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Palynostratigraphy of Devonian sediments in the Zagros Basin, southern Iran

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Abstract

A total of 100 surface samples from the Zakeen and Faraghan formations were collected and processed in the palynological laboratory of the Exploration Directorate of the National Iranian Oil Company. The majority of surface samples contain well-preserved and abundant palynomorph taxa (acritarchs, miospores and scolecodonts). A total of 65 palynomorph taxa (9 acritarch species and 56 miospore species) were identified from the Zakeen and Faraghan formations. Five species are new and the remainder has been recorded from elsewhere. The new species are *Grandispora zakeenensis*, *Grandispora owensii*, *Auritolagenicula zagrosensis*, *Saharidia iranica* and *Papulogabata persica*. The recorded species are distributed through seven local stratigrphical assemblage zones. Zones I–III occur in a thickness of 95 m of the Zakeen Formation, suggesting an Early Devonian age (Lochkovian–Emsian). Zones IV–V are present within a 146-m thickness of the Zakeen Formation, indicating the Middle Devonian (Eifelian–Givetian). Zone VI occurs within a thickness of 44 m of this formation, suggesting a Frasnian age for this interval. Zone VII occurs in the Faraghan Formation, suggesting an Early Permian age. The Zakeen Formation differs from any other Devonian sediments in the Alborz Mountain Ranges and the Central Iranian Basin, but it is similar to the Devonian sequences (Tawil, Jauf and Jubah formations) of Saudi Arabia, allowing the potential for correlation of the Devonian strata between the southern and northern regions of the Persian Gulf.

Keywords: Devonian; Early Permian; miospores; acritarchs; biostratigraphy; Zagros Basin; southern Iran

1. Introduction

A clastic sequence of the Zakeen Formation is well-developed in the Tang-e-Zakeen of Kuh-e-Faraghan which is located approximately 103 km north of Bandar-e-Abbas city. The road from Bandar-e-Abbas city to Seyahou village is the principle link to the studied area (Fig. 1). The Zakeen Formation which encompasses the Devonian sediments in the Zagros Basin, southern Iran, lacks any fauna. Based largely on its stratigraphic relationships, it was assigned originally to the Early Permian (Szabo and Kheradpir, 1978). Since then, a detailed palynological study has been carried out on this formation and the Faraghan Formation by the author which has resulted in the identification of numerous palyno-

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morph taxa (acritarchs, miospores and scolecodonts). The palynomorph taxa recorded indicate that 285 m of the 340 m of the clastic sequence belongs to the Devonian and the remainder is Early Permian (Ghavidel-Syooki, 1997a,b, 1999). This paper is directed toward developing palynological information on the Zakeen Formation, in order to establish the age relationships of this formation and to resolve some aspects of the depositional environments. The Devonian sediments are recorded for the first time from the Zagros Mountain Ranges, southern Iran.

2. Stratigraphy

The studied area is located in the Tang-e-Zakeen of Kuh-e-Faraghan (Faraghan Mountain), which is located approximately 103 km north of Bandar-e-Abbas city. A thick Paleozoic sequence is well-developed in Tang-e-Zakeen. In ascending stratigraphic order, it has been divided into the Seyahou (Late Ordovician), Sarchahan (Early Silurian), Zakeen (Devonian) and Faraghan (Early Permian) formations (Ghavidel-Syooki, 1997a,b, 1999, 2000). The Seyahou Formation is 747 m thick and consists mainly of shale with subordinate sandstone and limestone. Based on acritarchs, chitinozoans as well as graptolites, this rock unit has been assigned to the Late Ordovician (Ghavidel-Syooki, 1997b, 2000; Rickards et al., 2000). The Sarchahan Formation which is 66 m thick and comprises of dark shales, rests conformably on the Seyahou Formation and is disconformably overlain by the Zakeen Formation. Based upon evidence from acritarchs, chitinozoans and graptolites, the Sarchahan Formation has been assigned an Early Silurian age (Ghavidel-Syooki, 1997b, 2000; Rickards et al., 2000). The Zakeen Formation is 285 m thick and consists mainly of sandstone with interbedded shale and subordinate dolomitic limestone. This formation lacks any marine fauna, but it contains well-preserved and abundant palynomorph taxa (acritarchs, miospores and scolecodonts). The Zakeen Formation, which rests disconformably on the Sarchahan Formation, is overlain by the Faraghan Formation. The Zakeen Formation has been assigned to the Devonian based on palynological data (Ghavidel-Syooki, 1997b, 1999). The Faraghan Formation is 55 m thick and consists of an alternation of sandstone, shale and limestone. Based on palynological data and some foraminifer species, this formation has been assigned to the Early Permian (Ghavidel-Syooki, 1997a; Szabo and Kheradpir, 1978).

3. Materials and methods

One hundred surface samples from the Zakeen Formation were treated and investigated for palynomorph taxa. The palynomorphs were extracted from shale, siltstone and fine-grained sandstone by standard palynological procedures, using saturated zinc bromide in order to separate the organic residues from the inorganic materials, screening the organic residues through 20-μm nylon mesh sieves. Extensive scanning electron and transmitted light microscopic examinations were carried out on the selected specimens throughout the study. All microscopic slides used in this study are on file in the paleontological collections of the Exploration Directorate of the National Iranian Oil Company under the sample numbers MG-8080 to MG-8089 and MG-7827 to MG-8023. Most surface samples contain well-preserved and abundant palynomorph taxa (acritarchs, miospores and scolecodonts), which permit the recognition of six ascending statigraphical zones for the Zakeen Formation.

4. Biostratigraphy

The objectives of this study are to summarize the stratigraphic range of assemblages and species that occur in the Zakeen Formation of the Zagros Mountain Ranges and to compare these data with zonal assemblages that have been reported from other parts of the world. A total of 65 miospore and acritarch taxa were identified and their distribution plotted on Fig. 2. Selected miospore and acritarch species are illustrated in Plates I–XIII. Seven assemblages have been recognized; they are described below in ascending stratigraphic order.

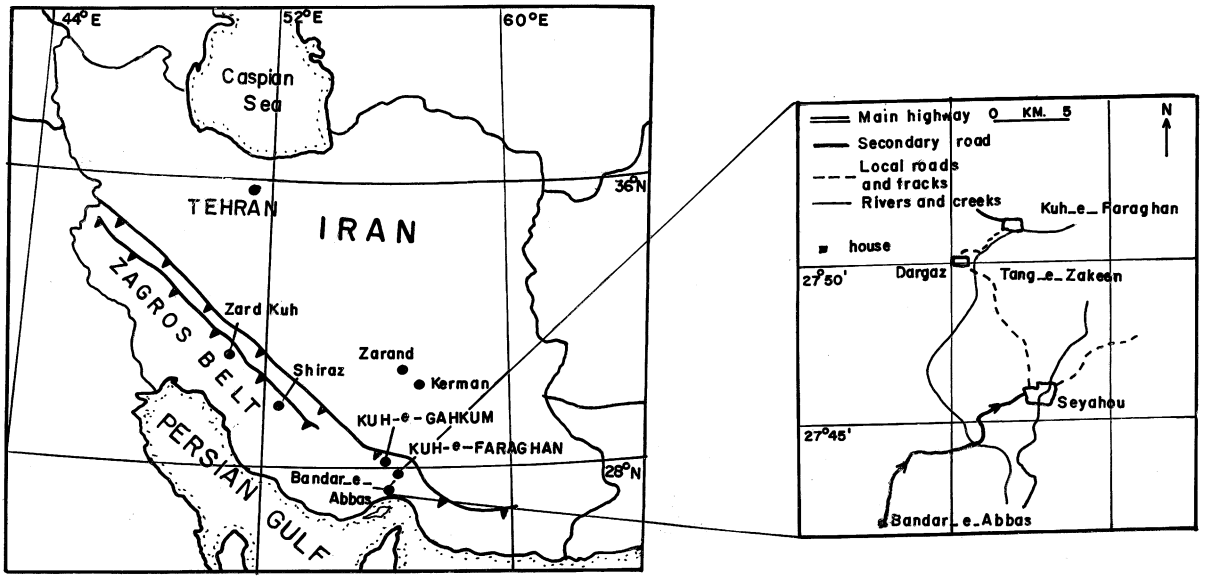


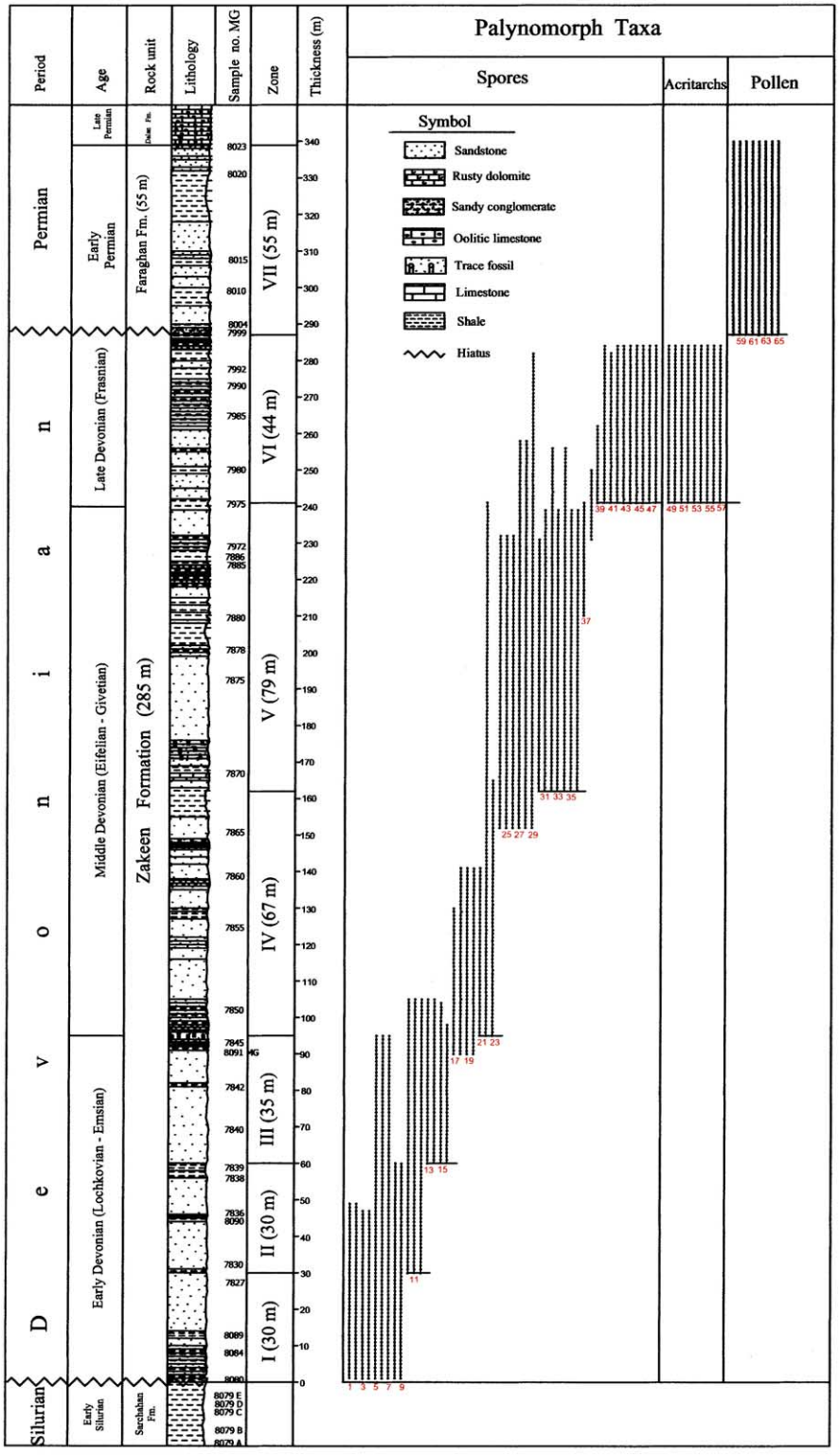
Fig. 1. Location map.

4.1. Spore assemblage zone I

This zone begins in the lower part of Zakeen Formation and extends through a thickness of 30 m. This part of the stratigraphic column rests on the sandy conglomerate of the lowermost part of the formation and consists mainly of shale, siltstone and fine-grained sandstone (Fig. 2). This assemblage zone is characterized by the occurrence of miospore species such as *Ambitisporites avitus*, *Ambitisporites dilutus*, *Retusotriletes dittonensis*, *Clivosispora reticulata*, *Amicosporites splendidus*, *Laeovancis divellomedium*, *Cymbosporites dammamensis*, *Chelinospora retorrida*, and *Cymbosporites proteus*. Except for two species, the remainder continue into the succeeding zone (Fig. 2). Likewise, the above-mentioned miospores are associated with some scolecodonts and a few long-ranging acritarchs (e.g. *Veryhachium* sp.). This assemblage zone is considered to belong to the Early Devonian (Lochkovian) since the above-mentioned spore species have been recorded from the Early Devonian strata of Canada (McGregor, 1973; McGregor and Camfield, 1976), England (Richardson and Lister, 1969; Richardson and McGregor, 1986), Germany (Riegel, 1973; Lanninger, 1968), Belgium (Becker et al., 1967; Streel, 1967), Portugal (Pereira et al., 1999), central Poland (Turnau, 1986), Saudi Arabia (Steemans, 1995), Libya (Hoffmeister, 1959; Richardson, 1985; Coquel and Moreau-Benoit, 1986), Iran (Ghavidel-Syooki, 1999), Spitsbergen (Allen, 1965), and Ireland (Higgs, 1999).

4.2. Spore assemblage zone II

This zone is marked by the appearance of additional spore species to supplement those recorded in zone I, e.g. *Stenozonotriletes minus*, *Verrucosisporites polygonalis* and *Clivosispora verrucata*. This assemblage zone occurs in a thickness of 30 m of the Zakeen Formation (Fig. 2). The miospore species of this zone continue into the succeeding zone. Moreover, some scolecodonts and long-ranging acritarchs (e.g. *Veryhachium* sp. and *Micrhystridium* sp.) are present in this interval. This assemblage zone is also assigned to the Early Devonian (Pragian–Emsian) since the above-mentioned spore taxa have been recorded from the Early Devonian sediments of Canada (McGregor, 1973; McGregor and Camfield, 1976), Germany (Riegel, 1973; Lanninger, 1968), France (Lé Herissé, 1983), central Poland (Turnau, 1986), Belgium (Streel, 1967), Spain (Cramer, 1983), Portu-


Period
Age
Rock unit
Lithology
Sample no. MG
Zone
Thickness (m)
Palynomorph Taxa
Spores
Acritarchs
Pollen
Symbol
Sandstone
Rusty dolomite
Sandy conglomerate
Oolitic limestone
Trace fossil
Limestone
Shale
Hiatus
Permian
Devonian
Silurian
Late Permian
Early Permian
Late Devonian (Frasnian)
Middle Devonian (Eifelian - Givetian)
Early Devonian (Lochkovian - Emsian)
Early Silurian
Dalan Fm.
Faraghan Fm. (55 m)
Zakeen Formation (285 m)
Sarchahan Fm.
VII (55 m)
VI (44 m)
V (79 m)
IV (67 m)
III (35 m)
II (30 m)
I (30 m)

gal (Pereira et al., 1999), Saudi Arabia (Steemans, 1995), Iran (Ghavidel-Syooki, 1999), and Ireland (Higgs, 1999).

4.3. Spore assemblage zone III

This zone is characterized by the appearance of *Dictyotriletes minor*, *Dibolisporites eifeliensis*, *Dibolisporites quebecensis* and *Dibolisporites wetteldorfensis* (Fig. 2) and some scolecodonts. This unit has a thickness of 35 m and consists of mainly fine-grained sandstones with intercalations of shale. The assemblage is indicative of the late Early Devonian (Emsian) since the above-mentioned miospore species have been recorded from the Emsian sediments of Canada (McGregor, 1973; McGregor and Camfield, 1976; McGregor and Playford, 1992), Germany (Riegel, 1973; Lanninger, 1968), France (Lé Herissé, 1983; Loboziak et al., 1991), Belgium (Streel, 1967), central Poland (Turnau, 1986), Saudi Arabia (Steemans, 1995), Iran (Ghavidel-Syooki, 1999), and Ireland (Higgs, 1999). Likewise, several miospore species occur near the top of zone III which continue into the succeeding zone, consisting of *Grandispora douglastownense*, *Grandispora macrotuberculata*, *Acinosporites lindlarensis* and *Dibolisporites echinaceus*. Moreover, based on measurement of 300 spores of zones I–III, the mean size of Early Devonian miospores is 40 to 45 μ and the mode is 33 and 35 μ. Comparison of the means and modes of miospores in zones I–III with those of zones IV–V supports the conclusion that the Early Devonian miospores of the Zakeen Formation are much smaller than those of the Middle and Late Devonian parts of this formation.

4.4. Spore assemblage zone IV

This zone is separated from zone III by a highly bioturbated sandstone and accounts for 67 m of the formation (Fig. 2). This zone of the Zakeen Formation comprises of sandstone, shale and a fishbone bed, just a few meters above the highly bioturbated sandstone bed. This zone is marked by the presence of miospore species such as *Acinosporites acanthomammillatus*, *Apiculatisporis adavalensis*, *Verrucosisporites premnus*, *Acinosporites macrospinosus*, *Cyclogranisporites amplus*, *Rhabdosporites langii*, *Rhabdosporites parvulus*, *Emphanisporites rotatus* and *Calyptosporites velatus*. These miospore species are accompanied by some scolecodonts and a few specimens of *Micrhystridium* sp. The above-mentioned miospore species of the Zakeen Formation are assigned to the Eifelian–early Givetian since they have been reported from the early Middle Devonian strata of Spitsbergen (Naumova, 1953; Allen, 1965; Avkhimovitch et al., 1989), Saudi Arabia (Hemer and Nygreen, 1967; Loboziak, 2000), southern Iran (Ghavidel-Syooki, 1999), South Africa (Sta-

Fig. 2. Stratigraphic distribution of palynomorph taxa in the Upper Paleozoic sequence of the Zagros Basin, southern Iran. The recorded taxa are listed below (numbers refer to the corresponding columns in the figure): (1) *Ambitisporites avitus*; (2) *Ambitisporites dilutus*; (3) *Retusotriletes dittonensis*; (4) *Clivosispora reticulata*; (5) *Amicosporites splendidus*; (6) *Laeovancis divellomedium*; (7) *Cymbosporites dammamensis*; (8) *Chelinospora retorrida*; (9) *Cymbosporites proteus*; (10) *Stenozonotriletes minus*; (11) *Verrucosisporites polygonalis*; (12) *Clivosispora verrucata*; (13) *Dictyotriletes minor*; (14) *Dibolisporites eifeliensis*; (15) *Diblosporites quebecensis*; (16) *Dibolisporites wetteldorfensis;* (17) *Grandispora douglastownense;* (18) *Grandispora macrotuberculata*; (19) *Acinosporites lindlarensis*; (20) *Dibolisporites echinaceus*; (21) *Acinosporites acanthomammillatus*; (22) *Apiculatisporis adavalensis*; (23) *Verrucosisporites premnus*; (24) *Acinosporites macrospinosus*; (25) *Cyclogranisporites amplus;* (26) *Rhabdosporites langii*; (27) *Rhabdosporites parvulus*; (28) *Calyptosporites velatus*; (29) *Emphanisporites rotatus*; (30) *Grandispora incognita*; (31) *Grandispora owensii* n.sp.; (32) *Cymbosporites catillus*; (33) *Convolutispora mimerensis;* (34) *Samarisporites concinnus*; (35) *Grandispora mammillata*; (36) *Grandispora zakeenensis* n.sp; (37) *Auritolagenicula zagrosensis* n.sp.; (38) *Geminospora lemurata*; (39) *Convolutispora subtilis*; (40) *Geminospora punctata*; (41) *Ancyrospora melvillensis;* (42) *Ancyrospora ampulla;* (43) *Ancyrospora carnarvonensis;* (44) *Ancyrospora pulchra*; (45) *Ancyrospora furcula*; (46) *Hystricosporites furcatus*; (47) *Hystricosporites reflexus*; (48) *Verrucosisporites confertus*; (49) *Chomotriletes vedugensis*; (50) *Chomotriletes bistchoensis*; (51) *Deltotosoma intonsum*; (52) *Dictyotidium torosum*; (53) *Histopalla capillosa*; (54) *Helosphaeridium microclavatum*; (55) *Gorgonisphaeridium abstrusum*; (56) *Saharidia iranica* n.sp.; (57) *Papulogabata persica* n.sp.; (58) *Vittatina subsaccata*; (59) *Caheniasaccites ellipticus*; (60) *Mabuitasaccites ovatus;* (61) *Corisaccites alutas*; (62) *Fusacolpites fusus*; (63) *Striomonosaccites triangularis*; (64) *Potonieisporites granulatus*; (65) *Boutakoffites elongatus*.

Plate I (see page 247).

1. *Retusotriletes dittonensis* Richardson & Lister, 1969 (×2000, MG-8082).
2. *Dibolisporites wetteldorfensis* Lanninger, 1968 (×3000, MG-8082).
3. *Laeovancis divellomedium* (Chibrikova) Burgess & Richardson, 1991 (×3000, MG-8082).
4. *Amicosporites splendidus* Cramer, 1967 (×3000, MG-8082).
5. *Clivosispora reticulata* Rodriguez, 1978 (×3000, MG-8083).
6. *Dictyotriletes minor* Naumova, 1953 (×4000, MG-8083).
7. *Dibolisporites quebecensis* McGregor, 1973 (×3000, MG-8082).
8. *Cymbosporites dammamensis* Steemans, 1995 (×3000, MG-8083).
9. *Cymbosporites proteus* McGregor & Camfield, 1976 (×3000, MG-8083).
10. *Clivosispora reticuluta* Rodriguez, 1978 (×2000, MG-8082).
11. *Ambitisporites avitus* Hoffmeister, 1959 (×2000, MG-8082).
12. Ambitisporites dilutus(Hoffmeister) Burgess & Richardson, 1969 (×2000, MG-8082).

Plate II (see page 248).

1. *Cymbosporites dammamensis* Steemans, 1995 (×3000, MG-8083).
2. *Chelinospora retorrida* Turnau, 1986 (×3000, MG-8082).
3. *Clivosispora reticulata* Rodriguez, 1978 (×4000, MG-8082).
4. *Stenozonotriletes minus* McGregor & Camfield, 1976 (×3000, MG-8082).
5. *Amicosporites splendidus* Cramer, 1967 (×3000, MG-8082).
6. *Clivosispora verrucata* McGregor, 1973 (×3000, MG-8082).

Plate III (see page 249).

1. *Dibolisporites eifeliensis* (Lanninger) McGregor, 1973 (×3000, MG-7866).
2. Detailed sculptural elements of fig. 1. (×6000).
3. *Dibolisporites eifeliensis* (Lanninger) McGregor, 1973 (×3000, MG-7866).
4. *Dibolisporites quebecensis* McGregor, 1973 (×3000, MG-7866).
5. Detailed sculptural elements of fig. 7 (×6000).
6. *Dibolisporites quebecensis* McGregor, 1973 (×3000, MG-7866).
7. *Acinosporites lindlarensis* Riegel, 1968 (×3000, MG-7866).
8. Detailed sculputural elements of fig. 9. (×6000).
9. *Grandispora zakeenensis* n.sp. (×3000, MG-7885).

Plate IV (see page 250).

1. *Acinosporites acanthomammillatus* Richardson, 1965 (×3000, MG-7878).
2. *Convolutispora mimerensis* (Vigran) Allen, 1965 (×3000, MG-7878).
3. Detailed sculptural elements of fig. 1 (×6000).
4. *Acinosporites macrospinosus* Richardson, 1965 (×1500, MG-7878).
5. *Cymbosporites catillus* Allen, 1965 (×3000, MG-7885).
6. *Verrucosisporites confertus* Owens, 1971 (×3000, MG-7885).

Plate V (see page 251).

1. *Grandispora incognita* (Kedo) McGregor & Camfield, 1976 (×2500, MG-7885).
2. *Grandispora douglastownense* McGregor, 1973 (×2000, MG-7885).
3. *Grandispora macroturberculata* (Arkhangelskaya) McGregor, 1973 (×1500, MG-7878).
4. *Apiculatisporis adavalensis* De Jersey, 1966 (×2000, MG-7980).
5. *Cyclogranisporites amplus* McGregor, 1960 (×3000, MG-7980).
6. *Convolutispora subtilis* Owens, 1971 (×3000, MG-7980).
7. *Geminospora punctata* Owens, 1971 (×3000, MG-7980).
8. Sculpture elements of fig. 5 (×6000).

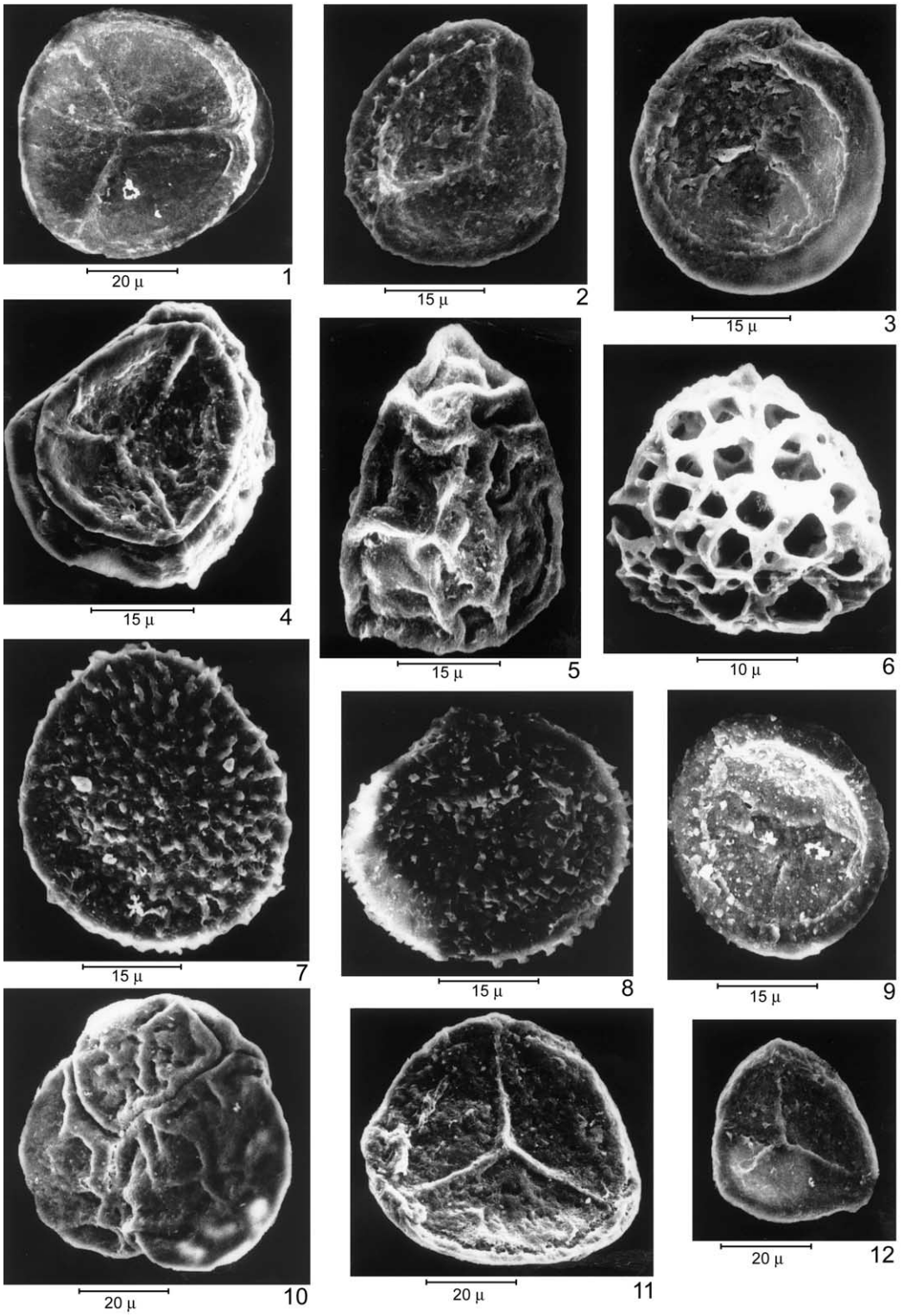


Plate I (*Caption on page 246*).

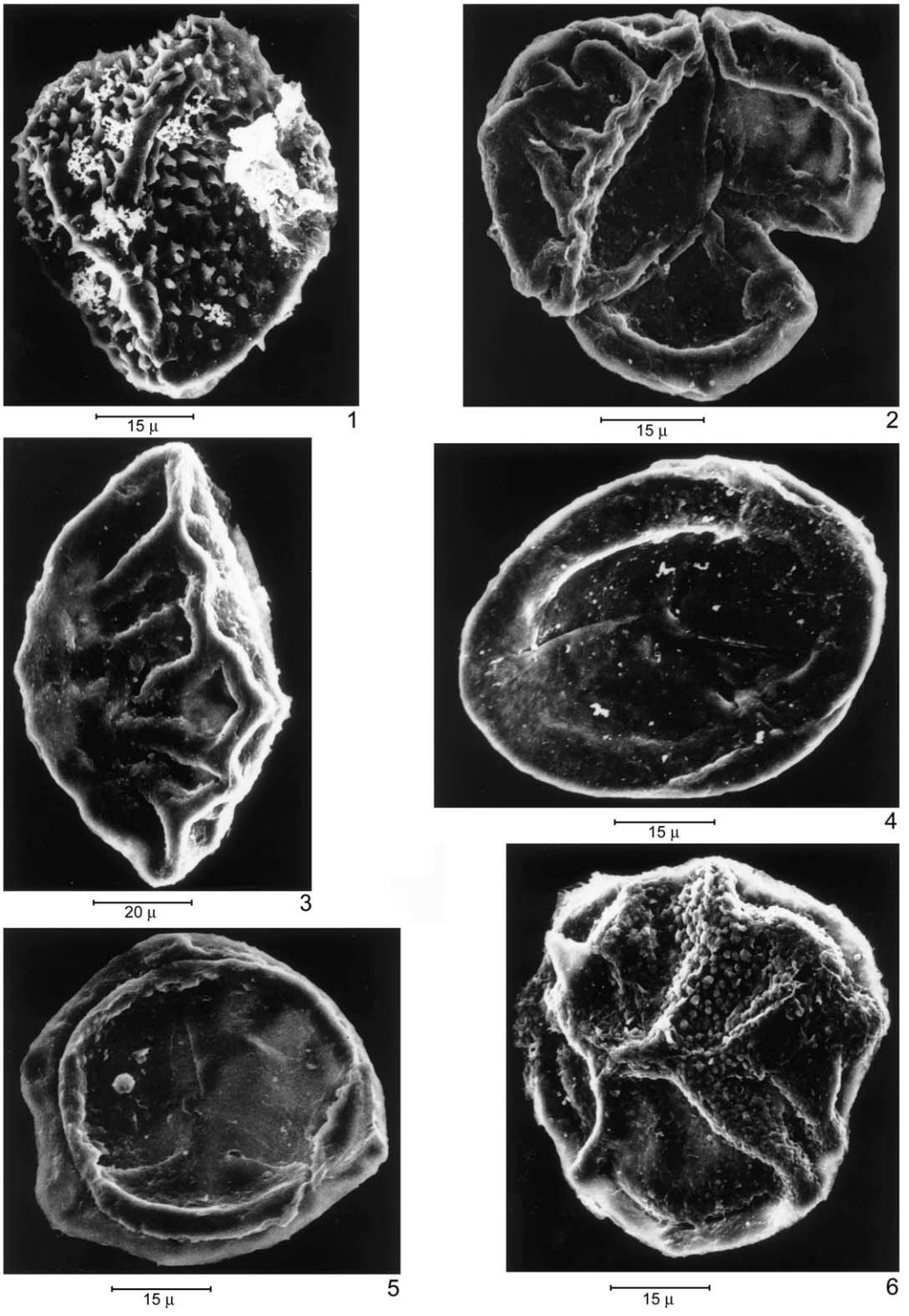


Plate II (*Caption on page 246*).

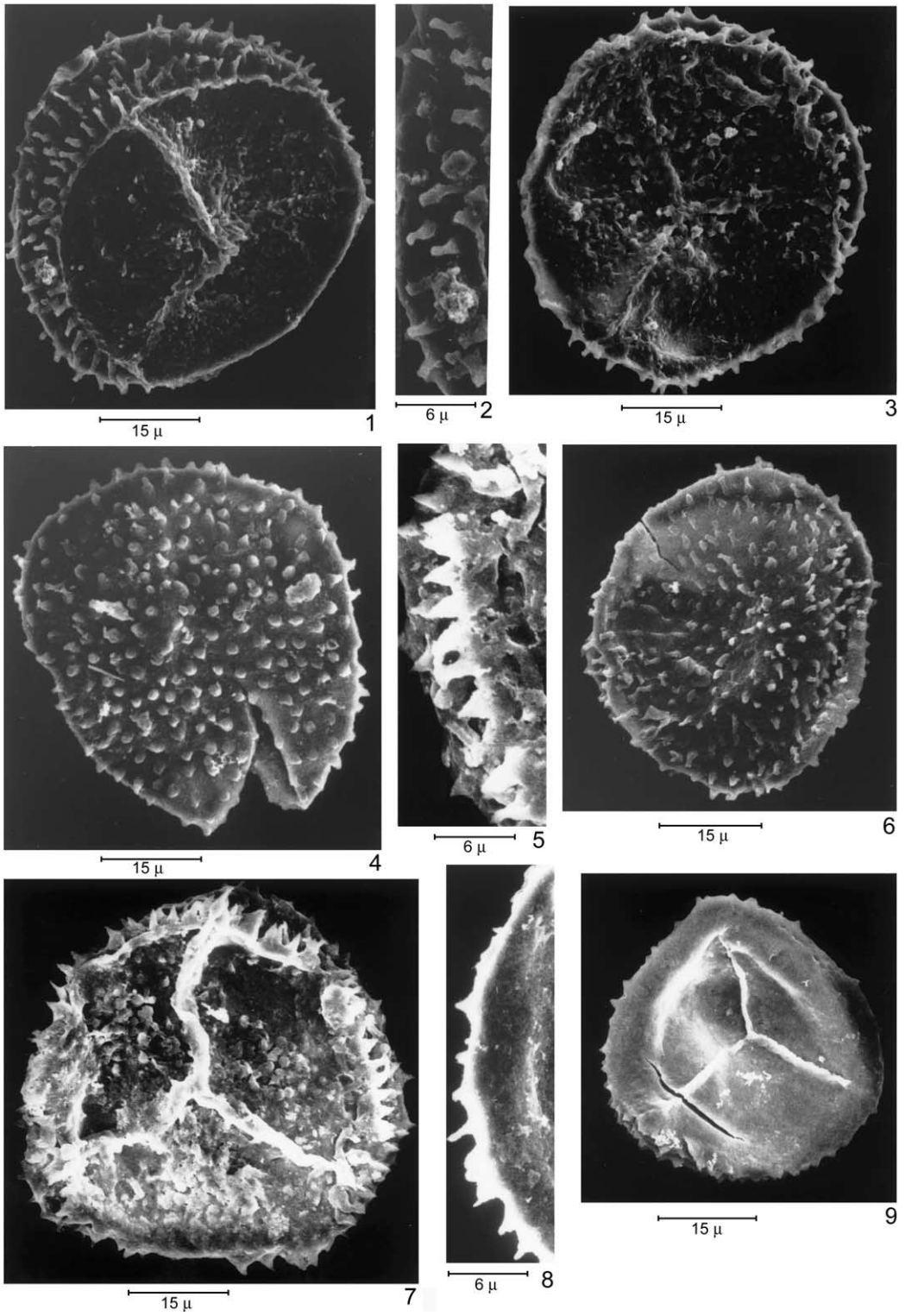


Plate III (*Caption on page 246*).

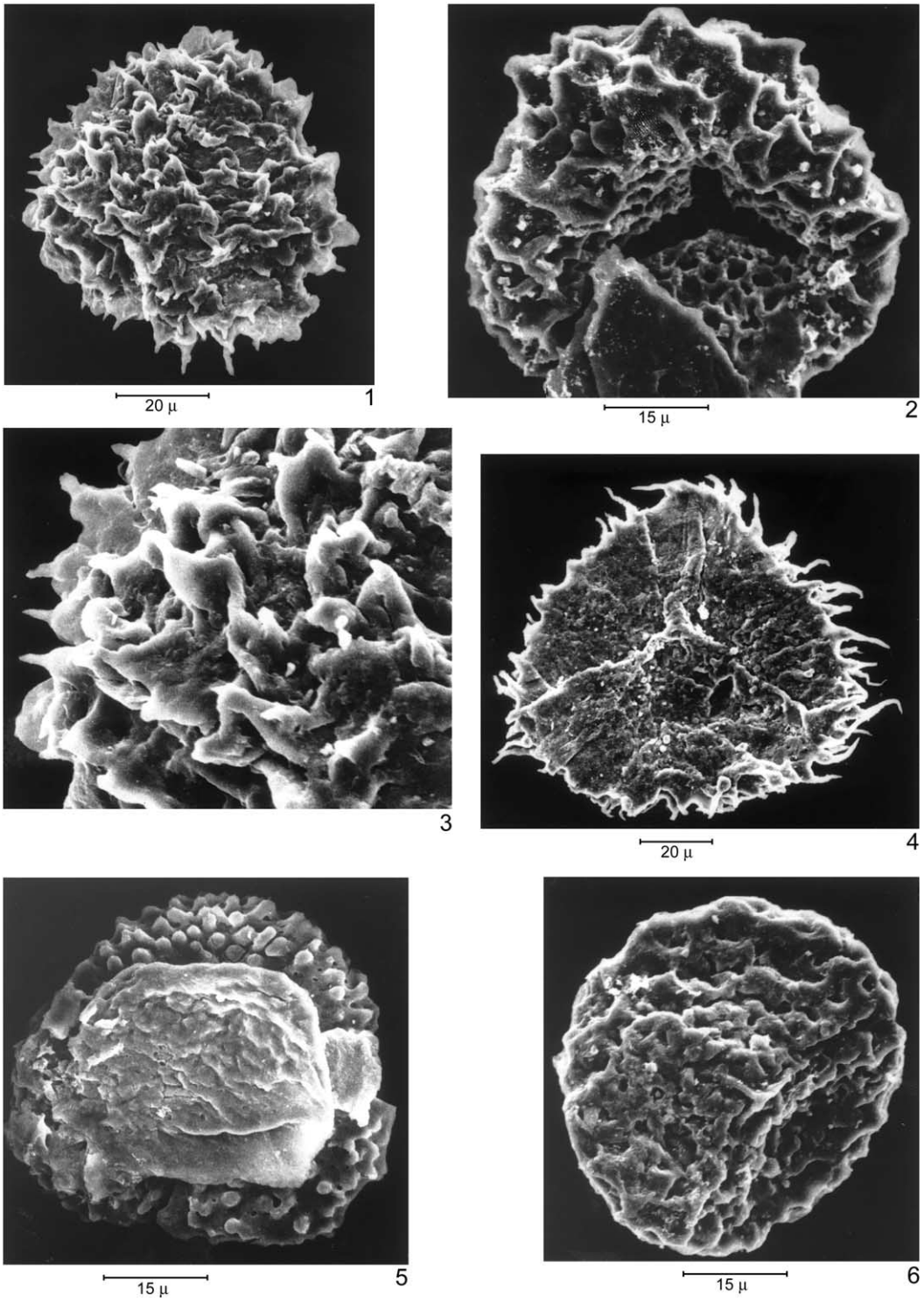


Plate IV (*Caption on page 246*).

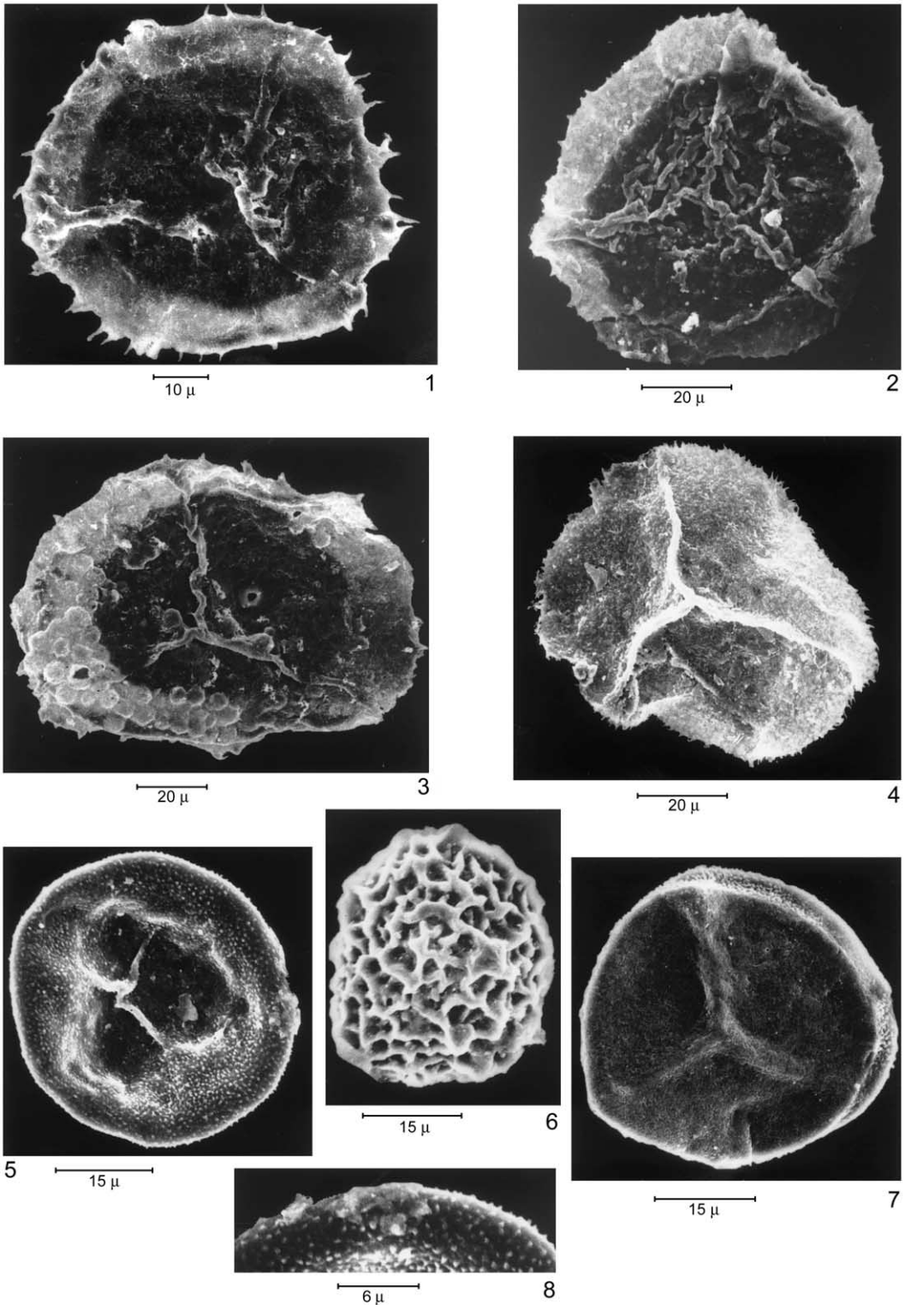


Plate V (*Caption on page 246*).

Plate VI (see page 253).

1. *Grandispora mammillata* Owens, 1971 (×1500, MG-7980).
2. Detailed sculptural elements of fig. 1 (×6000).
3. *Auritolagenicula zagrosensis* n.sp. (×1000, MG-7979).
4. *Grandispora mammillata* Owens, 1971 (×1500, MG-7885).
5. *Calyptosporites velatus* (Eisenack) Richardson, 1965 (×2000, MG-7878).
6. Detailed sculptural elements of fig. 3 (×3000).

Plate VII (see page 254).

1. *Geminospora lemurata* Balme, 1962 (×3000, MG-7880).
2. Detailed sculptural elements of fig. 1 (×6000).
3. *Geminospora lemurata* Balme, 1962 (×3000, MG-7880).
4. *Dibolisporites echinaceus* (Eisenack) Richardson, 1975 (×2500, MG-7880).
5. Detailed sculptural elements of fig. 4 (×6000).
6. *Calyptosporites velatus* (Eisenack) Richardson, 1962 (×1500, MG-7878).
7. *Emphanisporites rotatus* McGregor, 1961 (×3000, MG-7885).
8. *Grandispora owensii* n.sp. (×2000, MG-7866).

Plate VIII (see page 255).

1. *Samarisporites concinnus* Owens, 1971 (×3000, MG-7885).
2. Detailed sculptural elements of fig. 1 (×6000).
3. *Grandispora zakeenensis* n.sp. (×3000, MG-7885).
4. *Verrucosisporites polygonalis* Lanninger, 1967 (×3000, MG-7850).
5. Detailed sculptural elements of fig. 4 (×6000).
6. *Verrucosisporites polygonalis* Lanninger, 1967 (×3000, MG-7850).
7. *Rhabdosporites langii* (Eisenack) Richardson, 1960 (×1000, MG-7885).
8. Detailed sculptural elements of fig. 7 (×3000).
9. *Rhabdosporites parvulus* Richardson, 1965 (×2000, MG-7866).

Plate IX (see page 256).

1. *Saharidia iranica* n.sp. (×3000, MG-7982).
2. *Chomotriletes bistchoensis* Staplin, 1961 (×2500, MG-7980).
3. *Deltotosoma intonsum* Playford, 1981 (×3000, MG-7980).
4. *Chomotriletes vedugensis* Naumova, 1953 (×3000, MG-7980).
5. *Gorgonisphaeridium abstrusum* Playford, 1981 (×6000, MG-7982).
6. *Dictyotidium torosum* Playford, 1981 (×3000, MG-1982).

Plate X (see page 257).

1. *Chomotriletes vedugensis* Naumova, 1953 (×3000, MG-7982).
2. *Helosphaeridium microclavatum* Playford, 1981 (×3000, MG-7982).
3. *Histopalla capillosa* Playford, 1981 (×3000, MG-7980).
4. *Emphanisporites rotatus* McGregor, 1961 (×3000, MG-7979).
5. *Verrucosisporites premnus* Richardson, 1965 (×3000, MG-7979).
6. *Verrucosisporites premnus* Richardson, 1965 (×3000, MG-7979).
7. *Papulogabata persica* n.sp. (×1000, MG-7982).

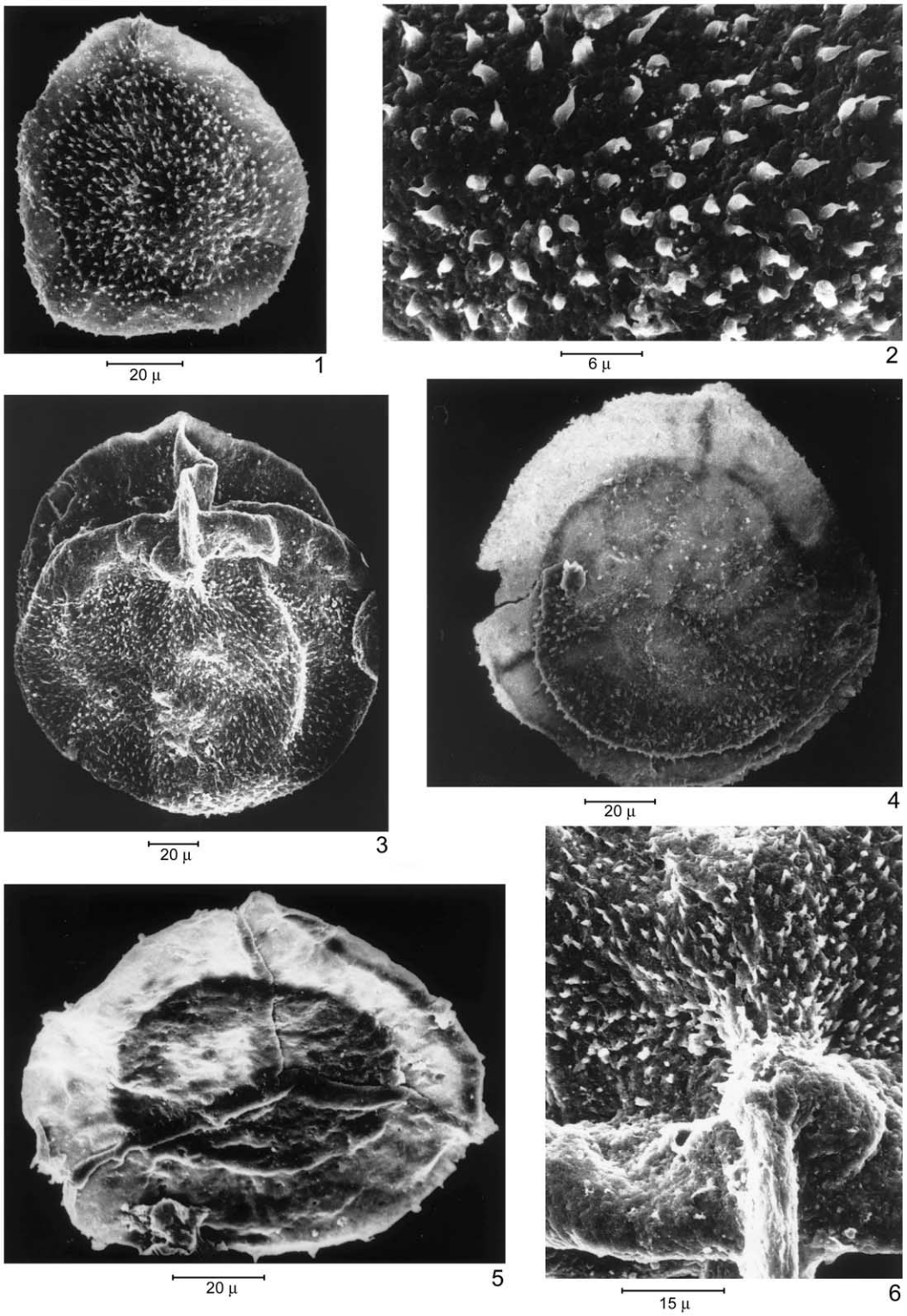


Plate VI (*Caption on page 252*).

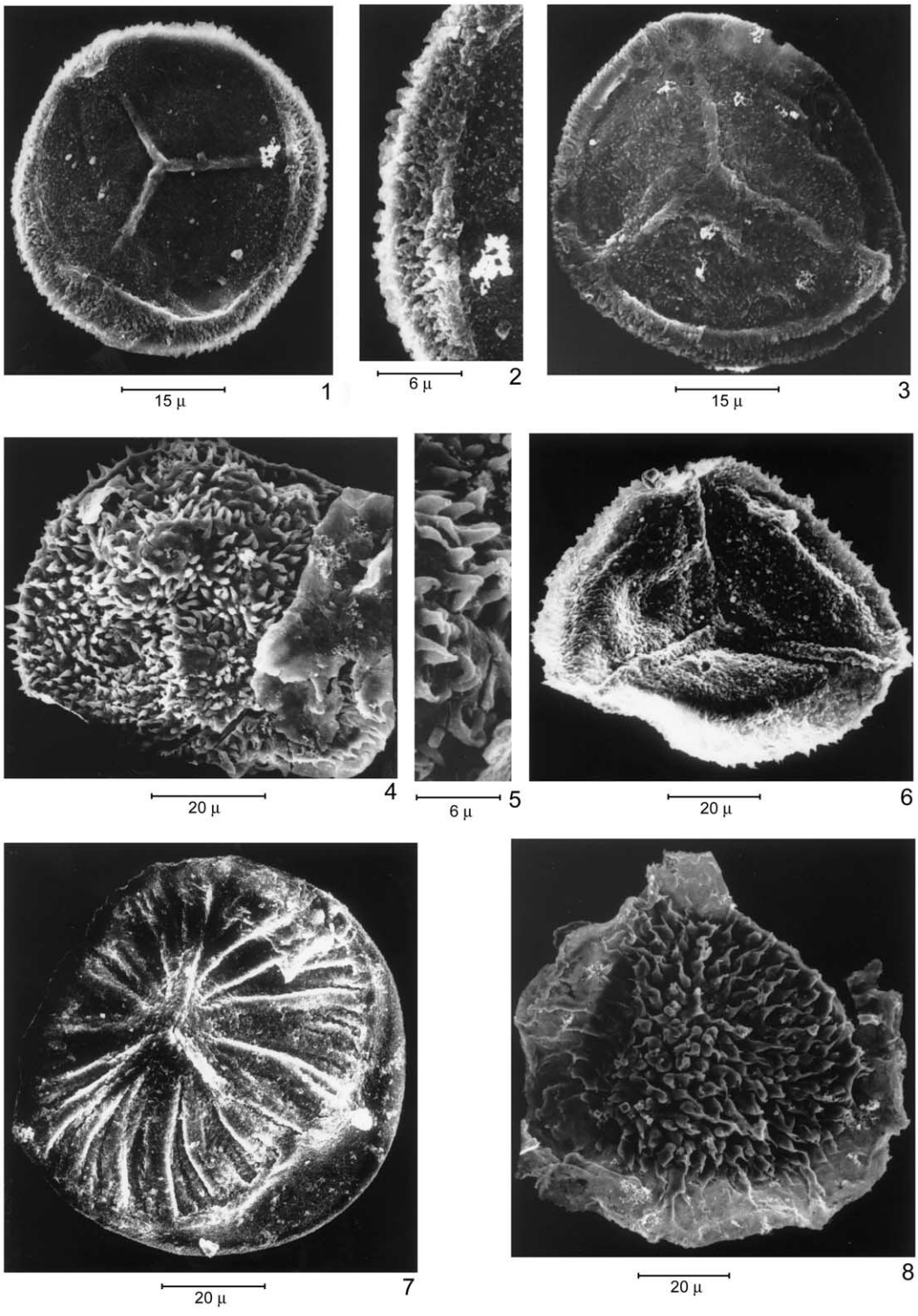


Plate VII (*Caption on page 252*).

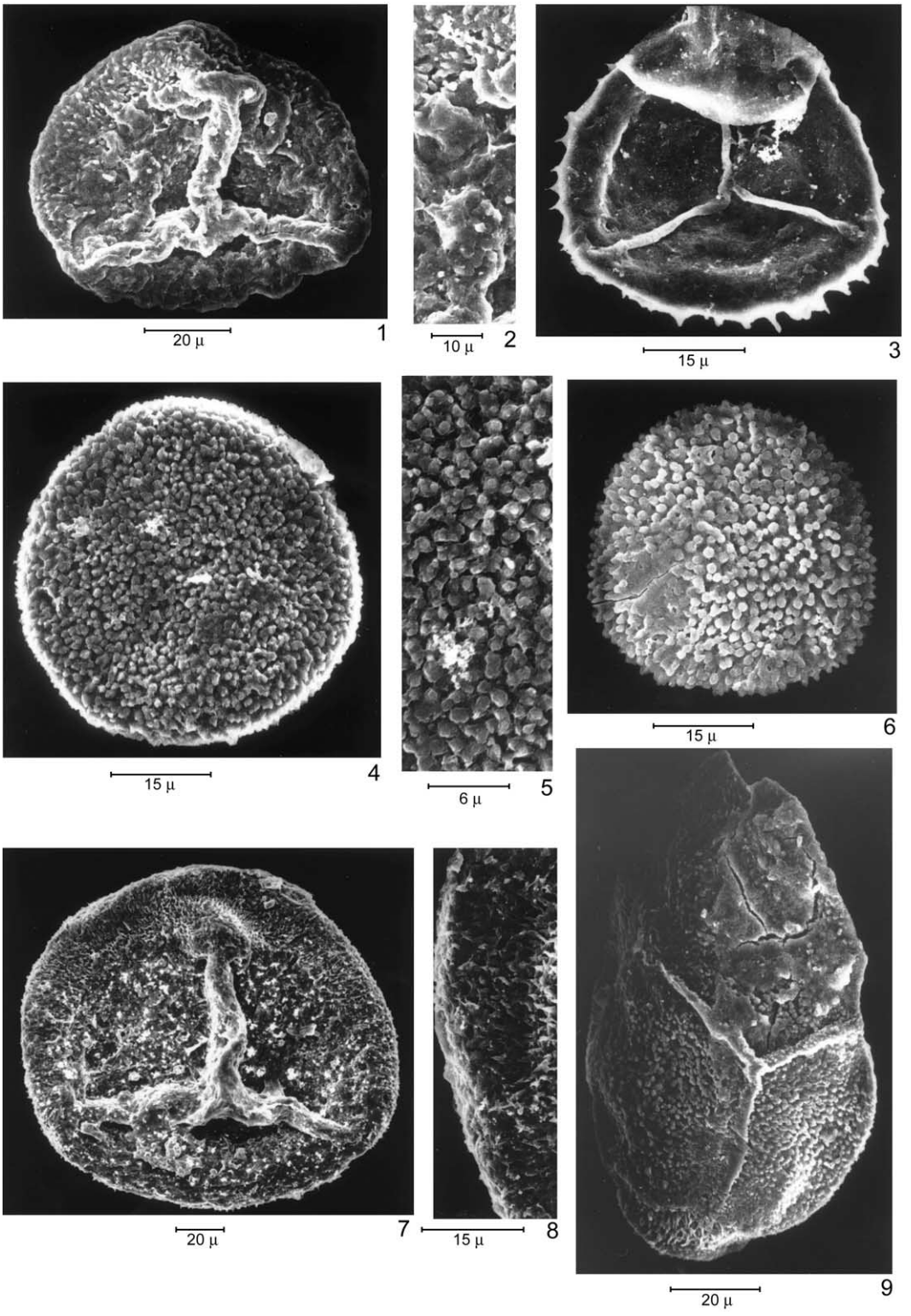


Plate VIII (*Caption on page 252*).

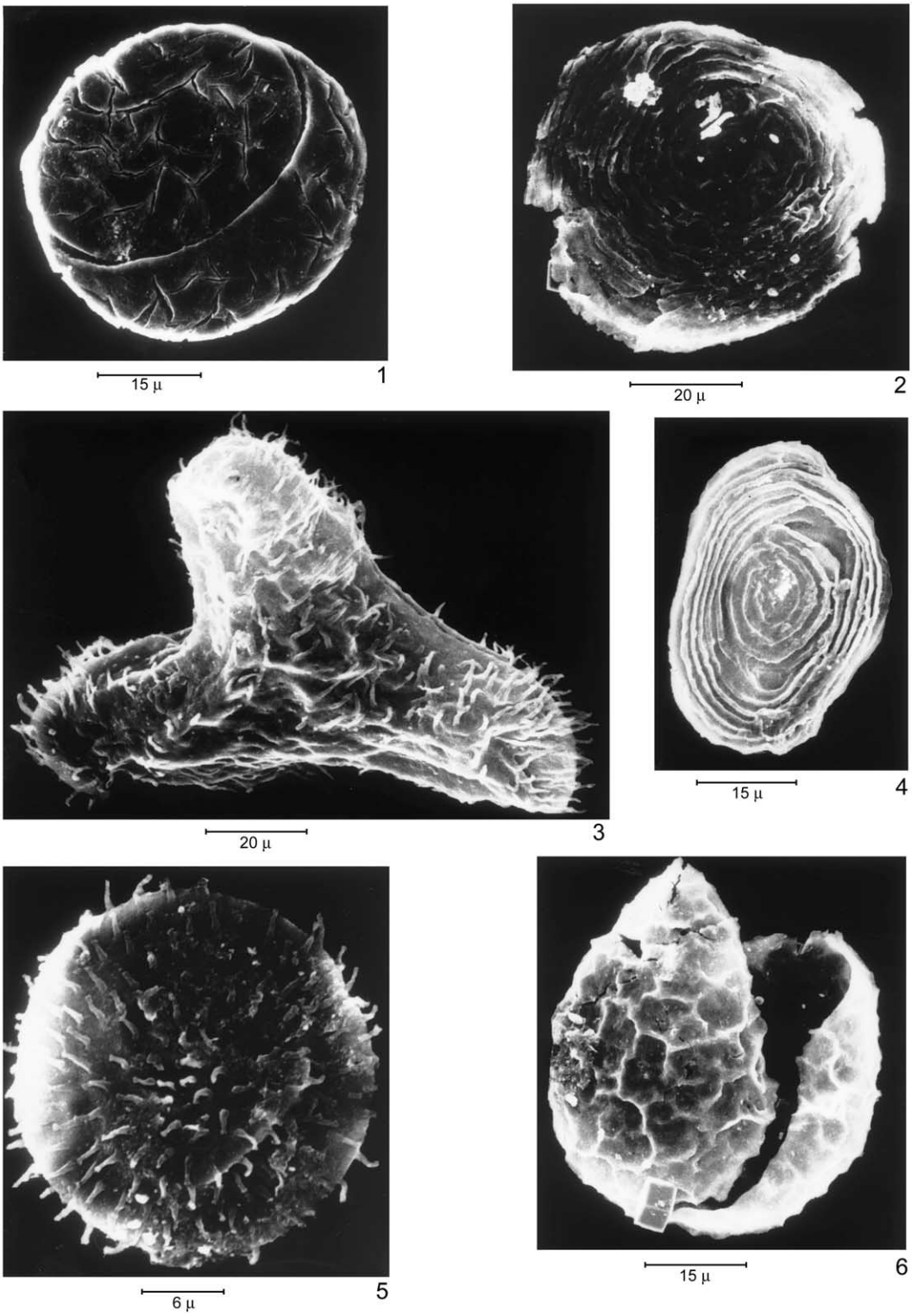


Plate IX (*Caption on page 252*).

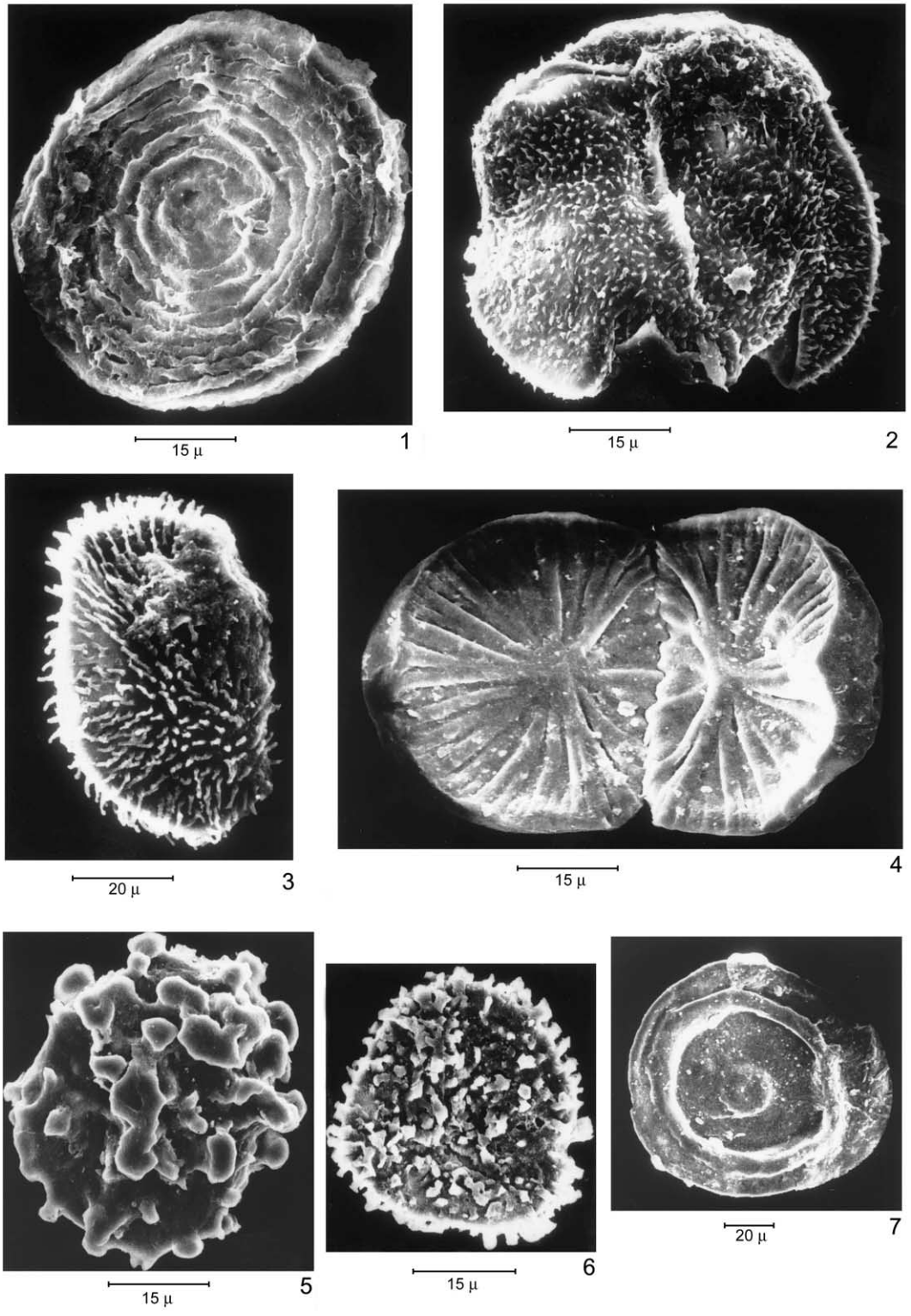
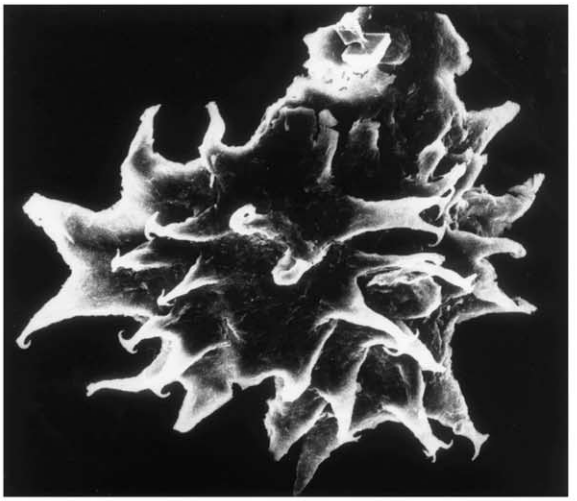


Plate X (*Caption on page 252*).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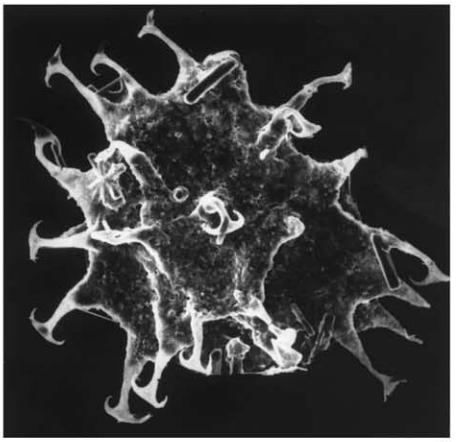
1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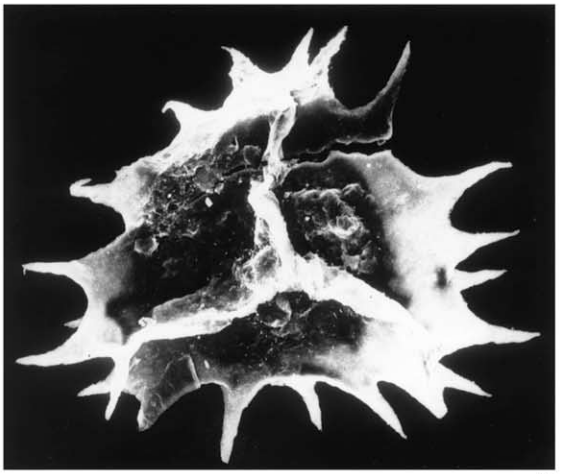
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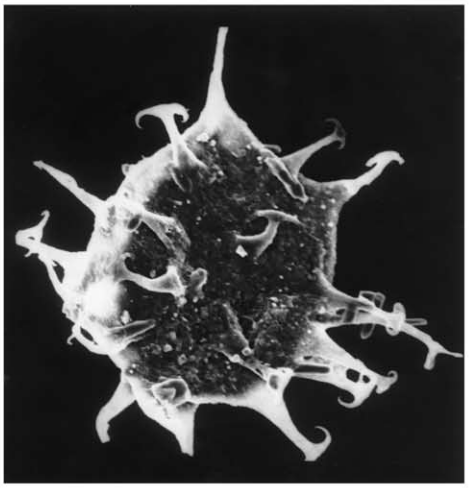
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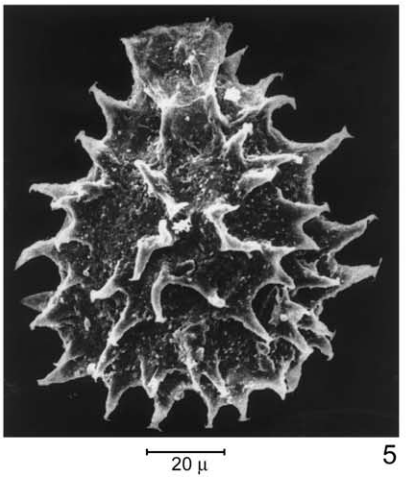
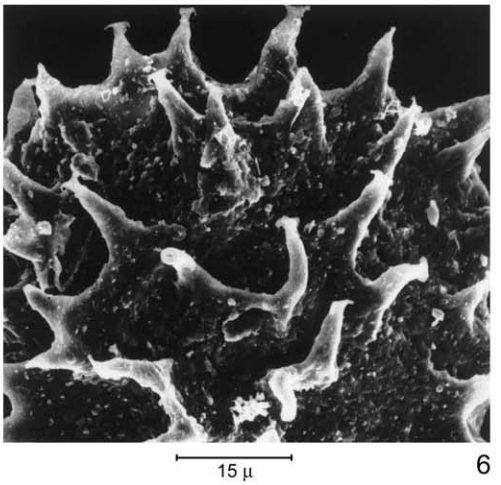
4


20 µ
5


15 µ
6

pleton, 1977), North Africa (Richardson, 1985), North America (Hoffmeister et al., 1955; McGregor, 1973; McGregor and Camfield, 1976; Owens, 1971; Ravn and Benson, 1988), Germany (Riegel, 1973; Streel et al., 1987; Ashraf et al., 1991), Scotland (Richardson, 1965; Richardson and McGregor, 1986), and Argentina (Ottone, 1996).

4.5. Spore assemblage zone V

This zone of Zakeen Formation has a thickness of 79 m and consists of mainly micaceous sandstones with haematitic iron-stained nodules and shale (Fig. 2). This interval is marked by the presence of additional Middle Devonian miospore species to supplement those recorded in zone IV, e.g. *Grandispora incognita*, *Cymbosporites catillus*, *Grandispora owensii* n.sp., *Convolutispora mimerensis*, *Grandispora mammillata*, *Grandispora zakeenensis* n.sp., *Samarisporites concinnus*, and *Geminospora lemurata*. This miospore assemblage zone is associated with some scolecodont specimens in this thickness of Zakeen Formation. This assemblage zone suggests a Givetian age for this part of the Zakeen Formation since the above-mentioned species have been recorded from the Givetian strata of Scotland (Richardson, 1965), Germany (Riegel, 1973; Ashraf et al., 1991), Spitsbergen (Allen, 1965), Africa (Richardson, 1985; Loboziak et al., 1989, 1992), Argentina (Ottone, 1996), central Poland (Turnau, 1986), southern Iran (Ghavidel-Syooki, 1999), and Canada (McGregor, 1973; McGregor and Camfield, 1976, 1982; Owens, 1971), Belgium (Streel and Loboziak, 1987).

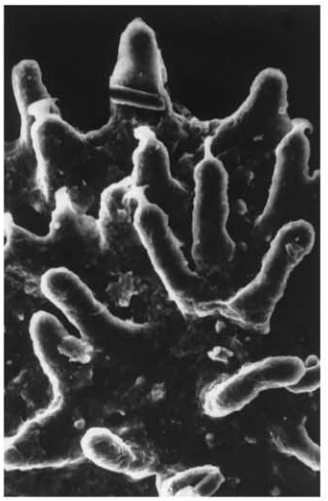
4.6. Acritarch and spore assemblage zone VI

This zone includes a thickness of 44 m of the upper part of the Zakeen Formation and consists of mainly sandstone and shale. This zone is characterized by the disappearance of the Middle Devonian species and the appearance of Late Devonian miospore species consisting of *Convolutispora subtilis*, *Geminospora punctata*, *Verrucosisporites confertus*, *Ancyrospora ampulla*, *Ancyrospora melvillensis*, *Ancyrospora carnarvonensis*, *Ancyrospora furcula*, *Auritolagenicula zagrosensis* n.sp., *Ancyrospora pulchra*, *Hystricosporites furcatus*, and *Hystricosporites reflexus*. The above-mentioned miospore species have co-occurrence with the Late Devonian index acritarch species such as *Chomotriletes vedugensis*, *Chomotriletes bistchoensis*, *Deltotosoma intonsum*, *Dictyotidium torosum*, *Histopalla capillosa*, *Helosphaeridium microclavatum*, *Gorgonisphaeridium abstrusum*, *Saharidia iranica* n.sp., and *Papulogabata persica* n.sp. (Fig. 2). This assemblage zone is assigned a Frasnian age since the above-mentioned acritarch and miospore taxa have been recorded from the early Late Devonian (Frasnian) strata of Australia (Balme, 1962, 1988; De Jersey, 1966; Playford, 1981; Playford and Dring, 1981), Canada (Staplin, 1961; Owens, 1971), the United States (Wicander and Playford, 1985), Argentina (Ottone, 1996), Spitsbergen (Allen, 1965), France (Taugourdeau-Lantz, 1967; Loboziak and Streel, 1981), Iran (Kimyai, 1979; Ghavidel-Syooki, 1995, 1997b, 1999, 2001; Hashemi and Playford, 1998), and Saudi Arabia (Hemer and Nygreen, 1967; Loboziak, 2000). Therefore, the Famennian sediments are not present in the studied area.

One of the most marked aspects of this assemblage zone is the occurrence of bifurcate spinose miospores such as *Hystricosporites* and *Ancyrospora*. Some species of these two genera have been recorded elsewhere from Middle Devonian sediments (Richardson, 1962), suggesting the pos-

Plate XI.

1. *Ancyrospora pulchra* Owens, 1971 (×2000, MG-7983).
2. *Hystricosporites reflexus* Owens, 1971 (×1500, MG-7998).
3. *Ancyrospora melvillensis* Owens, 1971 (×1500, MG-7979).
4. *Hystricosporites reflexus* Owens, 1971 (×2000, MG-7983).
5. *Ancyrospora furcula* Owens, 1971 (×1500, MG-7994).
6. Detailed sculptural elements of fig. 5 (×3000).



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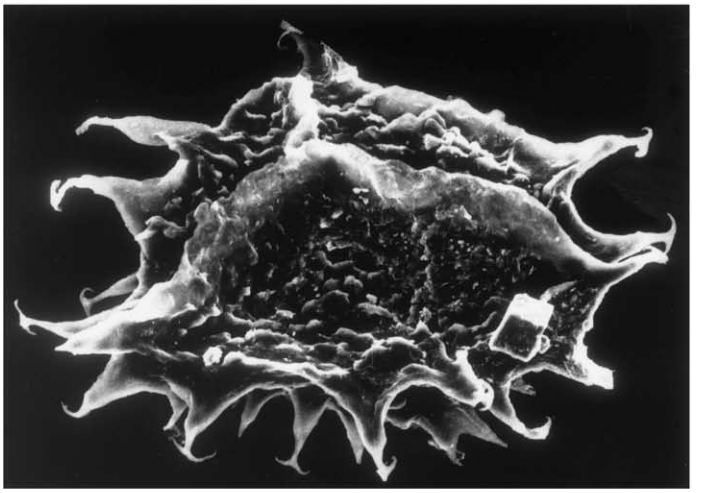

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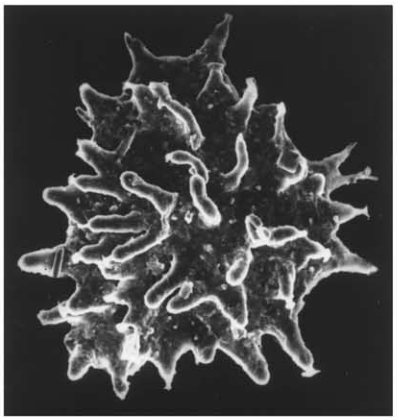

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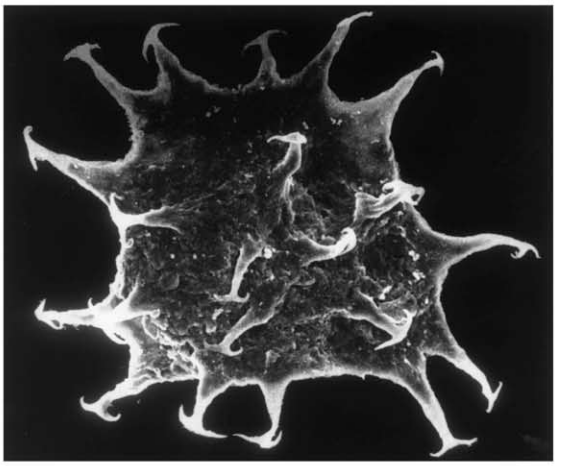

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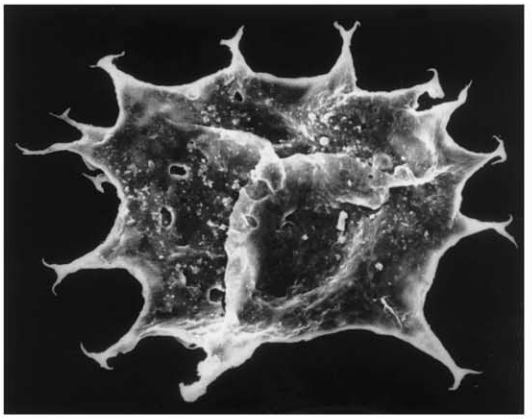


5

6

sibility of a Middle Devonian age assignment for this interval of the Zakeen Formation. However, the presence of numerous Late Devonian index miospore (e.g. *Convolutispora subtilis* and *Verrucosisporite confertus*) and acritarch (e.g. *Chomotriletes vedugensis*, *Chomotriletes bistchoensis*, *Papulogabata annulata*, and *Deltotosoma intonsum*) species suggests a Frasnian age for the upper part of this formation. Therefore, it must be assumed that bifurcate spinose miospores are confined to the Late Devonian in the study area. A similar pattern has been recorded by Hemer and Nygreen (1967) from the Devonian strata of the Arabian Peninsula. The similarity of the palynomorph assemblage zones of the northern Persian Gulf and the Saudi Arabian zones suggests that these two areas were part of the same paleo-phytogeographic province during the Devonian period.

4.7. Pollen assemblage zone VII

This zone occurs at the base of the Faraghan Formation and extends in 55 m thickness of this formation (Fig. 2). This zone is characterized by the disappearance of the whole Devonian palynomorph taxa and the appearance of Early Permian index pollen species including *Vittatina subsaccata*, *Caheniasaccites ellipticus*, *Mabuitasaccites ovatus*, *Corisaccites alutas*, *Fusacolpites fusus*, *Striomonosaccites triangularis*, *Boutakoffites elongatus*, and *Potonieisporites granulatus*. Based on the above-mentioned pollen species, an Early Permian age is assigned to the Faraghan Formation. Since these pollen species have been recorded from the Early Permian strata of Saudi Arabia (Hemer and Nygreen, 1967), Iran (Ghavidel-Syooki, 1995, 1997a), Pakistan (Venkatachala and Kar, 1966), India (Bhardwaj, 1955), North Africa (Bose and Kar, 1966, 1967; Bose and Maheshwari, 1968), Russia (Samoilovich, 1953), Turkey (Akyol, 1975), and the United States (Wilson, 1962; Jizba, 1962; Tschudy and Kosanke, 1966). Likewise, some foraminifer species which have been recorded from this formation support the Early Permian age (Szabo and Kheradpir, 1978). As a result of this study, the Carboniferous sediments are not present in the Zagros Basin, southern Iran. Therefore, a major hiatus occurs between the Zakeen and Faraghan formations, encompassing the Famennian and the entire Carboniferous interval.

5. Systematics

Five new palynomorph taxa which may have biostratigraphic and paleogeographic implications are described here. All other palynomorph species have already been fully described elsewhere and therefore do not need further descriptions. The following palynomorphs have been identified.

Spore taxa:

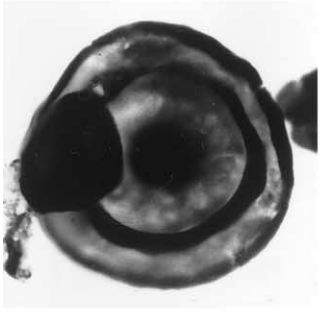
Acinosporites acanthomammillatus Richardson, 1965
Acinosporites lindlarensis Riegel, 1968
Ambitisporites avitus Hoffmeister, 1959
Ambitisporites dilutus (Hoffmeister, 1959) Burgess & Richardson, 1969
Amicosporites splendidus Cramer, 1967
Ancyrospora carnarvonensis (Balme) Brideaux & Richardson, 1970
Ancyrospora furcula Owens, 1971
Ancyrospora melvillensis Owens, 1971
Ancyrospora pulchra Owens, 1971
Ancyrospora ampulla Owens, 1971
Apiculatisporis adavalensis De Jersey, 1966

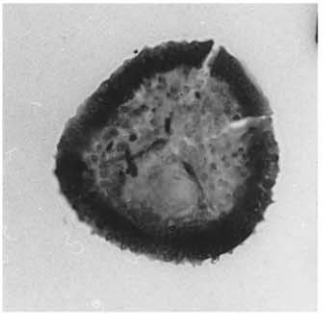
Plate XII.

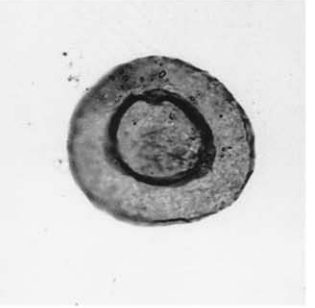
1. Detailed sculptural elements of fig. 3 (×3000).
2. *Ancyrospora pulchra* Owens, 1971 (×2000, MG-7983).
3. *Ancyrospora ampulla* Owens, 1971 (×1500, MG-7996).
4. *Hystricosporites reflexus* Owens, 1971 (×1500, MG-7979).
5. *Ancyrospora carnarvonensis* (Balme) Brideaux & Radford, 1970 (×1500, MG-7980).
6. *Hystricosporites furcatus* Owens, 1971 (×1500, MG-7994).

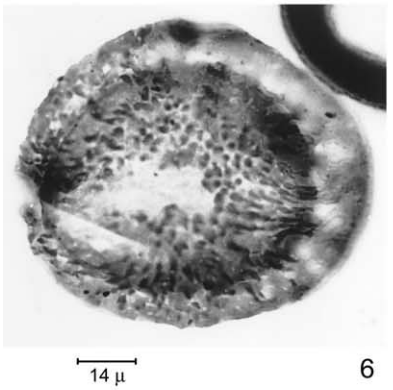

18 µ
1

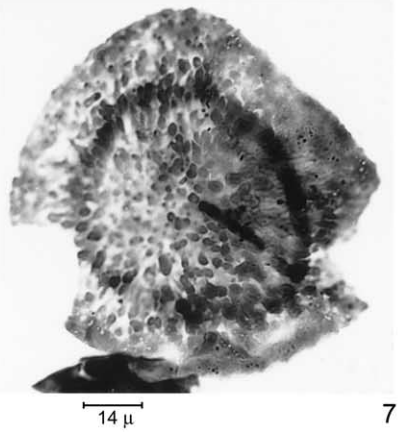

18 µ
2


22 µ
3


12 µ
4


15 µ
5


14 µ
6


14 µ
7

Apiculatisporites macrospinosus Richardson, 1965
Auritolagenicula zagrosensis Ghavidel-Syooki, sp.nov.
Calyptosporites velatus Richardson, 1965
Chelinospora retorrida Turnau, 1986
Clivosispora reticulata Rodriguez, 1978
Clivosispora verrucata McGregor, 1973
Convolutispora mimerensis Allen, 1965
Convolutispora subtilis Owens, 1971
Cylogranisporites amplus McGregor, 1960
Cymbosporites catillus Allen, 1965
Cymbosporites dammamensis Steemans, 1995
Cymbosporites proteus McGregor and Camfield, 1976
Diblosporites quebecensis McGregor, 1973
Dibolisporites echinaceus Richardson, 1965
Dibolisporites eifeliensis (Lanninger) McGregor, 1973
Dibolisporites wetteldorfensis Lanninger, 1968
Dictyotriletes minor Naumova, 1953
Emphanisporites rotatus McGregor, 1961
Geminospora lemurata Balme, 1962
Geminospora punctata Owens, 1971
Grandispora douglastownense McGregor, 1973
Grandispora incognita (Kedo) McGregor & Camfield, 1976
Grandispora macrotuberculata (Arkhangelskaya) McGregor, 1973
Grandispora mammillata Owens, 1971
Grandispora owensii Ghavidel-Syooki, sp.nov.
Grandispora zakeenensis Ghavidel-Syooki, sp.nov.
Hystricosporites furcatus Owens, 1971
Hystricosporites reflexus Owens, 1971
Laeovancis divellomedium (Chibrikova) Burgess & Richardson, 1991
Retusotriletes dittonensis Richardson & Lister, 1969
Rhabdosporites langii (Eisenack) Richardson, 1960
Rhabdosporites parvulus Richardson, 1965
Samarisporites concinnus Owens, 1971
Stenozonotriletes minus McGregor & Camfield, 1976
Verrucosisporites confertus Owens, 1971
Verrucosisporites polygonalis Lanninger, 1968
Verrucosisporites premnus Richardson, 1965

Pollen taxa:
Boutakoffites elongates Bose & Kar, 1966.
Caheniasaccites ellipticus Bose & Maheshwari, 1968
Corisaccites alutas Venkatachala & Kar, 1966
Fusacolpites fusus Bose & Kar, 1966
Mabuitasaccites ovatus Bose & Kar, 1966
Potonieisporites granulatus Bose & Kar, 1966
Striomonosaccites triangularis Bose & Kar, 1966
Vittatina subsaccata Samoilovich, 1953

Achritarch taxa:
Chomotriletes bistchoensis Staplin, 1961
Chomotriletes vedugensis Naumova, 1953
Detotosoma intonsum Playford, 1981
Dictyotidium torosum Playford, 1981
Gorgonisphaeridium abstrusum Playford, 1981
Helosphaeridium microclavatum Playford, 1981
Histopalla capillosa Playford, 1981
Papulogabata persica Ghavidel-Syooki, sp.nov.
Saharidia iranica Ghavidel-Syooki, sp.nov.

GROUP ACRITARCHA EVITT, 1963
Genus *Papulogabata* Playford, 1981

Type species: *Papulogabata annulata* Playford, 1981

Papulogabata persica n.sp. (Plate X, 7)
Description: Outline circular to subcircular with entire regular margin. Vesicle surface is smooth or scabrate and it is peripherally thickened. The

Plate XIII.

1. *Auritolagenicula zagrosensis* n.sp. (×1300, MG-7980)
2. *Auritolagenicula zagrosensis* n.sp. (×1300, MG-7980)
3. *Papulogabata persica* n.sp. (×1600, MG-7980)
4. *Grandispora zakeenensis* n.sp. (×2000, MG-7885)
5. *Saharidia iranica* n.sp. (×1600, MG-7980)
6. *Grandispora owensii* n.sp. (×1600, MG-7866)
7. *Grandispora owensii* n.sp. (×1600, MG-7866)

excystment is cyclopyle which is simple and circular in outline. The cyclopyle is rounded and centrally located in polar position and it is surrounded by a thin vesicle wall. This species is much larger than all other species of *Papulogabata*.
Type locality: Kuh-e-Faraghan,approximately 103 km north of Bandar-e-Abbas, northern coast of Persian Gulf.
Type stratum: Zakeen Formation of Kuh-e-Faraghan in Zagros Mountain Ranges of Iran.
Holotype: Plate X, 7; Sample no. MG-7980.
Dimensions: Total diameter of vesicle range from 102–113 μ. Operculum diameter is 22 μ.
Measurements: 25 specimens.
Derivation name: Latin Persia, references to ancient name of Iran.

Genus *Saharidia* Combaz, 1967
Type species: *Saharidia downiei* Combaz, 1967

Saharidia iranica n.sp. (Plate IX, 1)
Description: Vesicle is circular, or spheroidal in outline with a thin wall (1–2 μ) and cyclopyle opening. The vesicle diameter is 40×45 μ and the diameter of the cyclopyle is 28×30 μ. Both vesicle and cyclopyle are covered by corrugate ornamentations. *Saharidia iranica* differs from all other species of *Saharidia* in type of ornamentation as well as size range.
Type locality: Kuh-e-Faraghan, approximately 103 km north of Bandar-e-Abbas, northern Coast of Persian Gulf.
Type stratum: Zakeen Formation of Kuh-e-Faraghan, in the Zagros Mountain Ranges of Iran.
Holotype: Plate IX, 1; Sample no. MG-7980.
Dimensions: Diameter of vesicle 40×45 μ; Diameter of cyclopyle opening 28×38 μ.
Measurements: 15 specimens.
Derivation name: Reference to Iran from where this species is described.

ANTETURMA PROXIGERMINATES Potonié, 1970
TURMA TRILETES Reinsch emend Dettmann, 1963
SUBTURMA LAGENOTRILETES Potonié & Kremp, 1954
INFRATURMA GULATI Bhardwaj, 1955
Genus *Auritolagenicula* Dybova-Jachowicz et al., 1979

Type species: *Aurilolagenicula angulata* (Zerndt) Dybova-Jachowicz et al., 1979.

Auritolagenicula zagrosensis n.sp. (Plate VI, 3)
Description: Spore body is circular to oval in outline. Trilete mark is distinct and expands at proximal pole and forms a prominent gula. This spore is large with a diameter of 152×168 μ. Contact area is smooth, or rarely bears small spines. The proximal surface and entire distal surface are covered by densely distributed spinose ornamentations. The spines are normally discrete with bulbous bases. The size range and ornamentation of this species differs from all other species of *Auritolagenicula*.
Type locality: Kuh-e-Faraghan, approximately 103 km north of Bandar-e-Abbas, northern coast of Persian Gulf.
Type stratum: Zakeen Formation at Kuh-e-Faraghan, in Zagros Mountain Ranges of Iran.
Holotype: Plate VI, 3; Sample no. MG-7980.
Dimensions: 168×154 μ.
Derivation name: Reference to the Zagros Mountain Ranges which extend NW–SE of Iran.

SUPRASUBTURMA PSEUDOSACCITITRILETES Richardson, 1965.
INFRATURMA MONOPSEUDOSACCITI Smith and Butterworth, 1967.
Genus *Grandispora* (Hoffmeister, Staplin & Malloy) Neves and Owens, 1966.

Type species: *Grandispora spinosa* Hoffmeister, Staplin & Malloy, 1955.

Grandispora owensii n.sp. (Plate VII, 8)
Description: Miospores radial, trilete with triangular to rounded triangular outline. The exine consists of two layers. Intexine forms a triangular inner body which is surrounded by exoexine which extends in the equatorial plane with almost constant width. The proximal surface of exoexine is laevigate, but the distal surface bears distinctive conate ornamentations. The size range

of this spore is 65–81 μ. The exoexine extends 13–26 μ beyond the margin of the intexine which forms the inner body, 54–67 μ in diameter.

The spinose elements are 5–8 μ in length with bulbous bases which have gently tapering sides and sharply pointed terminations. This species is differentiated from all orther species of Grandispora by fairly large and dense coni-spinae ornamentations on the inner body and blader of spore. However, this species is very similar to *Spinozonotriletes* sp.A of Owens (1971), but the former differs from the latter in size range and distribution of sculptural elements.

Type locality: Kuh-e-Faraghan, approximately 103 km north of Bandar-e-Abbas, northern coast of Persian Gulf.

Type stratum: Zakeen Formation at Kuh-e-Faraghan, in Zagros Mountain Ranges of Iran.

Holotype: Plate VII, 8; sample no. MG-7866

Measurements: 20 specimens.

Dimension: 80.5×79.5 μ.

Derivation name: In honour of Professor B. Owens, well-known English palynologist.

Grandispora zakeenensis n.sp.(Plate VIII, 3)

Description: Miospores camerate, subtriangular in shape and ranging from 41 to 45 μ in diameter. The inner body is smooth, or scabrate and symmetrically placed inside the equatorial margin. The trilete mark is simple and extends the whole radius of spore. The sculptural elements are simple or bulbous based spines which are confined to the outer margin. The length of spines is variable, commonly 5–8 μ. This species is differentiated from all other species of *Grandispora* in its very small size range and uniform ornamentations.

Type locality: Kuh-e-Faraghan, approximately 103 km north of Bandar-e-Abbas, northern coast of Persian Gulf.

Type stratum: Zakeen Formation at Kuh-e-Faraghan in Zagros Mountain Ranges of Iran.

Holotype: Plate VIII, 3; Sample no. MG-7885.

Measurements: 25 specimens.

Dimensions: 42.5×41 μ.

Derivation name: From Zakeen Formation where it was found.

6. Conclusions

Sixty-five palynomorph taxa were encountered from the clastic sequence of the Zakeen Formation and the local stratigraphic distribution of all known taxa is plotted on Fig. 2. These species have been arranged into seven ascending stratigraphic assemblage zones. Zones I–III are present in 95 m of the Zakeen Formation, suggesting an Early Devonian (Lochkovian–Emsian) age for this interval. Zones IV–V occur in 144 m of the Zakeen Formation, indicating a Middle Devonian (Eifelian–Givetian) age for this thickness. Zone VI belongs to the early Late Devonian (Frasnian) age and zone VII suggests an Early Permian age. As a result of this study, the Devonian sediments are recorded for the first time in the Zagros Basin, southern Iran. The encountered Devonian miospore and acritarch taxa of the Zakeen Formation have been recorded also from the Devonian strata of England, Belgium, France, Germany, Canada, Western Australia, Libya, Tunisia, Argentina, Saudi Arabia, and Spitsbergen. This finding suggests that the parent plants of these miospores were cosmopolitan and were able to survive under varied climatic conditions. However, the genera and related species of *Ancyrospora* and *Hystricosporites* occur in the youngest zone of the Zakeen Formation, suggesting a Middle to early Late Devonian age for this interval of the formation, but the presence of numerous Late Devonian acritarch taxa (*Chomotriletes vedugensis*, *Chomotriletes bistchoensis*, *Papulogabata annulata*, *Deltotosoma intonsum*, etc.) supports the Frasnian age for this zone of the Zakeen Formation. Therefore, it must be assumed that the bifurcate spinose miospores are confined to the Late Devonian strata in the Zagros basin of Iran. A similar pattern has been recorded from the Late Devonian deposits of the Arabian Peninsula (Hemer and Nygreen, 1967), suggesting the same paleo-phytogeographic province for Saudi Arabia and southern Iran.

On the other hand, the palynomorph assemblage zones and lithology of the Zakeen Formation are quite similar to those recorded from the Devonian sediments (Tawil, Juaf and Jubah formations) of Saudi Arabia. Therefore, a stratigraphic correlation is possible between the north-

ern and southern parts of the Persian Gulf. Based on paleontological data, two hiata are recognizable within the Paleozoic sequence of the studied area. The first hiatus is between the Sarchahan (Early Silurian) and Zakeen formations. This hiatus includes the Middle and Late Silurian sediments, possibly corresponding to the Caledonian Orogeny. The second hiatus occurs between the Zakeen and Faraghan formations, encompassing the Famennian and the entire Carboniferous deposites, possibly corresponding to the Hercynian Orogeny. The presence of acritarchs and scolecodonts throughout the Zakeen Formation as well as skolithos ichnofacies suggests a shallow marine environment for this formation.

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