al-Amir Formation, Ladinian, 5IRA, S 1, EFC. B 843

Plate 55

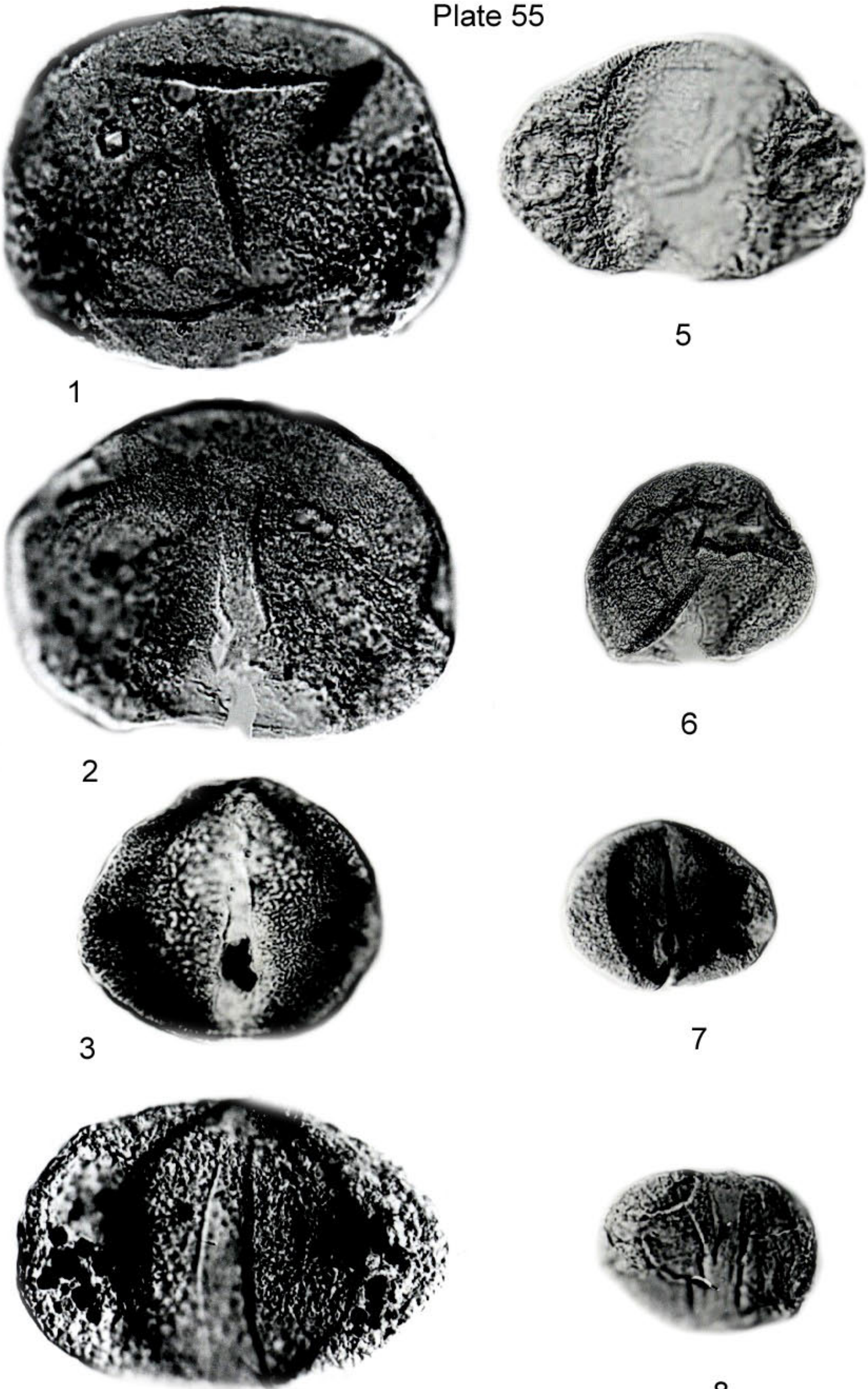

PLATE 56

1. *Platysaccus reticulates* Mädler 1964
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 2, EFC. B 890

2. Unidentified grain
X 400, Iraq Al-Amir Formation, Ladinian, 2IRA, S 1, EFC. B 686

3. Unidentified grain
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 501

4. *Podosporites amicus* Scheuring 1970
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. A 597

5. *Podocarpidites keuperianus* (Mädler 1964a) Schuurman 1977
X 1000, Iraq Al-Amir Formation, Ladinian, 9IRA, S 3, EFC. B 552-553

6. *Microcachryidites daubingeri* Klaus 1964
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 342

7. *Microcachryidites daubingeri* Klaus 1964
X 1000, Iraq Al-Amir Formation, Ladinian, 5IRA, S 2, EFC. B 25

8. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3,EFC. B 736

9. *Aratrisporites fimbriatus* (Klaus 1960) Mädler 1964
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 735

10. *Aratrisporites* sp. (Leschik 1955) emend. Playford and Dettmann 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 9IRA, S 2, EFC. B 624

11. Unidentified grain
X 1000, Iraq Al-Amir Formation, Ladinian, 5IRA, S 1, EFC. B 179

Plate 56

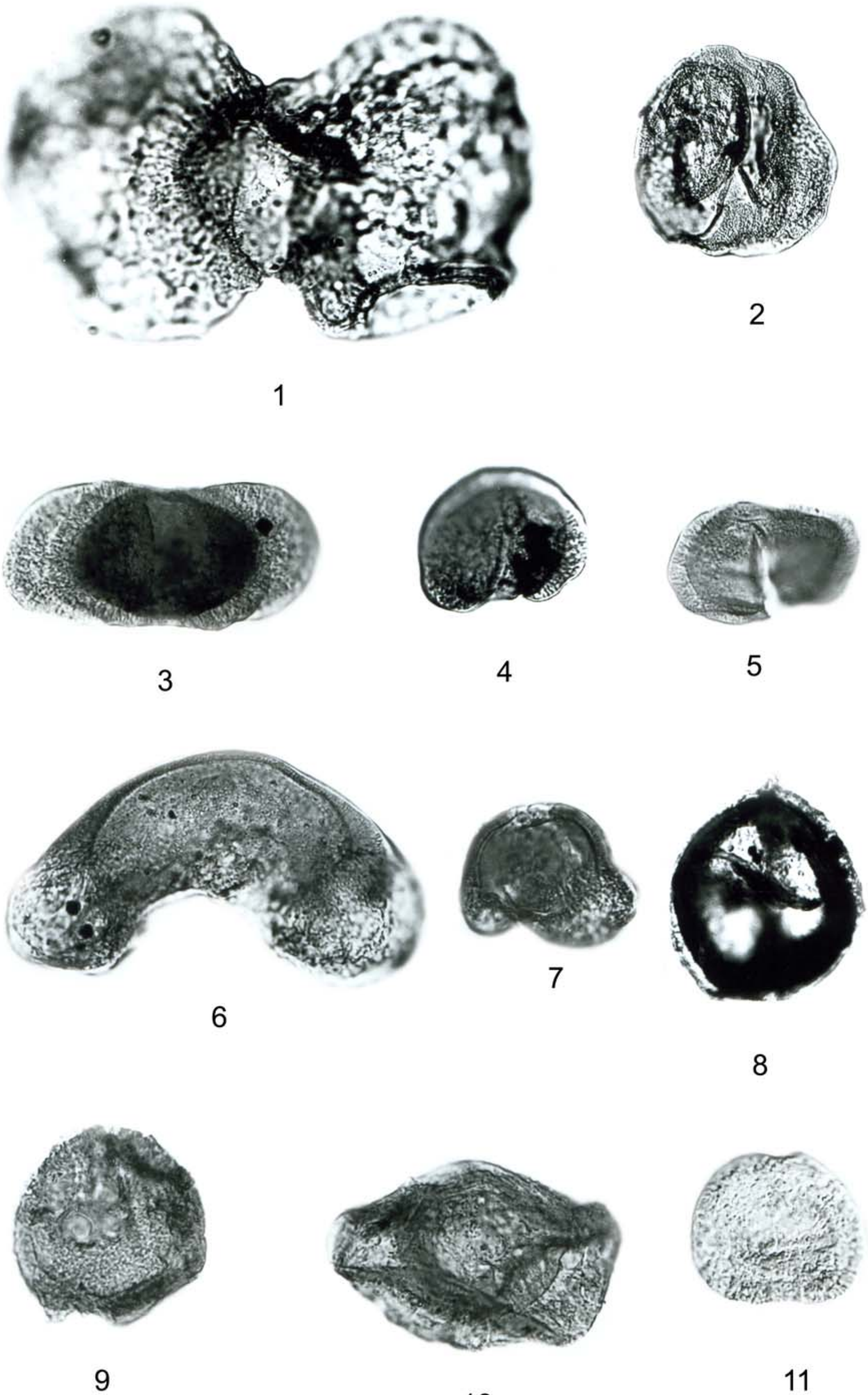

PLATE 57

1. *Aratrisporites fischeri* (Klaus 1960) emend. Playford and Dettmann 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 617

2. *Aratrisporites* sp. (Leschik 1956a) emend. Playford and Dettmann 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 1, EFC. B 647

3. *Aratrisporites saturnii* (Thiergardt 1949) emend. Mädler 1964a
X 1000, Iraq Al-Amir Formation, Ladinian, 2IRA, S 1, EFC. B 112

4. *Aratrisporites* sp. (Leschik 1956a) emend. Playford and Dettmann 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 736-737

5. *Aratrisporites* .sp.(Leschik 1956a) emend. Playford and Dettmann 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 2, EFC. B 845

6. *Aratrisporites* sp. (Leschik 1956a) emend. Playford and Dettmann 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4,EFC. B 319

7. *Aratrisporites parvispinosus* (Leschik 1955) emend. Playford 1965
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 224

8. *Aratrisporites* cf. *quadriiuga* Visscher 1966 emend
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 617

Plate 57

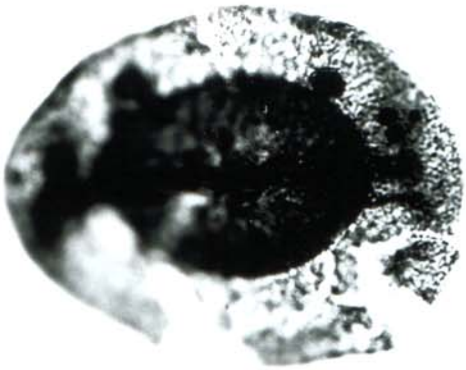

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PLATE 58

1. *Enzonalasporites vigens* Leschik 1956a
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 728

2. *Paracirculina scurrilis* Scheuring 1970
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 2, EFC. A 538-539

3. *Patinasporites densus* Leschik 1956a
X 1000, Iraq Al-Amir Formation, Ladinian, 9IRA, S 3, EFC. B 558

4. *Patinasporites densus* Leschik 1956a
X 1000, Iraq Al-Amir Formation, Ladinian, 5IRA, S 1, EFC. B 765-766

5. *Praecirculina granifer* Klaus 1960
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 515

6. *Laevigatosporites* sp. Ibrahim 1933
X 1000, Iraq Al-Amir Formation, Ladinian, 5IRA, S 1, EFC. B 878

7. *Laevigatosporites* sp. Ibrahim 1933
X 1000, Iraq Al-Amir Formation, Ladinian, 6IRA, S 2, EFC. B 839

8. *Duplicisporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Iraq Al-Amir Formation, Ladinian, 6IRA, S 2, EFC. B 445

9. *Camerosporites secatus* (Leschik 1956a) emend. Scheuring 1970
X 1000, Iraq Al-Amir Formation, Ladinian, 5IRA, S 1, EFC. B 515-516

10. *Cycadopites* sp.Woodehouse 1933
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 4, EFC. B 735

11. *Leiosphaeridia* sp. (Eisenack 1938) emend. Dovinie, Evitt and Sarjeant
X 1000, Iraq Al-Amir Formation, Ladinian, 4IRA, S 3, EFC. B 80-81

12. *Concavisporites toralis* (Leschik 1956a) emend. Nilsson 1958
X 1000, Um Tina Formation, Carnian, 3UTI, S 1, EFC. B 134

Plate 58

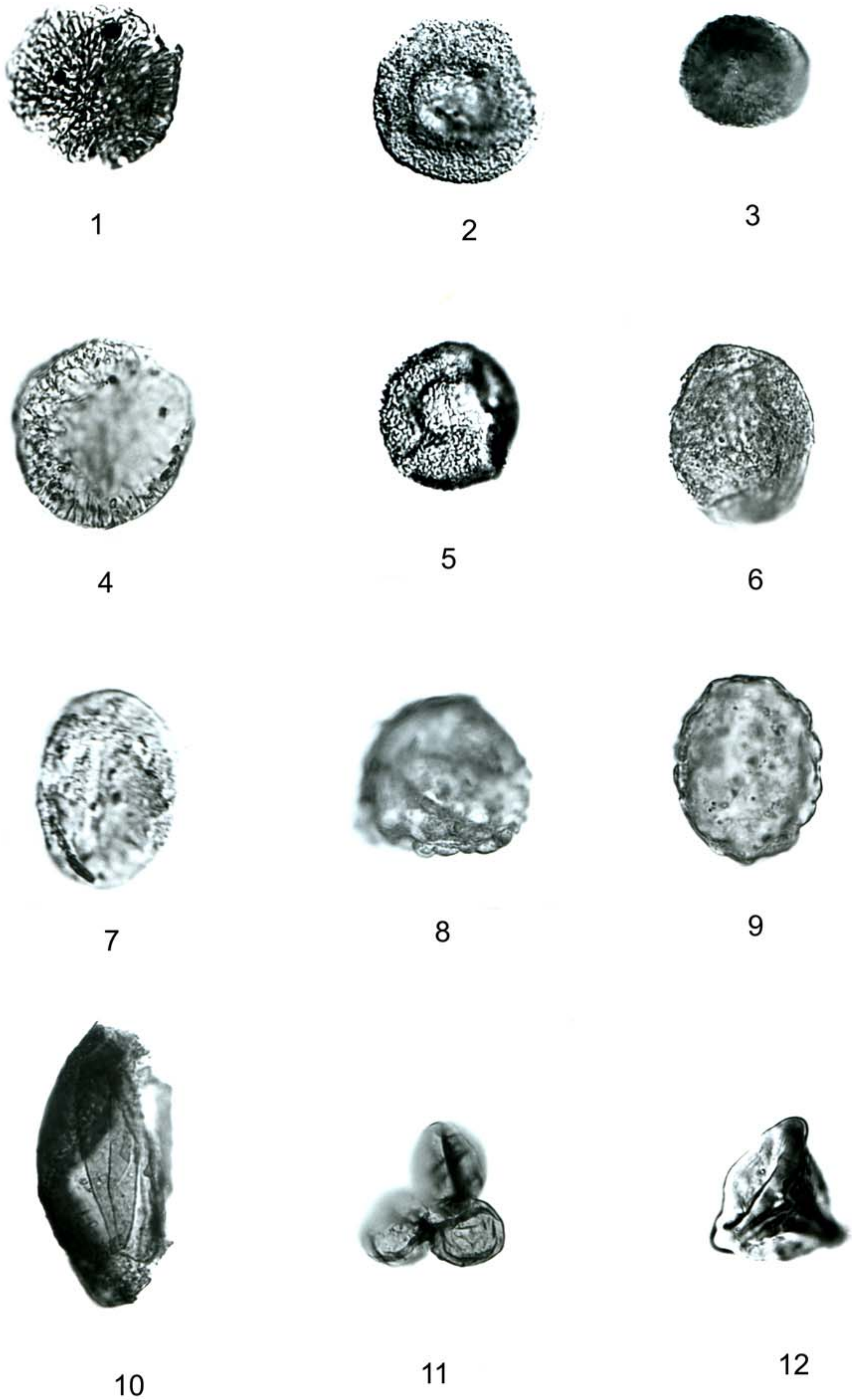


PLATE 59

1. *Lunatisporites* sp. Leschik 1955
X 1000, Um Tina Formation, Carnian, 3UTI, S 2, EFC. B 197

2. *Lunatisporites* sp. Leschik 1955
X 1000, Um Tina Formation, Carnian, 3UTI, S 5, EFC. B 37

3 *Lunatisporites* sp. Leschik 1955
X 1000, Um Tina Formation, Carnian, 3UTI, S 7, EFC. B 537

4. *Lunatisporites acutus* Leschik 1955
X 1000, Um Tina Formation, Carnian, 3UTI, S 4, EFC. B 761

5. *Falcisporites stabilis* Balme 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 3, EFC. B 174

6. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Um Tina Formation, Carnian, 3UTI, S 6, EFC. B 379

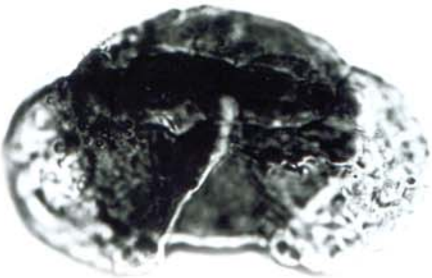
7. *Triadispora* sp. (Klaus 1964) sensu Brugman 1979
X 1000, Um Tina Formation, Carnian, 3UTI, S 5, EFC. B 761

8. *Paracirculina quadruplicis* Scheuring 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 7, EFC. B 719

9. *Paracirculina quadruplicis* Scheuring 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 7, EFC. B 719

10. *Sulcatisporites* cf. *kraeuselii* Mädler 1964
X 1000, Um Tina Formation, Carnian, 3UTI, S 3, EFC. B 452

Plate 59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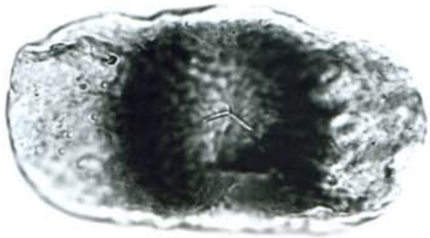
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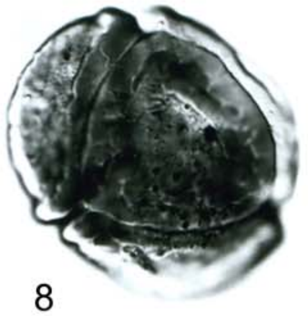
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PLATE 60

1. *Duplicisporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 2, EFC. B 552

2. *Duplicisporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 7, EFC. B 755

3. *Duplicisporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 6, EFC. B 400

4. *Duplicisporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 3, EFC. B 470

5. *Duplicisporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 2, EFC. B 574

6. *Camerosporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 3, EFC. B 697

7. *Camerosporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 6, EFC. B 424

8. *Camerosporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 3,EFC. B 892

9. *Camerosporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Um Tina Formation, Carnian, 3UTI, S 7, EFC. B 613

10. *Punctatisporites* sp. (Ibrahim 1933) Potonie and Kremp 1954
X 1000, Um Tina Formation, Carnian, 3UTI, S 3, EFC. B 890

11. *Todisporites marginales* Bharadwaj and Singh 1964
X 1000, Um Tina Formation, Carnian, 3UTI, S 3, EFC. B 524

Plate 60

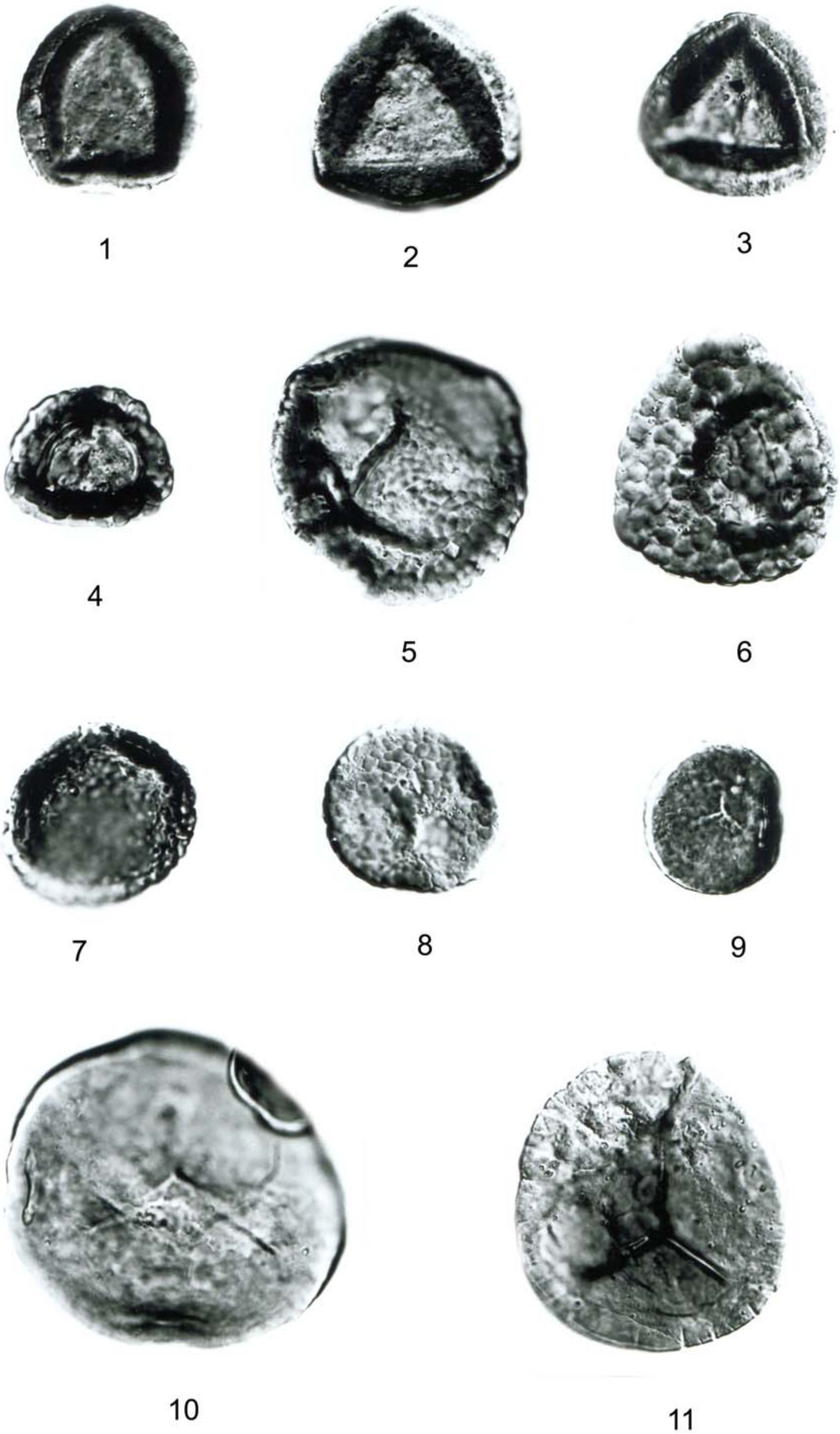


PLATE 61

1. *Vesicaspora fuscus* (Pautsch 1958) emend Morbey 1975
X 1000, Abu Ruweis Formation, Carnian, 7ARU, S 1, EFC. B 401

2. *Podocarpites keuperianus* (Mädler 1964a) Schuurman 1977
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 2, EFC. B 277

3. *Minutosaccus* sp.Mädler 1964
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 1, EFC. B 721

4. *Infernopollenites salcatus* (Putsch 1958) Scheuring 1970
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 1, EFC. A 868

5. *Pityosporites neomundanus* Leschik 1955
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 2,EFC. B 506

6. *Triadispora crassa* .(Klaus 1964) sensu Brugman 1979
X 1000, Abu Ruweis Formation, Carnian, 7ARU, S 2, EFC. A 414

7. *Triadispora suspecta* Scheuring 1970
X 1000, Abu Ruweis Formation, Carnian, 3ARU, S 2, EFC. B 175

8. *Partitisporites novimundanus* Leschik 1956a
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 2, EFC. B 125

9. *Lunatisporites acutus* Leschik 1955
X 1000, Abu Ruweis Formation, Carnian, 3ARU, S 1, EFC. B 361

Plate 61

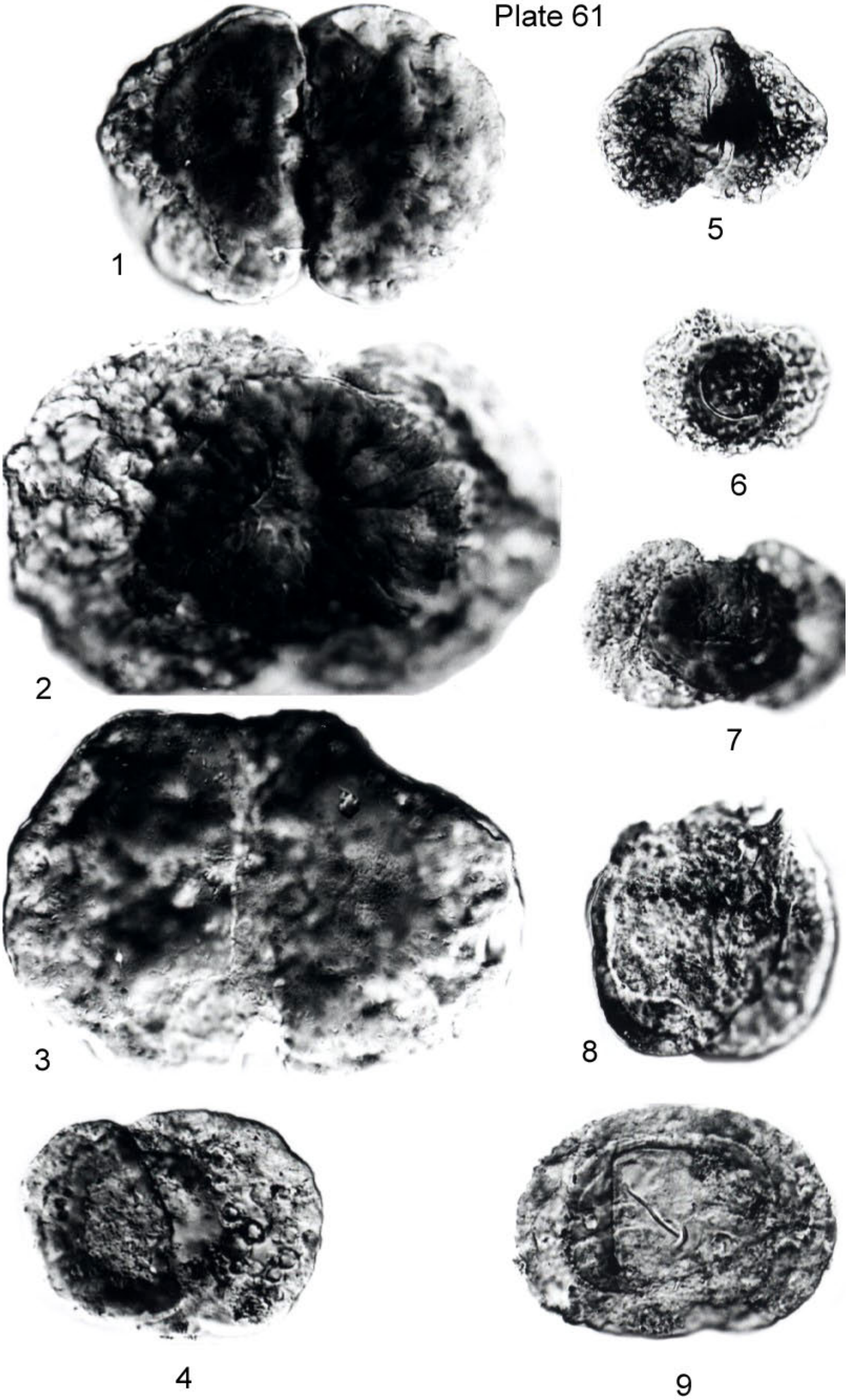


PLATE 62

1. *Minutosaccus* sp. Mädler 1964
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 1, EFC. B 605

2. *Vesicaspora fuscus* (Pautsch 1958) emend Morbey 1975
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 4, EFC. B 528

3. *Minutosaccus* sp. Mädler 1964
X 1000, Abu Ruweis Formation, Carnian, 2ARU, S 2, EFC. B 269

4. *Pityosporites neomundanus* Leschik 1955
X 1000, Abu Ruweis Formation, Carnian, 3ARU, S 1, EFC. A 572

5. *Pityosporites neomundanus* Leschik 1955
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 4, EFC. B 343

6. *Lunatisporites acutus* Leschik 1955
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 5, EFC. B 508-509

Plate 62

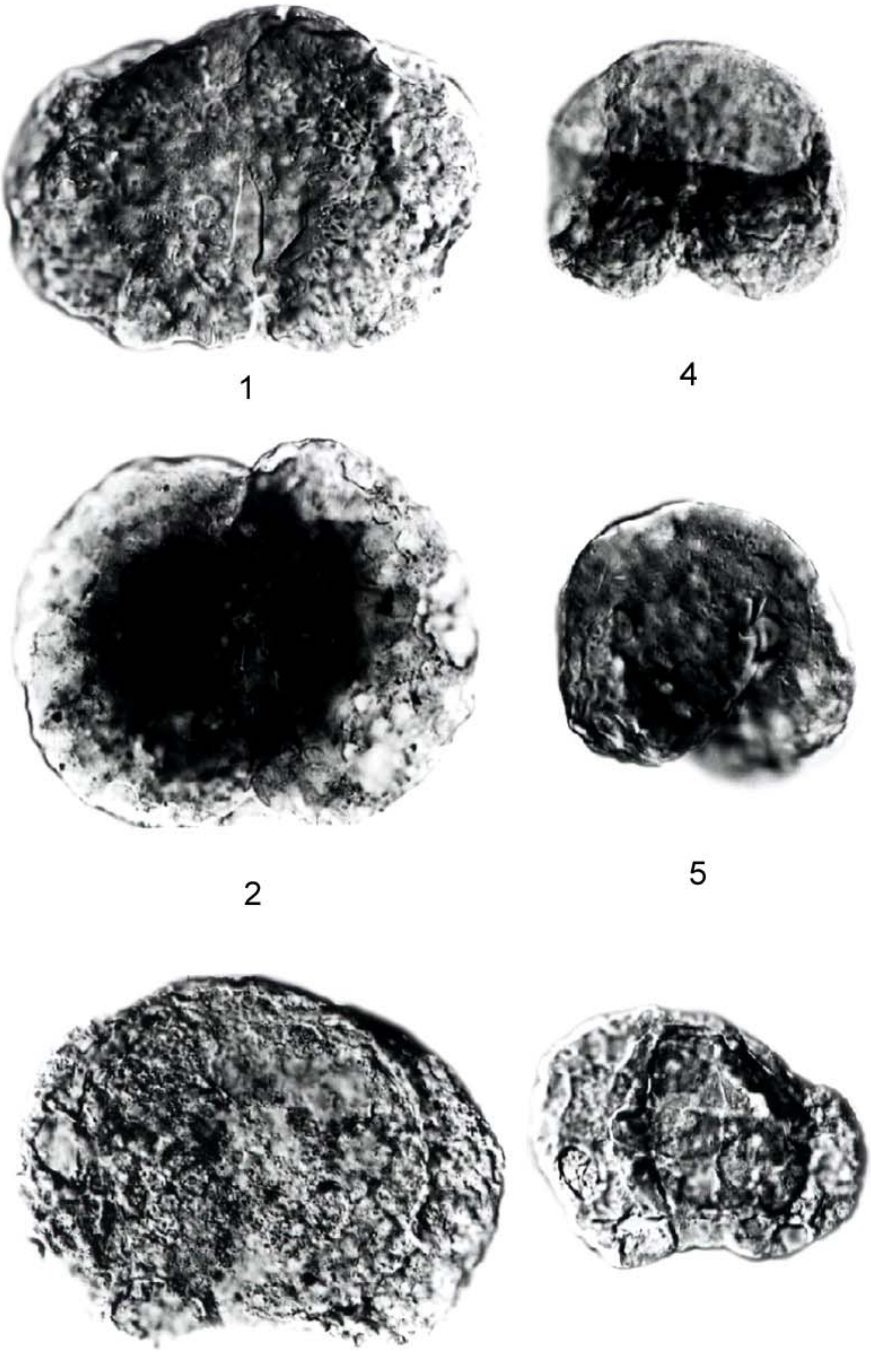


PLATE 63

1. *Samaropollenites specious* Goubin 1965
X 1000, Abu Ruweis Formation, Carnian, 3ARU, S 2, EFC. B 334

2. *Pityosporites* sp. Seward 1914
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 5, EFC. B 7

3. *Microcachryidites sittleri* Klaus 1964
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 4, EFC. B 346

4. Unidentified grain
X 1000, Abu Ruweis Formation, Carnian, 7ARU, S 3, EFC. B 894

5. *Striatoabieites aytugii* Visscher 1966
X 1000, Abu Ruweis Formation, Carnian, 2ARU, S 1, EFC. B 440

6. *Corollina* sp. (Tetrad) Malyavkina 1949
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 2, EFC. B 371

7. *Paracirculina* sp. Klaus 1960
X 1000, Abu Ruweis Formation, Carnian, 3ARU, S 1, EFC. B 874

8. *Corollina torosa* (Reissinger 1950) emend. Cornet and Traverse
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 2, EFC. B 876

Plate 63

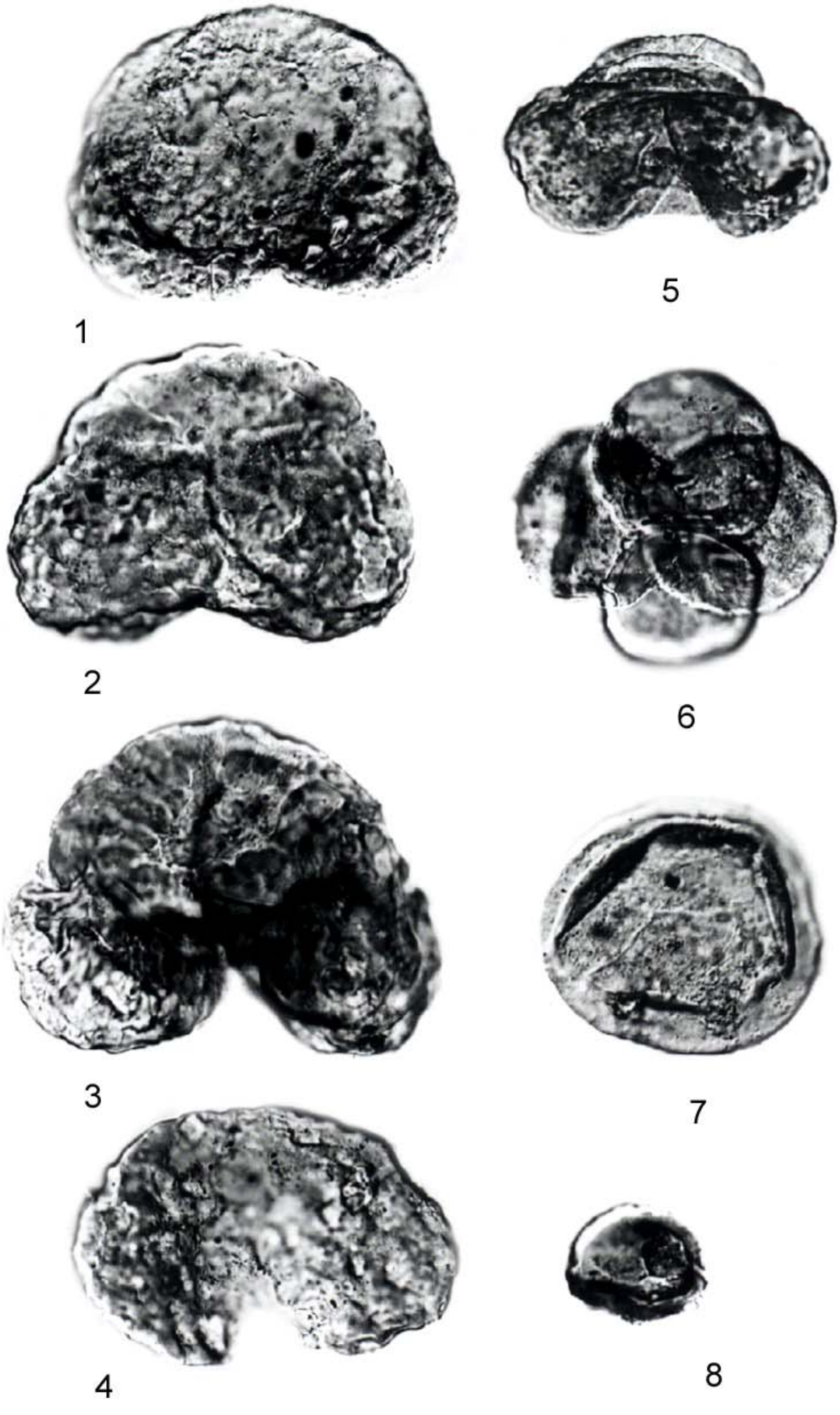


PLATE 64

1. *Heliosporites reissingeri* (Harris 1957) emend. Muir and Van Konijnenburg-Van Cittert 1970
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 2, EFC. B 313

2. *Semiretisporites gothae* Reinhardt 1961
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 2, EFC. B 364

3. *Semiretisporites gothae* Reinhardt 1961
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 3, EFC. B 835

4. *Patinasporites densus* Leschik 1956a
X 1000, Abu Ruweis Formation, Carnian, 3ARU, S 1, EFC. B 286

5. *Patinasporites densus* Leschik 1956a
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 2, EFC. B 778

6. *Patinasporites densus* Leschik 1956a
X 1000, Abu Ruweis Formation, Carnian, 3ARU, S 1, EFC. B 470

7. *Patinasporites densus* Leschik 1956a
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 3, EFC. B 401

8. *Patinasporites densus* Leschik 1956a
X 1000, Abu Ruweis Formation, Carnian, 7ARU, S 2, EFC. B 515

Plate 64

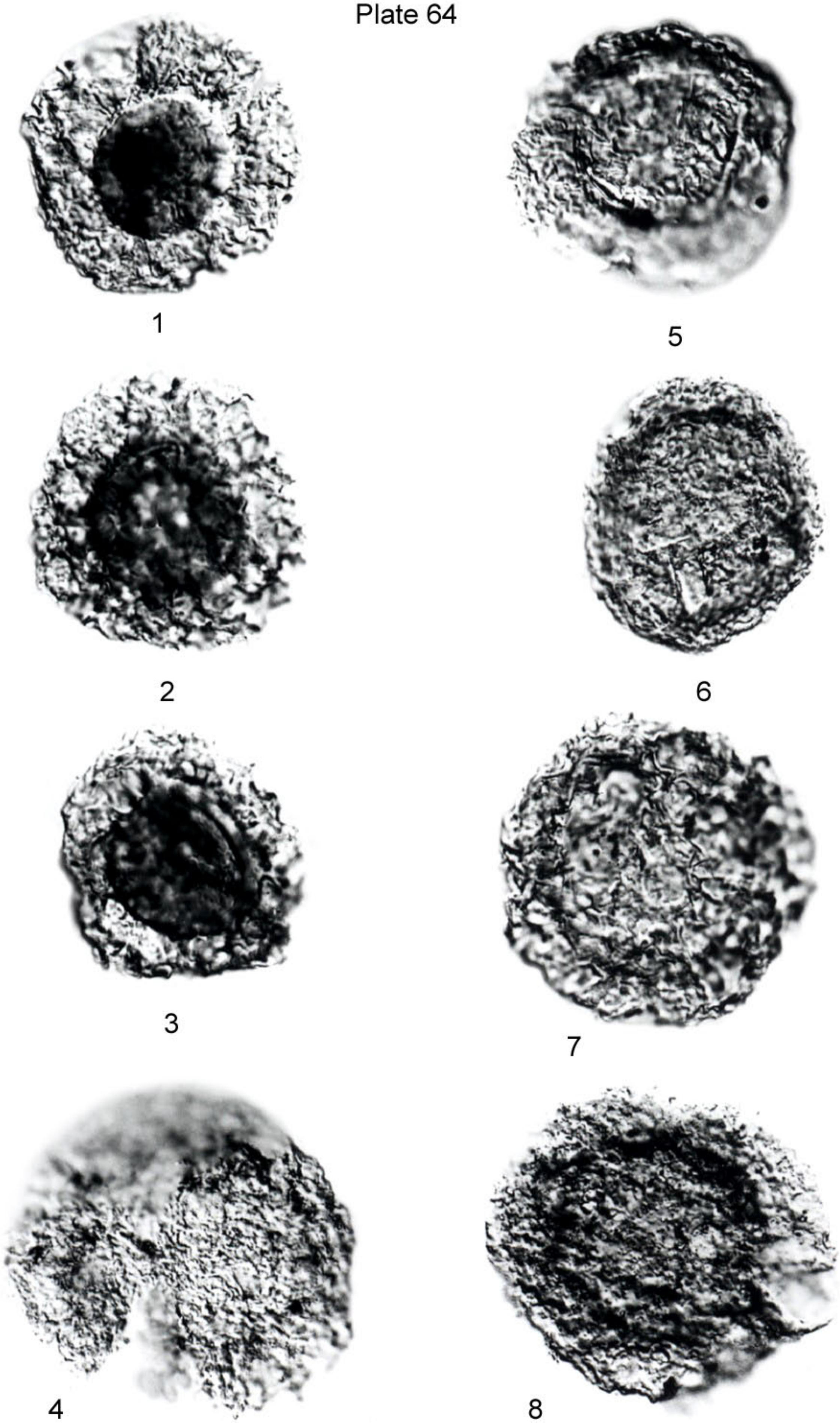


PLATE 65

1.*Duplicisporites granulatus* Leschik 1956a
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 2, EFC. B 423

2. *Duplicisporites granulatus* Leschik 1956a
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 2, EFC. B 96

3. *Duplicisporites verrucosus* Leschik 1956a
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 2, EFC. B 327

4. *Duplicisporites granulatus* Leschik 1956a
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 2, EFC. B 393

5. *Camerosporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 4, EFC. B 528

6. *Camerosporites* sp. (Leschik 1956a) emend. Scheuring 1970
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 4, EFC. B 453

7. *Camerosporites secatus* Leschik 1955
X 1000, Abu Ruweis Formation, Carnian, 3ARU, S 1, EFC. B 379

8. *Paracirculina scurrilis* Scheuring 1970
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 1, EFC. B 609

9. *Paracirculina scurrilis* Scheuring 1970
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 1, EFC. B 226

10. *Paracirculina scurrilis* Scheuring 1970
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 2, EFC. B 393

11. *Pseudenzonalasporites summus* Scheuring 1970
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 2, EFC. B 366

12. *Pseudenzonalasporites summus* Scheuring 1970
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 2, EFC. B 270

13. *Enzonalasporites vigens* Leschik 1956a
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 2, EFC. B 665

14. *Praecirculina granifer*.Klaus 1960
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 1, EFC. B 148

15. *Paracirculina scurrilis* Scheuring 1970
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 1, EFC. B 226

Plate 65

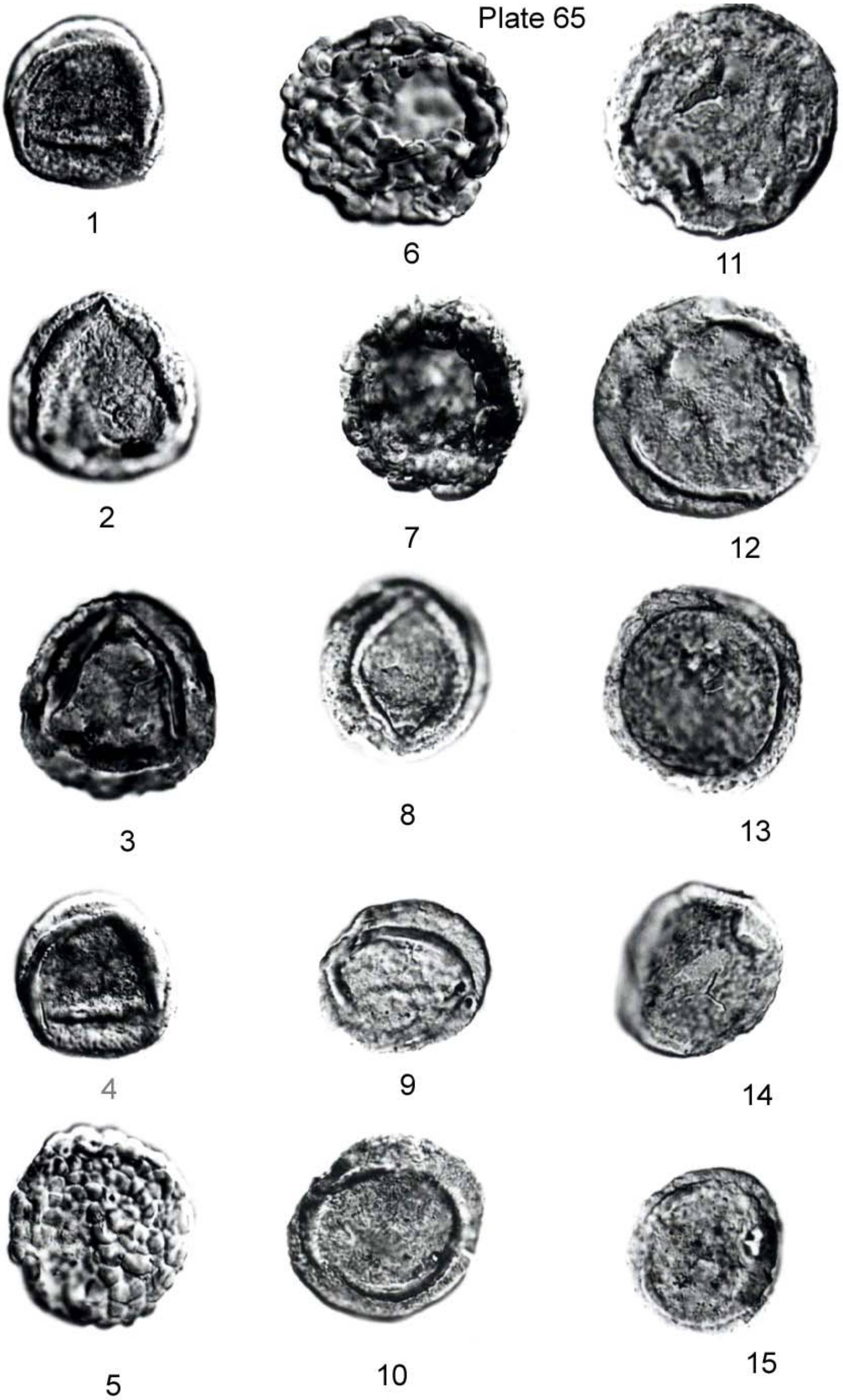


PLATE 66

1. *Chasmatosporites apertus* (Rogalska 1954) emend. Nilsson 1958
X 1000, Abu Ruweis Formation, Carnian, 7ARU, S 2, EFC. B 226

2. *Sellaspora rugoverrucata* Van Der Eem 1983
X 1000, Abu Ruweis Formation, Carnian, 3ARU, S 4, EFC. B 226

3. *Corollina torosa* (Reissiner 1950) Cornet and Traverse 1975
X 1000, Abu Ruweis Formation, Carnian, 3ARU, S 4, EFC. B 226

4. *Ovalipollis ovalis* Krutzsch 1955
X 1000, Abu Ruweis Formation, Carnian, 2ARU, S 1, EFC. B 226

5. *Matonisporites equiexinus* Couper 1958
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 1, EFC. B 226

6. *Matonisporites equiexinus* Couper 1958
X 1000, Abu Ruweis Formation, Carnian, 2ARU, S 1, EFC. B 226

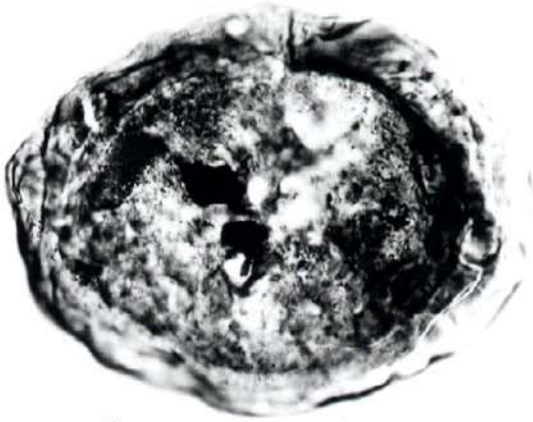
7. *Trachysporites* cf. *sparsus* (Bharadwaj and Singh1964) emend. Lund 1977
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 5, EFC. B 226

8. *Deltoidospora toralis* (Lischik 1955) emend. Lund 1977
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 1, EFC. B 226

9. *Tigrisporites* cf. *halleinis* Klaus 1960
X 1000, Abu Ruweis Formation, Carnian, 4ARU, S 1, EFC. B 226

10. *Convolutispora microrugulata* Schulz 1967
X 1000, Abu Ruweis Formation, Carnian, 16ARU, S 4, EFC. B 226

Plate 66



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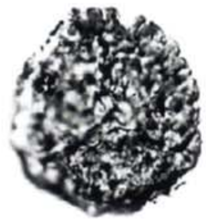

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Selbstständigkeitserklärung

Hiermit erkläre ich, dass ich diese Arbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus anderen Quellen entnommen wurden, habe ich als solche gekennzeichnet.

Münster, 26.11.2004

Abdallah Abu Hamad

Weiterhin erkläre ich, dass ich mich zurzeit ausschließlich an der Universität Hamburg im Fachbereich Geowissenschaften um eine Promotion bemühe und keine weiteren Anträge gestellt wurden.

Münster, 26.11.2004

Abdallah Abu Hamad