Rivista Italiana di Paleontologia e Stratigrafia
(*Research in Paleontology and Stratigraphy*)
vol. 124(3): 573-595. **November 2018**

PALYNOSTRATIGRAPHY OF THE PERMIAN FARAGHAN FORMATION IN THE ZAGROS BASIN, SOUTHERN IRAN

AMALIA SPINA[1*], MICHAEL H. STEPHENSON[2], SIMONETTA CIRILLI[1], MOHAMMAD ARIA-NASAB[3] & ROBERTO RETTORI[1]

[1*] Corresponding Author. Department of Physics and Geology, University of Perugia (Italy). E-mail: amalia.spina@unipg.it.
[2]British Geological Survey, Keyworth, UK.
[3]National Iranian Oil Company, Tehran, Iran.

To cite this article: Spina A., Stephenson M.H., Cirilli S., Aria-Nasab M. & Rettori R. (2018) - Palynostratigraphy of the Permian Faraghan Formation in the Zagros Basin, southern Iran. *Riv. It. Paleontol. Strat.*, 124(3): 573-595.

Keywords: Permian; palynology; stratigraphy; Faraghan Formation; Zagros Basin; Iran.

Abstract. A detailed microfloristic study was conducted in the Faraghan Formation in nine boreholes drilled by the National Iranian Oil Company (NIOC) and in four outcrops in the Zagros Basin. The Faraghan Formation, widely distributed in the Zagros area, generally consists of shale intercalated with sandstone and pebble conglomerate, with thin carbonate intercalations near the top. Due to the lack of significant fossils, the age of this rock unit has been strongly debated in the Iranian literature and uncertainly attributed to the Pennsylvanian or Cisuralian. In this study, the age of the Faraghan Formation was reviewed in light of new biostratigraphic advances in the Arabian Peninsula. The assemblage is characterized by an abundance of monosaccate pollen such as *Florinites*? *balmei*, *Caheniasaccites* spp., *Plicatipollenites* spp., *Potonieisporites* spp. and *Striomonosaccites* spp., and bisaccate pollen such as *Alisporites* spp., *Corisaccites alutas*, *Distriatites insolitus*, *Hamiapollenites* spp. and *Striatopodocarpites* spp.. The assemblage also contains polyplicate pollen such as *Vittatina* spp.. Spores such as *Indotriradites mundus* and *Thymospora opaqua* are also present. The stratigraphic ranges of the taxa allow reference to the biozone schemes for Oman and assignment of the Faraghan Formation to the Guadalupian.

Introduction

The Zagros region, extending from southwest Iran to southwest Iraq, is one of the major global oil producing provinces. Almost all the studies performed in the Zagros Basin have been concentrated mainly on petroleum geology, sedimentology and structural geology (Sampo 1969; Setudehnia 1972; Kashfi 1976; Bahroudi & Talbot 2003; Alavi 2004; Sepehr & Cosgrove 2004; Insalaco et al. 2006; Fakhari et al. 2008; Zamanzadeh et al. 2009a, b; Agard et al. 2011; Esrafili-Dizaji & Rahimpour-Bonab 2013). However, biostratigraphic studies, crucial also for correlation and palaeogeographic reconstruction of the Permian in this area are limited. A recent project of the Arianzamin Pars Geological Center (Tehran, Iran) and the University of Perugia (Italy) on the palaeontology and biozonation of Palaeozoic sedimentary rocks of the Zagros Basin aimed to improve knowledge of the palynology of the Faraghan Formation. In the Zagros region, this formation crops out in several areas including Dena, Faraghan and the Zardkuh Mountains. The formation is also reported in several boreholes drilled by the National Iranian Oil Company (NIOC). A Sakmarian-Kungurian age was originally proposed for the Faraghan Formation (Ghavidel-syooki 1984, 1988, 1993, 1994, 1995, 1996, 1997) based on palynology.

In the present work, we studied palynological assemblages from the Faraghan Formation and the base of Dalan Formation, to review the age of the Faraghan Formation in light of new biostratigraphic advances in the Arabian Peninsula.

Received: January 17, 2018; accepted: September 25, 2018

Geological setting

The Iranian plateau is composed of numerous continental terranes joined along ophiolitic suture zones. In the first reconstructions (e.g. Stöcklin 1974; Berberian & King 1981), during Palaeozoic–Triassic three main regions are distinguished: North Iran (including the Alborz region), Central Iran (comprising Yazd, Tabas and Lut blocks) and the Snandaj–Sirjan Zone. This latter was divided by a branch of the Permian Neotethys oceanic basin from the Zagros region (Zanchi et al. 2009 with references). During the late Palaeozoic, the Zagros Basin was located in the northern part of the Arabian Platform (e.g. Beydoun 1988; Konert et al. 2001; Zharkov & Chumakov 2001). The Zagros Basin (about 2000 km in length and 250 km in width) extends from southeast Turkey through north Syria and Iraq to west and southwest Iran (Fig. 1). It is characterized by late Precambrian to Neogene sedimentary successions. In the Zagros part of the Arabian Plate, the thickness of Palaeozoic to Cretaceous sediments is more than 14 km, deposited over the Neoproterozoic igneous and metamorphic rocks of the basement. This large thickness is the consequence of the rifting and subsidence of the AfroArabian plate margin (Berberian & King 1981; Motiei 1993; Bahroudi & Talbot 2003; Stern & Johnson 2010). The eastern Arabian platform has been affected by significant cycles of extension and compression. During the late Palaeozoic, an extensional tectonic regime linked to the break-up of Gondwana affected the northeastern Arabian passive continental margin. Around the margin of the Arabian platform along the Zagros suture zone and the Gulf of Oman, the Neo-Tethys was developed and progressively widened during the Mesozoic (Stöcklin 1968; Şengör 1990; Glennie 2001; Angiolini et al. 2003a, b; Cavazza et al. 2004), causing the separation of the Sanandaj-Sirjan zone from the Arabian platform (Alavi 2004).

The Palaeozoic lithostratigraphy of the Zagros area is presented in detail in the geological literature (e.g. James & Wynd 1965; Setudhenia 1972; Koop & Stoneley 1982; Motiei 1993; Ghavidel-syooki 2003; Alavi 2004; Ghavidel-syooki et al. 2011; Zoleikhaei et al. 2015; Fig. 2). The base of the sedimentary succession is characterized by the Hormuz Formation of late Precambrian age, deposited in an evaporitic basin. The early Cambrian to Late Devonian is marked by the development of epi-continental basins (Setudehnia 1972). During Devonian time, the Zakeen Formation was deposited, consisting mainly of sandstone with interbedded shale and subordinate dolomitic limestone. This formation together with the Faraghan Formation was originally considered as a single lithostratigraphic unit of early Permian age (Szabo & Kheradpir 1978). Later, Ghavidel-syooki (1994) reported a distinct hiatus (70-80 My long) between the Zakeen and Faraghan formations on the basis of palynological data. Using these results, the unit was split into two formations attributing the Zakeen Formation to the Devonian and the Faraghan to the Permian. These formations represent different sub-environments of a shallow marine siliciclastic shelf (Szabo & Kheradpir 1978; Zamanzadeh 2008; Zamanzadeh et al. 2009a, b; Zoleikhaei et al. 2015). Nevertheless recently, Sabouri et al. (2014) documented palynological evidence of rocks of Mississippian age in the Zagros Basin. The authors indicated an unconformity (referred to as the Hercynian unconformity) separating the Visean deposits from the overlying Faraghan Formation. The Faraghan Formation passes up into the Dalan Formation, which is characterized by oolitic grainstones to mudstone-wackestone shallow-marine carbonates (dolomite, dolomitic limestone), locally reefal, with intercalations of evaporites (Zamanzadeh 2008; Zamanzadeh et al. 2009a, b). This formation was attributed to the Middle-Late Permian on the basis of foraminifer content (Insalaco et al. 2006; Davydov & Arefifard 2013). Parvizi et al. (2013) also documented calcareous algae from the Dalan Formation of relatively broad stratigraphic distribution in the Permian period characterizing shallow-marine, warm, well-oxygenated and relatively high-energy environments. The unit that succeeds the Dalan Formation is the Kangan Formation. This consists of a mixed carbonate-evaporite succession that, together with the Dalan Formation, is considered equivalent to the Khuff Formation of Saudi Arabia, Qatar, United Arab Emirates and Oman (Al-Jallal 1995; Insalaco et al. 2006).

Stratigraphy of the Faraghan Formation

The name Faraghan Formation was establi-

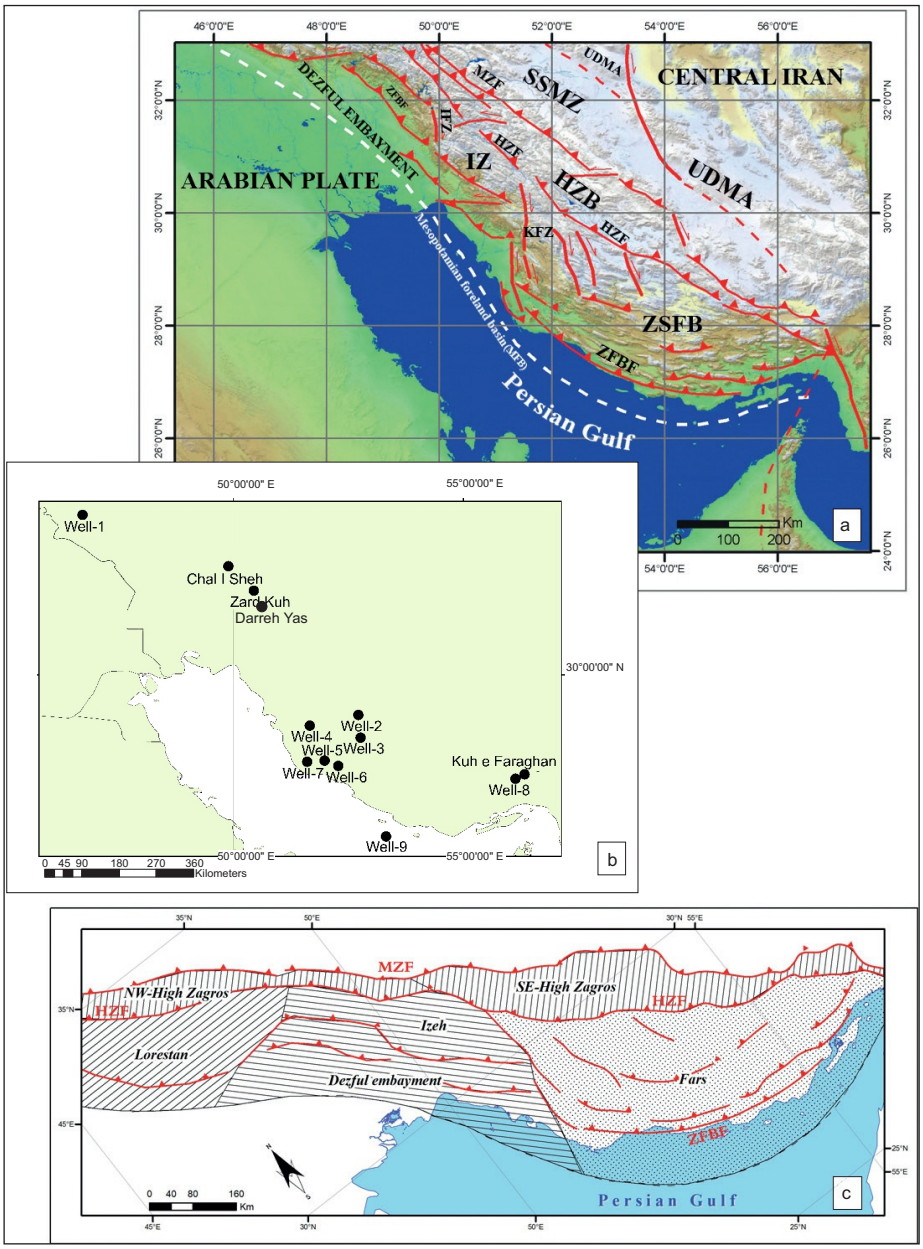

Fig. 1 - a) Clear segmentation of the fault network in the Zagros. ZFBF, Zagros Foreland Basin Fault; UDMA, Urumieh–Dokhtar Magmatic Arc; SSMZ, Sanandaj–Sirjan Metamorphic Zone; MZF, Main Zagros Fault; HZF, High Zagros Fault; HZB, High Zagros Belt; ZSFB, Zagros Simply Folded Belt; IZ, Izeh Zone; IFZ, Izeh Fault Zone; KFZ, Kazerun Fault Zone. b) Location map of the studied outcrops and wells. c) Domains in the Zagros (from Madani-Kivi and Zulauf 2015; modified)

shed at Kuh-e-Faraghan Mountain by Sazabo and Kherapdir (1978). Kuh-e Faraghan is one of the main areas in the Zagros Mountains where a complete Palaeozoic to Tertiary succession is exposed. The Faraghan Formation, widely distributed in the Zagros area, generally consists of shale intercalated with sandstone and pebble conglomerate, with thin carbonate intercalations near the top. Its thickness varies from about 300 to 10 m. The Faraghan Formation lacks significant fossils. For this reason, the age of this rock unit has been debated in the Iranian literature. Before the study of Szabo and Kherapdir (1978), the Faraghan Formation used to be called the "Carboniferous sandstones" or the "Permo-Carboniferous sandstones" due to the presence of plant remains of Sigillaria persica in the Chal i Sheh area. The deposition of the Faraghan Formation took place in a variety of settings (sabkha, beach, submarine channel, estuary, shoreface, offshore; Zamanzadeh 2008). The siliciclastic shelf of the Faraghan Formation gradually changed into the carbonate shelf of the Dalan Formation (Szabo & Kheradpir 1978; Kashfi 1992).

The stratigraphic sections (four outcrops and nine boreholes; Fig. 1 and 2) analyzed in the present study are located in five parts of the Zagros area: the Lorestan Domain, the NW High Zagros, the Fars Domain, and the SE High Zagros and Persian Gulf.

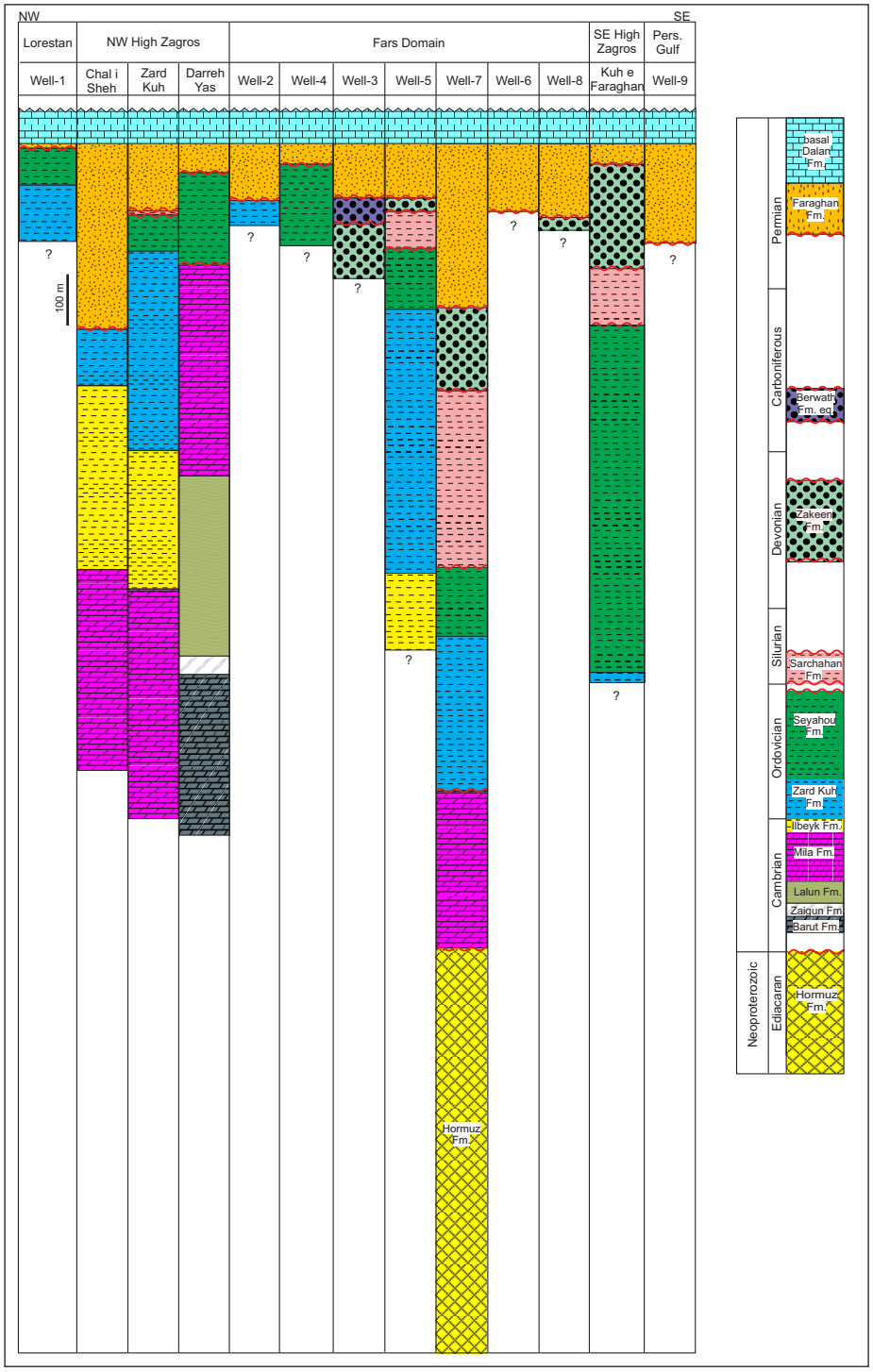

Fig. 2 - General lithostratigraphic chart for the Palaeozoic studied successions (outcrops and wells), approximately oriented NW-SE in Zagros Basin. Hormuz Formation: halite, anhydrite, sandstone, shale, dolostone and igneous rocks. Barut Formation: dolostone and shale. Zagun Formation: shale and sandstone. Lalun Formation: sandstone and shale. Mila Formation: dolostone, limestone and shale. Ilbek Formation: shale and sandstone. Zard Kuh Formation: shale and sandstone. Seyahou Formation: shale with sandstone, siltstone, conglomerate and limestone. Sarchahan Formation: shale with conglomerate, sandstone and carbonate. Zakeen Formation: sandstone with shale. Berwath Formation equivalent: shale and limestone. Faraghan Formation: sandstone and shale. Dalan Formation: limestone and dolostone. Lithostratigraphic data: Courtesy of Arianzamin Pars Geological Center and NIOC.

Lorestan Domain

In the Lorestan Domain, the Faraghan Formation was found in Well-1, located in the southwest of Lorestan Province at a distance of 30 km from Ilam city (Figs 1 and 2). The well, having a depth of 3156 m, reaches at the bottom the Zard Kuh Formation. The Faraghan Formation is about 10 m thick and is characterized by sandstone with shaly intercalations (Fig. 3), unconformably overlying the Seyahou Formation (Floian to Katian, Ghavidel-syooki 1996; Ghavidel-syooki et al. 2011, 2014; Ghobadi Pour et al. 2015).

NW High Zagros

The Faraghan Formation is well represented in the NW High Zagros area (Figs 1 and 2). In the Chal i Sheh area, the studied section crops out 70 km southwest of Fereydoon shar city. Here the formation mainly consists of siltstone, sandstone and shale with conglomerate beds only in the lower

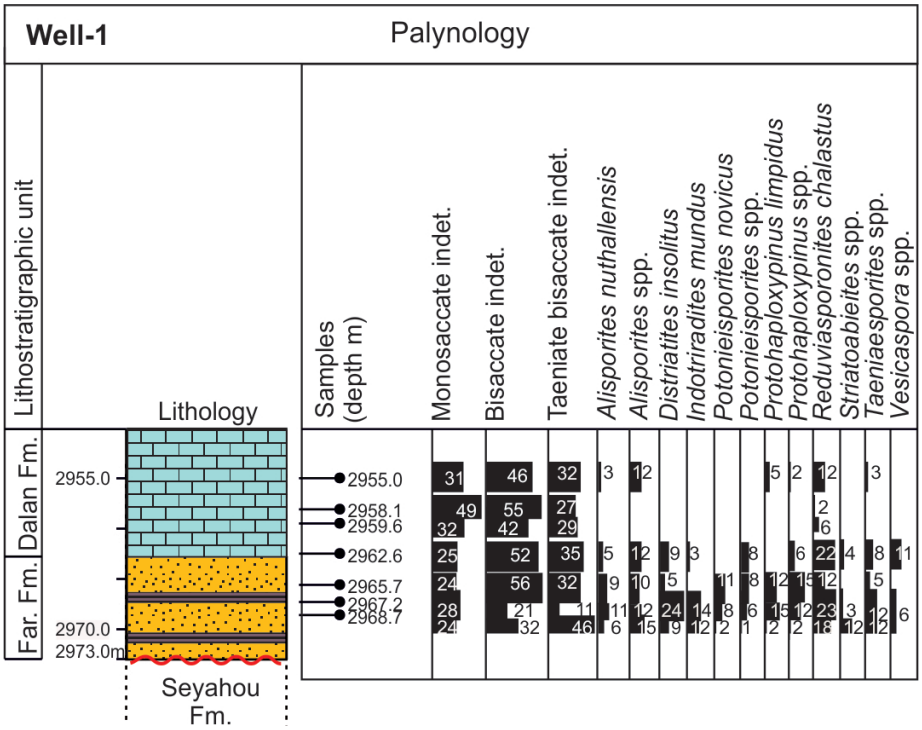

Fig. 3 - Well-1: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

part (Fig. 4). The Faraghan Formation unconformably overlies the Zard Kuh Formation attributed to Early Ordovician (Ghavidel-syooki 1996; Ghavidel-syooki et al. 2011, 2014). Recent detailed fieldwork data indicates that the Faraghan Formation is about 365 m thick in this area, significantly less than the thickness of 500 m reported by Ghavidel-syooki (1993). The Faraghan Formation crops out also in the Zard Kuh area situated about 30 km south of Chelgard city. Here it is about 134 m thick, and is characterized by sandstone and shale (Fig. 5), and unconformably overlies the Sarchahan Formation attributed to latest Ordovician-earliest Silurian (Hirnantian to Llandovery, Saberi et al., 2016). The Faraghan Formation is also present in Darreh Yas in the southwestern Shahr-e Kurd and northern Ardal City. Here it is considerably less thick reaching about 60 m thick. It consists of shale with intercalations of sandstone, conglomerate and limestone (Fig. 6) and unconformably overlies the Seyahou Formation.

Fars Domain

In this area the Faraghan Formation has been found in several wells: -2, -3, -4, -5, -6, -7 and -8 (Figs 1 and 2). In Well-2 – terminating at a depth of 3719 m-, the Faraghan Formation is about 114 m thick. It is characterized mainly by sandstone with scattered shaly intercalation in the lower part and with rare dolostone in the upper part (Fig. 7). In Well-3 – 4030 m depth -, the Faraghan Formation is about 107 m thick and characterized by shale. A sandstone intercalation was mainly recognized near the base (Fig. 8). Here, the Faraghan Formation unconformably overlies Visean rocks correlated to the Berwath Formation in Saudi Arabia (Sabouri et al. 2014). The Well-4 is 3815 m depth. The Faraghan Formation is about 46 m thick, unconformably overlying the Ordovician Seyahou Formation. It consists mainly of sandstone intercalated with shale beds (Fig. 9). In Well-5 – reaching a depth of 4180 m - the Faraghan Formation is about 106 m thick and represented by sandstone intercalated with siltstone and shale in the lower part and shales in the upper part (Fig. 10). Shale beds, recently attributed by microflora to the Visean (Sabouri et al. 2014), lie unconformably below the Faraghan Formation. Well-6 terminates at a depth of 3288 m. Here, the Faraghan Formation is about 133 m thick and mainly characterized by sandstone and siltstone in the lower part, and siltstone with scattered shale and sandstone intercalations in the upper part (Fig. 11). Its lower boundary is uncertain. In Well-7 – depth 3140 m-, the Faraghan Formation is about 52 m thick, and mainly consists of shales with scattered sandstone intercalation in the lower part and dolostone and shale in the upper part (Fig. 12). The formation unconformably overlies the Zakeen

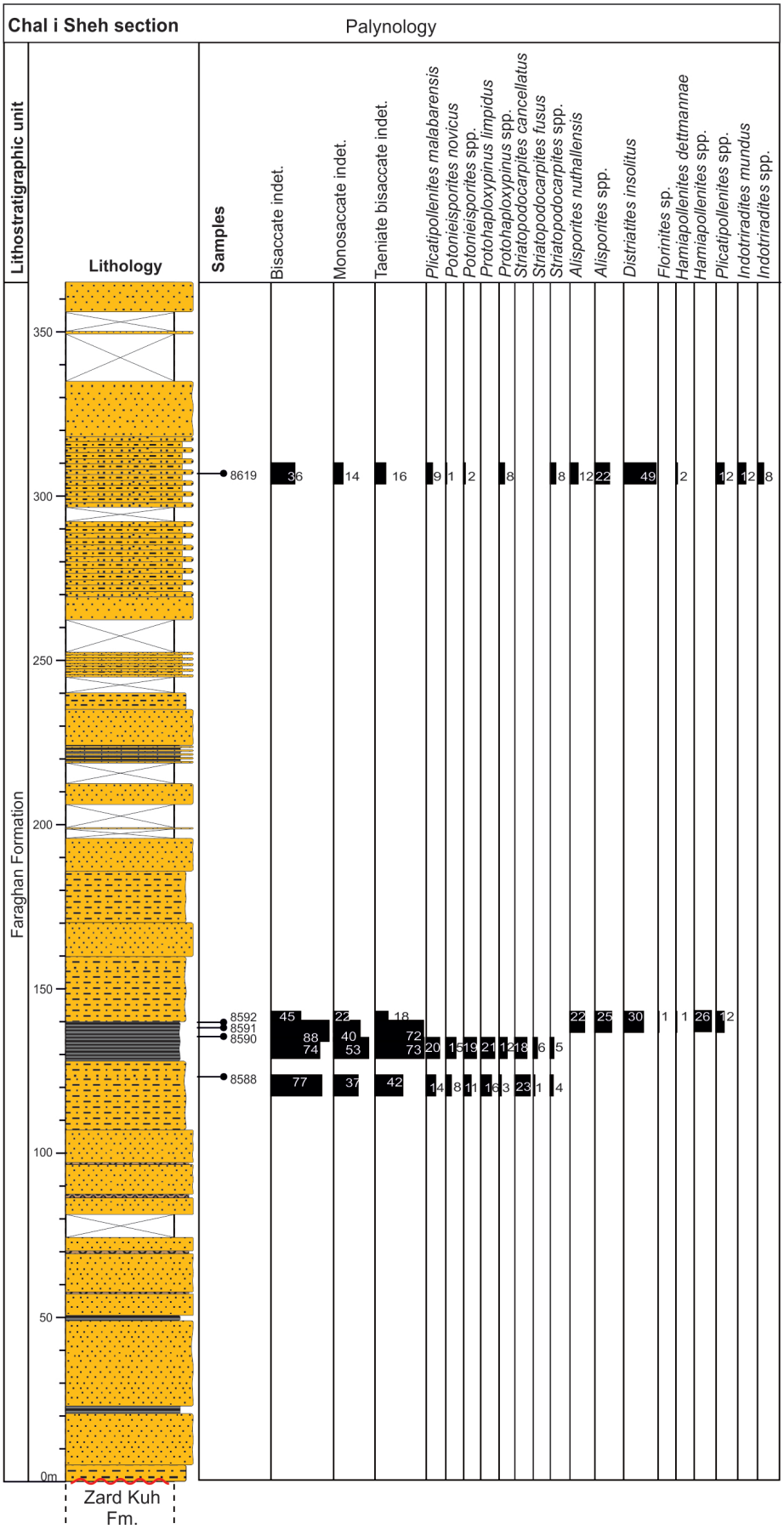

Fig. 4 - Chal i Sheh section: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

Formation. Well-8 reaches a depth of 4364 m, with the Faraghan Formation about 144 m thick. The lower part mainly consists of shale beds with rare sandstone and the upper part consists of sandstone (Fig. 13). The Faraghan Formation unconformably overlies the Devonian Zakeen Formation. It unconformably overlies the Zard Kuh Formation.

SE High Zagros

The Faraghan Formation, about 40 m thick, crops out in its type locality at Kuh e Faraghan, located approximately 80 km N of Bandar Abba. In this area the Faraghan Formation mostly consists of sandstone with shaly intercalations and it unconformably overlies the Zakeen Formation (Fig. 14).

Persian Gulf

Well-9 (depth 3820 m) in the Persian Gulf represents about 195 m of the Faraghan Formation, characterized by sandstone, shale and dolostone (Fig. 15). Its lower boundary is uncertain.

Previous palynological work on the Faraghan Formation

Detailed palynological studies of the Faraghan Formation were carried out by Ghavidel-syooki (1984, 1988, 1993, 1994, 1995, 1996, 1997 and NIOC internal reports) in surface sections (Chal i Sheh, Kuh e Faraghan, Kuh e Gahkum, Kuh e Surmeh, Zard kuh) as well as subsurface sections.

Throughout the Faraghan Formation in the Chal i Sheh area, Ghavidel-syooki (1993) described the Pollen Spore Assemblage Zone IV characterized by pollen such as *Alisporites* sp., *Ephedripites ellipticus*, *Fusacolpites fusus*, *Hamiapollenites perisporites*, *Nuskoisporites triangularis*, *N. rotatus*, *Pityosporites giganteus*, *Protohaploxypinus diagonalis*, *Sulcatisporites ovatus* and *Striatopodocarpites* sp. Spores such as *Horriditriletes ramosus*, *Punctatisporites gretensis* and *Thymospora perverrucosa* were also reported. The base of zone IV coincides with the appearance of pollen such as *F. fusus*, *H. perisporites*, *Potonieisporites granulatus* and *Vittatina costabilis* and on the basis of these occurrences the author attributed the Faraghan Formation to the Cisuralian (Sakmarian to Kungurian). The same age was attributed to other Faraghan assemblages by Ghavidel-syooki (1994, 1995, 1997) documented in the Faraghan, Gahkum and other Zagros areas. These assemblages consist of *Corisaccites alutas*, *Complexisporites polymorphus*, *Hamiapollenites karrooensis*, *H. perisporites*, *H. saccatus*, *H. tractiferinus*, *Klausipollenites schaubergeri*, *Lueckisporites virkkiae*, *Platysaccus papilionis*, *Plicatipollenites indicus*, *Potonieisporites granulatus*, *Striatoabieites multistriatus*, *Striatopodocarpites cancellatus*, *S. rarus*, *Sulcatisporites ovatus*, *Vittatina costabilis*, *V. lata* and *V. subsaccata*.

Palynostratigraphy

Materials and methods

One hundred and five samples of 20 g each were studied. Samples from surface sections were processed at the Sedimentary Organic Matter Laboratory of the Department of Physics and Geology of University of Perugia. The organic residue was concentrated using hydrochloric acid (HCl, 37%) and hydrofluoric acid (HF, 50%) and sieved with a 10 mμ filter. Light microscope observations were performed on palynological slides using Leica DM1000 and Nikon Eclipse 80i microscopes with differential interference contrast (DIC) techniques in transmitted light. The material from boreholes comprised cuttings and core samples, made available by NIOC. The slides are stored in the palynological laboratories of NIOC (Rey Storage of Exploration Directorate, National Iranian Oil Company building, Hafez crossing, Taleghani Avenue, Tehran, Iran). A minimum of 100 palynomorphs, where possible, were counted from each slide. The remainder of each slide was then examined to identify taxa not present in the count. The yield of the samples was generally high. The term 'first occurrence' in this account pertains to first uphole occurrence. Data, determining the palynozonation given here, come from palynological analysis of surface (i.e. Kuh-e-Faraghan, Chal i Sheh, Zard Kuh and Darreh Yas sections) and core-samples (i.e. Well-2, Well-3, Well-5, Well-6 and Well-8). Palynomorphs coming from cuttings-samples (i.e. Well-1, Well-4, Well-7 and Well-9) support the palynozones. The Appendix gives the full author citations of the taxa mentioned in the text. A short description of the palynomorph content from each surface section and borehole is given as follows.

Chal i Cheh section

Five samples were processed from the Faraghan Formation (Fig. 4). Bisaccate pollen, such as *Alisporites nuthallensis* and *Distriatites insolitus* – the latter occurring in the sample 8592 -, and monosaccate pollen are abundant throughout the succession. Other bisaccate pollen such as *Hamiapollenites* spp. occurs only in the basal part of the formation. *Protohaploxypinus* spp., *Striatopodocarpites* spp. and trilete spores such as *Indotriradites mundus* were recognized from the upper portion of the Faraghan Formation (sample 8619).

Zard Kuh section

Five samples were analyzed (Fig. 5). The palynomorphs from the basal part of the Faraghan Formation are poorly preserved. Despite this, bi-

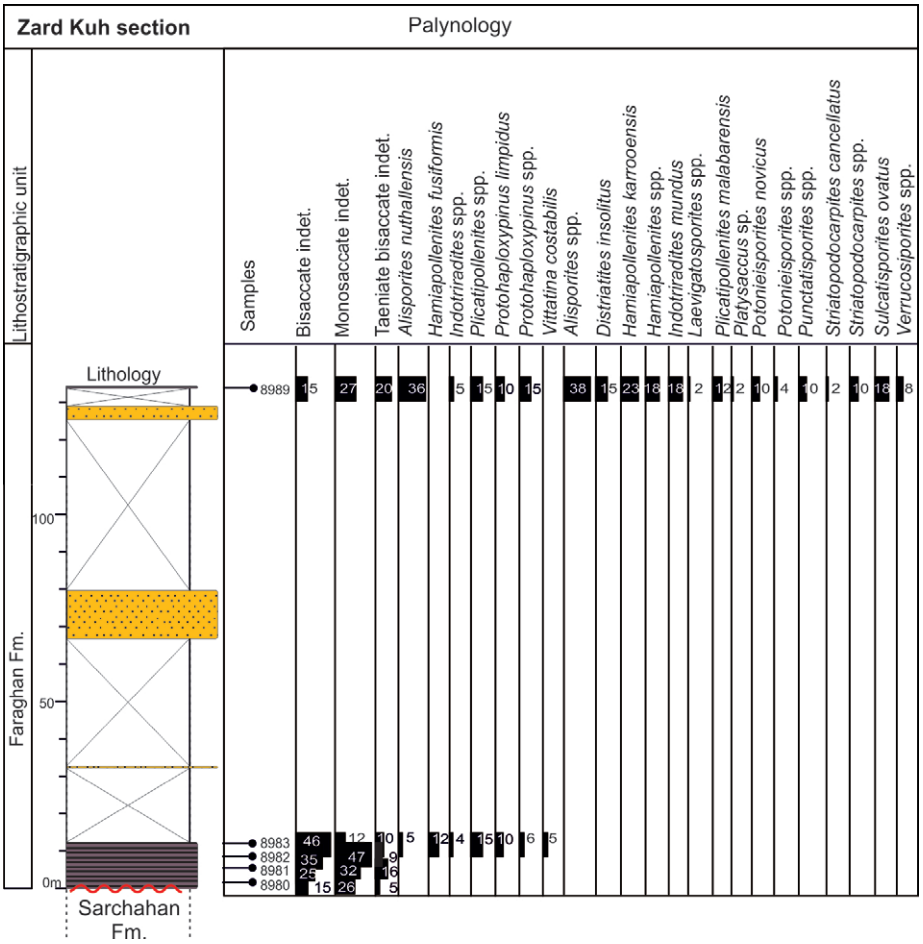

Fig. 5 - Zard Kuh section: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

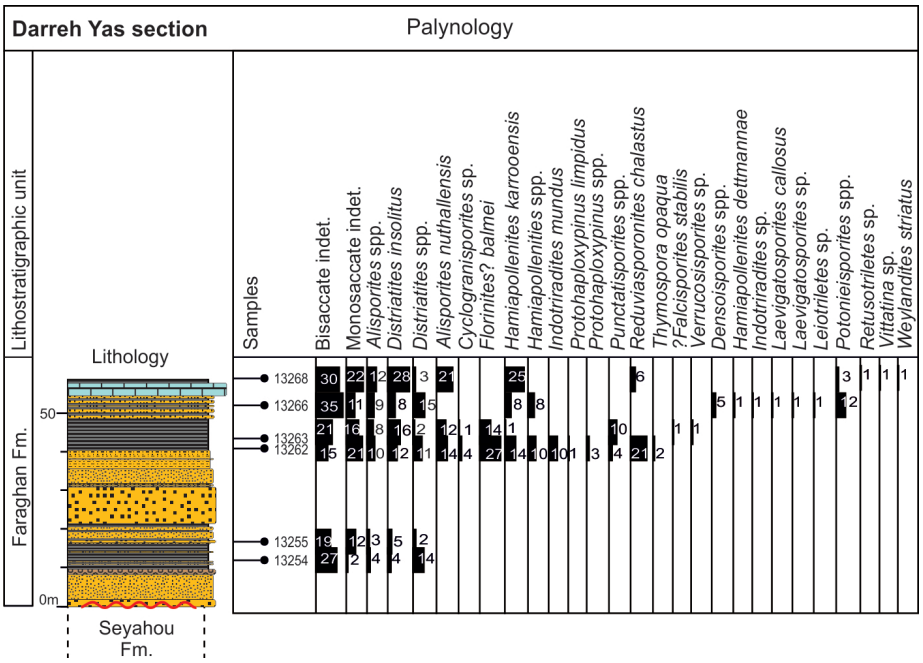

Fig. 6 - Darreh Yas section: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

saccate and monosaccate pollen were recognized as well as *Alisporites nuthallensis*, *Hamiapollenites fusiformis*, *Plicatipollenites* spp., *Protohaploxypinus* spp. and *Vittatina costabilis*. A sample from the upper part of the Faraghan Formation (sample 8989 from about 20 m below the lithostratigraphical boundary between the Faraghan and Dalan formations), yielded a rich palynomorph assemblage. Monosaccate pollen such as *Plicatipollenites malabarensis*, *Plicatipollenite*s spp., *Potonieisporites novicus* and *Potonieisporites* spp. and bisac-

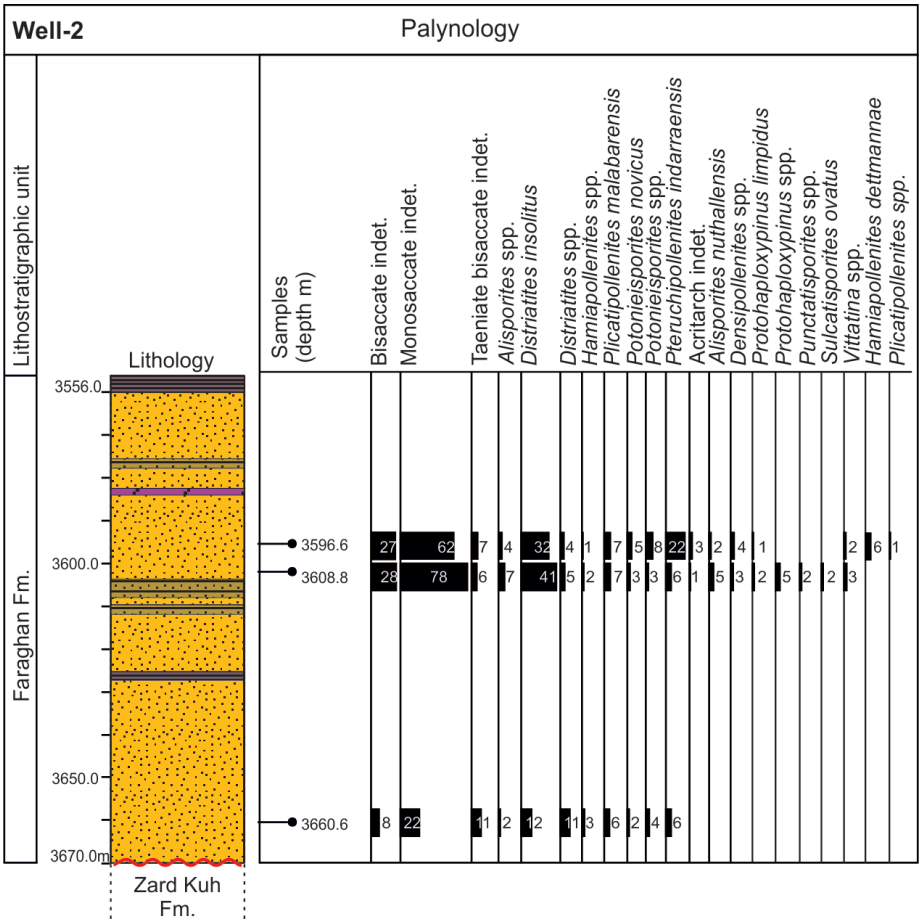

Fig. 7 - Well-2: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

cate pollen such as *Alisporites nuthallensis*, *Alisporites* spp., *Distriatites insolitus*, *Hamiapollenites karrooensis*, *Protohaploxypinus* spp. *Striatopodocarpites* spp. and *Sulcatisporites ovatus* are common. Moreover, spores such as *Indotriradites mundus*, *Indotriradites* spp. and *Laevigatosporites* spp. are present.

Darreh Yas section

Six samples were analysed from the Faraghan Formation (Fig. 6). The palynomorph content of the basal part of the succession is scarcely diversified and mainly consists of *Alisporites* spp., *Distriatites insolitus* and *Distriatites* spp. These taxa also characterize the upper portion of the Faraghan Formation (from sample 13262 to sample 13268) in assemblages with other pollen such as *Florinites*? *balmei*, *Hamiapollenites karrooensis* and *Hamiapollenites* spp., and spores such as *Indotriradites mundus* and *Indotriradites* sp., and the *incertae sedis* microfossil *Reduviasporonites chalastus*.

Kuh e Faraghan section

Four samples were processed from the Faraghan Formation (Fig. 14). Microflora, throughout the succession, consists of non-taeniate pollen such as *Alisporites nuthallensis*, *Alisporites* spp. as well as taeniate pollen such as *Protohaploxypinus* spp. and *Striatopodocarpites* spp. Monosaccate pollen are abundant and *Pteruchipollenites indarraensis* and *Vittatina costabilis* were also recorded, but only from the lower part of the formation. *Indotriradites mundus* and *Indotriradites* spp. occurred about 25 m from the base of the section (sample 6657).

Well-2

Only 3 core-samples of the basal-middle Faraghan Formation were studied from this borehole (Fig. 8). The assemblage consists of common *Alisporites nuthallensis*, *Alisporites* spp., *Distriatites insolitus*, *Hamiapollenites dettmannae*, *Hamiapollenites* spp., *Plicatipollenites malabarensis*, *Potonieisporites novicus*, *Protohaploxypinus* spp., *Pteruchipollenites indarraensis* and *Sulcatisporites ovatus*.

Well-3

Nine core-samples were processed from the upper Faraghan Formation. The interval studied (Fig. 9) yielded abundant bisaccate pollen such as *Distriatites insolitus* and *Pteruchipollenites indarraensis*, and less common monosaccate pollen such as *Plicatipolle-*

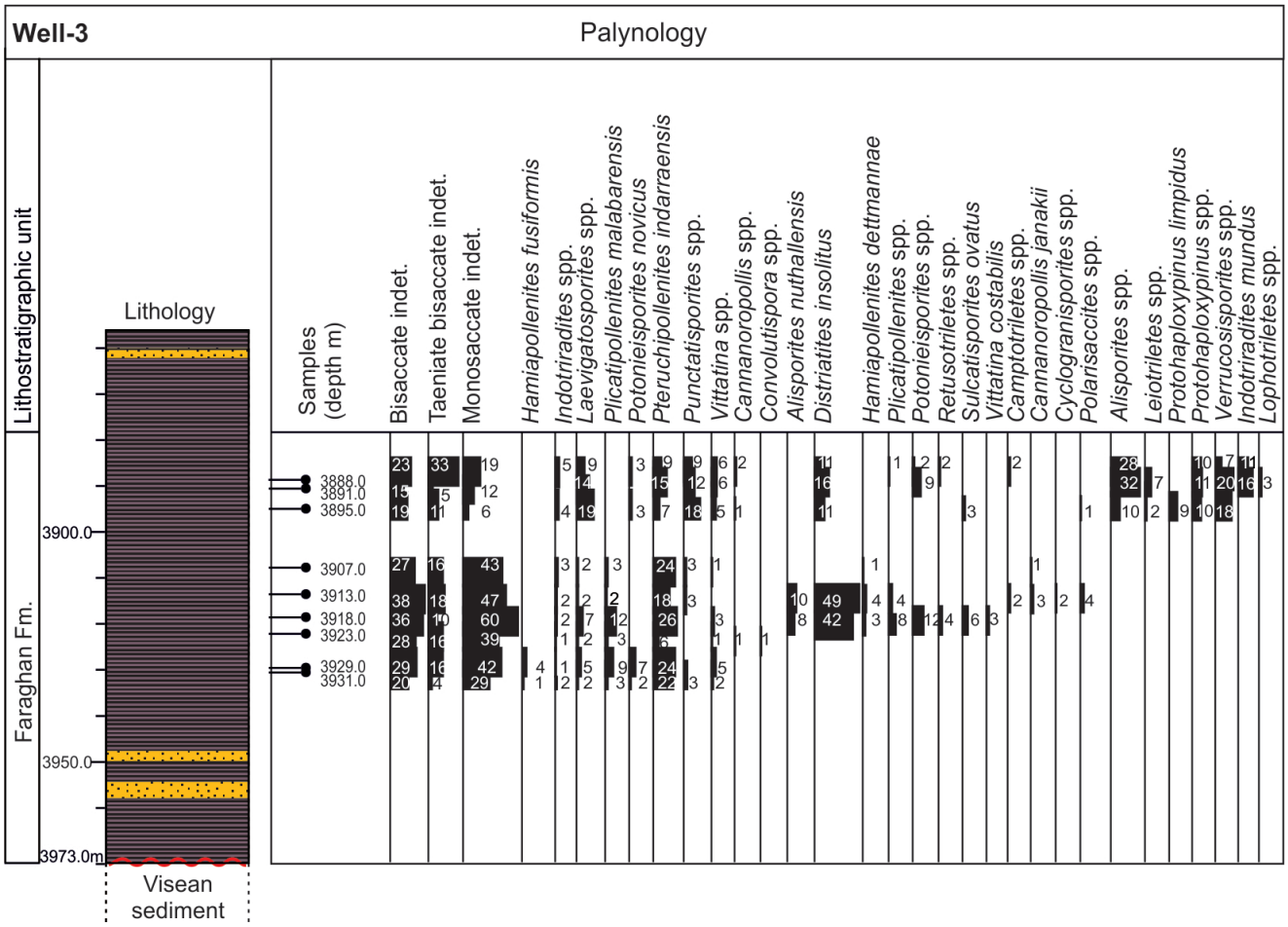

Fig. 8 - Well-3: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

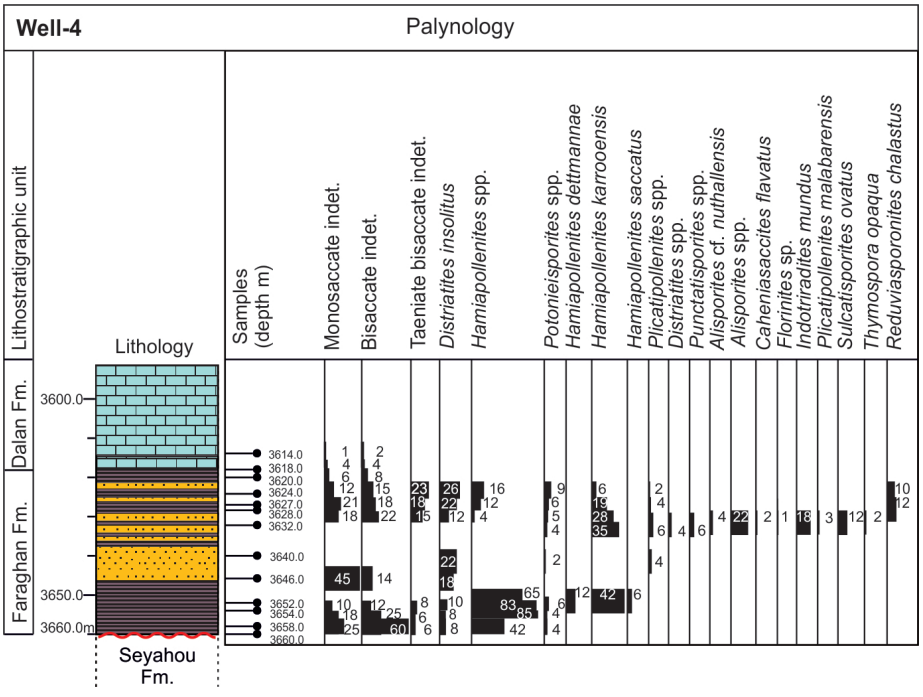

Fig. 9 - Well-4: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

nites malabarensis and *Potonieisporites novicus*. *Alisporites nuthallensis*, *Hamiapollenites dettmannae*, *H. fusiformis* and *Vittatina costabilis* occur only from the basal part of the studied interval. In the upper part of the forma-

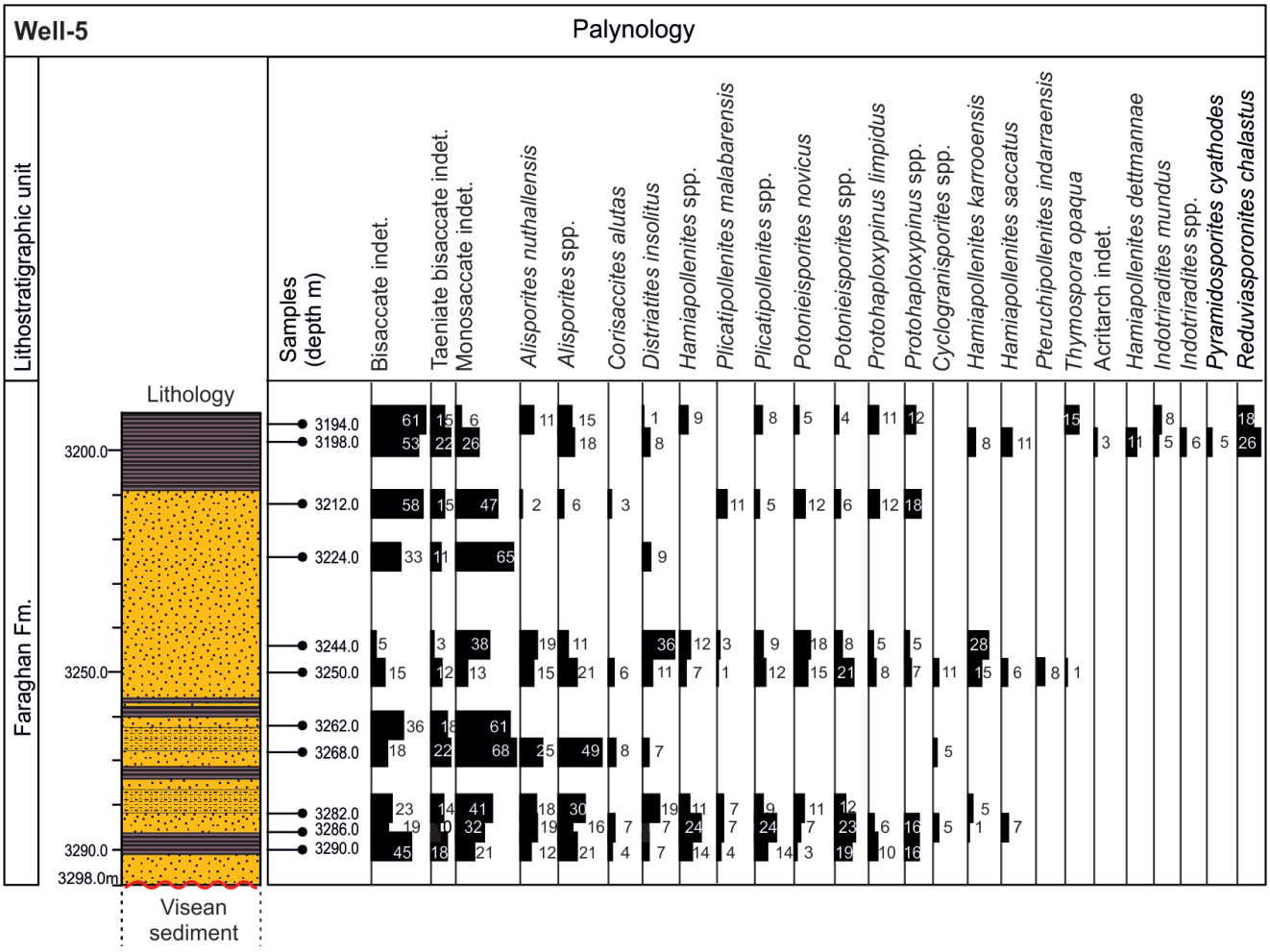

Fig. 10 - Well-5: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

tion close to the base of the Dalan Formation (sample from 3891.0 m), *Indotriradites mundus* is present.

Well-5

The palynological assemblage from 11 core-samples was well preserved and diverse (Fig. 11). The dominant taxa are *Distriatites insolitus*, *Plicatipollenites* spp. (including *P. malabarensis*) and *Potonieisporites* spp. (including *P. novicus*) and *Protohaploxypinus limpidus*. *Corisaccites alutas*, *Hamiapollenites dettmannae*, *H. karrooensis* and *H. saccatus* also occur, as well as *Alisporites nuthallensis* and *Pteruchipollenites indarraensis*. *Indotriradites mundus*, *Pyramidosporites cyathodes* and *Thymospora opaqua* are less common and occur only in the upper part of the Faraghan Formation. *Reduviasporonites chalastus* is also common in the upper part (sample from 3198.0 m).

Well-6

Eight core-samples were processed and analyzed (Fig. 12). The assemblage from the lower-middle part of the succession consists of *Alisporites nuthallensis*, *Cannanoropollis* spp., *Densipollenites* spp., *Distriatites insolitus*, *Plicatipollenites malabarensis*, *Potonieisporites novicus*, *Sulcatisporites ovatus*, *Striatopodocarpites* spp. and *Vittatina costabilis*. Other taxa such as *Cristatisporites* spp., *Cyclogranisporites* spp., *Protohaploxypinus amplus*, *Pteruchipollenites indarraensis*, *Punctatisporites* spp. and *Vittatina* spp. occur throughout the succession. The upper part of the Faraghan Formation (above 3174.0 m) contains *Indotriradites mundus* as well as *Indotriradites* spp., ?*I. ater*, *Laevigatosporites* spp., *Microbaculispora* spp. and ?*Reduviasporonites* spp..

Well-8

A well preserved and diverse assemblage was recovered from twenty core-samples (Fig. 7). Common palynomorphs include *Alisporites nuthallensis, Caheniasaccites ovatus*, *Cannanoropollis janakii*, *Corisaccites alutas*, *Distriatites insolitus*, *Hamiapollenites dettmannae, H. karrooensis*, *Indotriradites* spp., *Leiotriletes* spp., *Lophotriletes* spp., *Pakhapites ovatus*, *Plicatipollenites malabarensis*, *Potonieisporites novicus*, *Protohaploxypinus* spp. and *Sulcatisporites ovatus*. The top of the sampled section (from

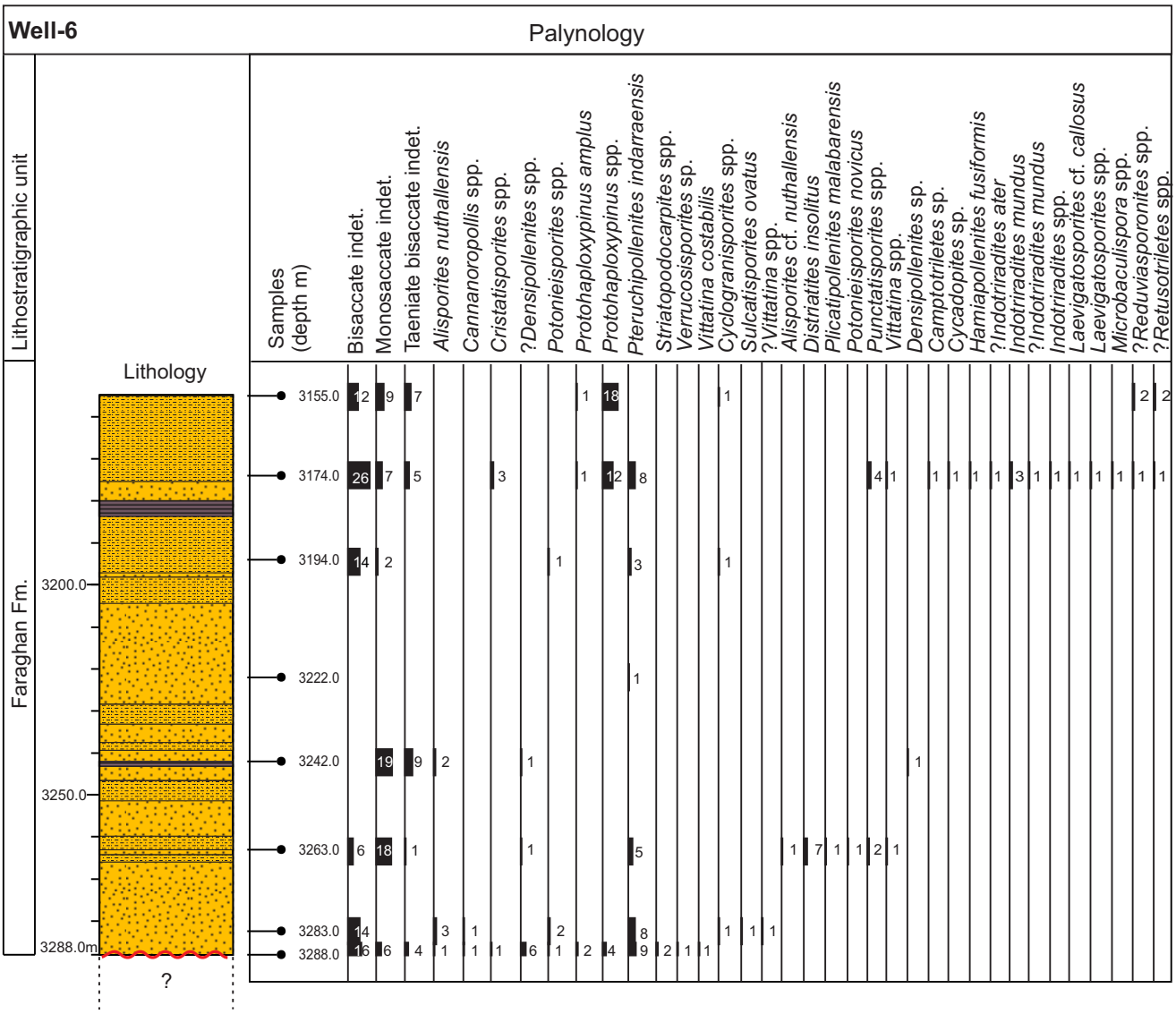

Fig. 11 - Well-6: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

sample 4306.8) contains *Densoisporites* spp., *Indotriradites mundus* and *Kraeuselisporites* spp.

Well-1

Seven cuttings-samples (four from the Faraghan Formation – samples from 2968.7 m to 2962.6 m - and three from the Dalan Formation – samples from 2959.6 m to 2955.0 m) yielded a moderately preserved, though not diverse assemblage (Fig. 3). Bisaccate pollen such as *Alisporites* spp., *Protohaploxypinus* spp. and *Taeniaesporites* spp. were found in association with monosaccate pollen such as *Potonieisporites* spp., including *P. novicus* and trilete spores such as *Indotriradites mundus*. *Reduviasporonites chalastus* was also documented. The investigated section of the Dalan Formation yielded *Protohaploxypinus* spp., *P. limpidus*, *Reduviasporonites chalastus* and *Taeniaesporites* spp. as well as indeterminate monosaccate and bisaccate pollen.

Well-4

Thirteen cuttings-samples were processed for palynology: twelve from the Faraghan Formation (samples from 3660.0 m to 3618.0 m) and one from the Dalan Formation (sample from 3614.0 m; Fig. 10). The Faraghan assemblage is characterized by an abundance of *Distriatites insolitus*, *Hamiapollenites* spp., especially *H. karrooensis*, *Plicatipollenites* spp. and *Potonieisporites* spp. *Indotriradites mundus* and *Thymospora opaqua* occur in a sample from the top part of the Faraghan Formation (sample from 3628.0 m). This part of the formation also contains *Caheniasaccites flavatus*, *Plicatipollenites malabarensis* and *Reduviasporonites chalastus*. The base of the Dalan Formation yielded

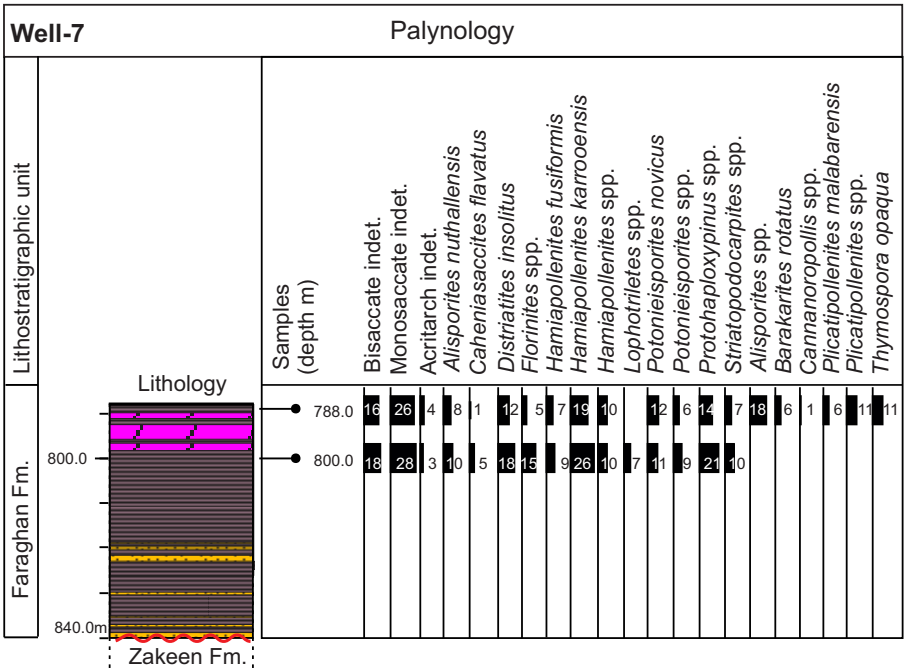

Fig. 12 - Well-7: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

only a few indeterminate specimens of monosaccate and bisaccate pollen.

Well-7

Only two cuttings-samples were studied from the upper Faraghan Formation (Fig. 13). *Alisporites nuthallensis*, *Distriatites insolitus*, *Hamiapollenites karrooensis* and *H. fusiformis* are present along with abundant monosaccate pollen such as *Florinites* spp., *Plicatipollenites malabarensis*, *Plicatipollenites* spp., *Potonieisporites novicus* and *Potonieisporites* spp., *Thymospora opaqua* is common.

Well-9

Twelve cuttings-samples (eleven from the Faraghan Formation and one from the Dalan Formation) yielded a well-preserved assemblage (Fig. 15). The Faraghan Formation contains abundant *Alisporites nuthallensis*, *Distriatites insolitus*, *Plicatipollenites* spp., *Potonieisporites* spp., *Protohaploxypinus* spp. and *Striatopodocarpites* spp. *Indotriradites mundus*, *Laevigatosporites* spp., *Punctatisporites* spp. and *Reduviasporonites chalastus* occur in the middle-upper part of the Faraghan Formation (above 3733.8 m).

Discussion

The assemblages from the Faraghan and Dalan formations are remarkably similar to those of the Gharif and Khuff formations to the west of the Persian Gulf, in Oman (Tab. 1). These were described by Stephenson et al. (2003), Stephenson (2006), and in more detail by Stephenson (2008). The latter study of an extensively cored and sampled section (196 core samples) of the Middle and Upper Gharif members (including the 'Khuff transition section') and the Khuff Formation in Barik-36 in the north central Oman Barik Field provides a particularly useful reference and comparison for the Faraghan and Dalan formations. In Barik-36, the Middle Gharif Member consists, toward the base, of palyniferous fluvial and lacustrine sandstones and mudstones succeeded by a thick stack of red palaeosols known as the 'Middle Gharif shale', which is palynologically barren. The Upper Gharif Member consists of similar fluvial facies interbedded with stacked palynologically barren palaeosols. Despite the barren sections, the productive parts allowed a detailed palynological succession to be reconstructed. Between 2771.67 and 2756.15 m of Barik-36 (the Middle Gharif Member), the assemblages contain common indeterminate bisaccate, monosaccate and taeniate bisaccate pollen. *Barakarites* spp., *Florinites flaccidus*, *Kingiacolpites subcircularis*, and *Vesicaspora* spp. also occur. Between 2698.6 and 2619.73 m (the Upper Gharif Member), are poorly- to moderately-preserved, low diversity assemblages that are dominated by bisaccate pollen including distally taeniate bisaccate pollen (mainly *Distriatites* and *Hamiapollenites*). Spores such as *Indotriradites* spp. and *Playfordiaspora cancellosa* also occur, as well as distinctive monolete spores. Between 2619.73 and 2614.84 m is the 'Khuff transition section' consisting

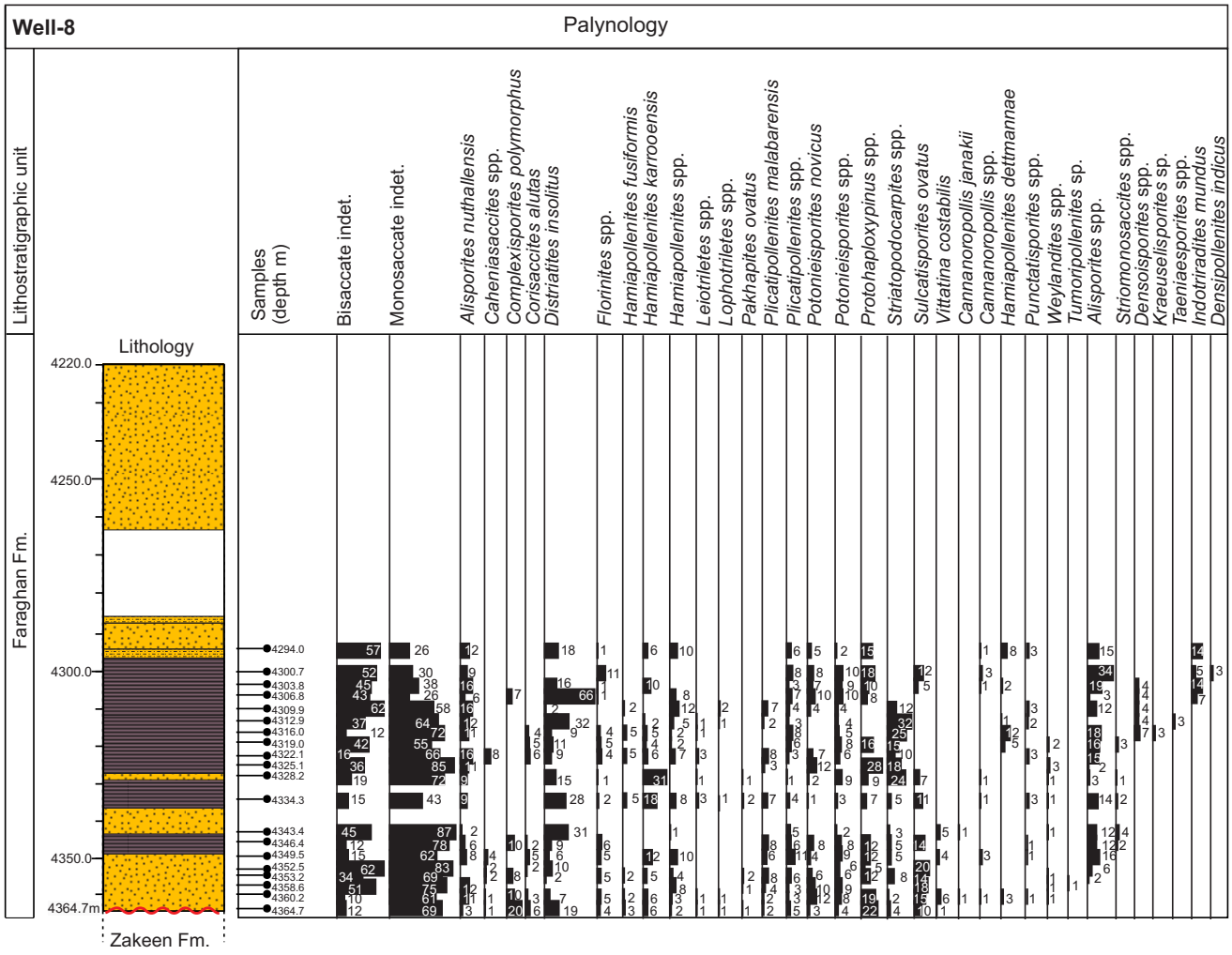

Fig. 13 - Well-8: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

of heterolithic beds overlain by the Khuff Formation carbonates and containing a distinctive assemblage dominated by bisaccate pollen and cingulizonate spores as well as probable freshwater or low-salinity

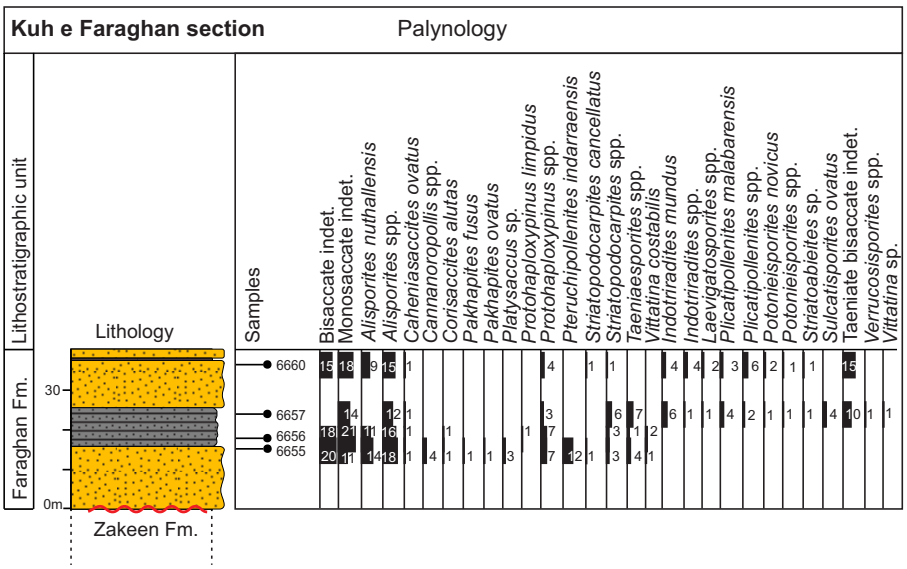

Fig. 14 - Kuh e Faraghan section: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

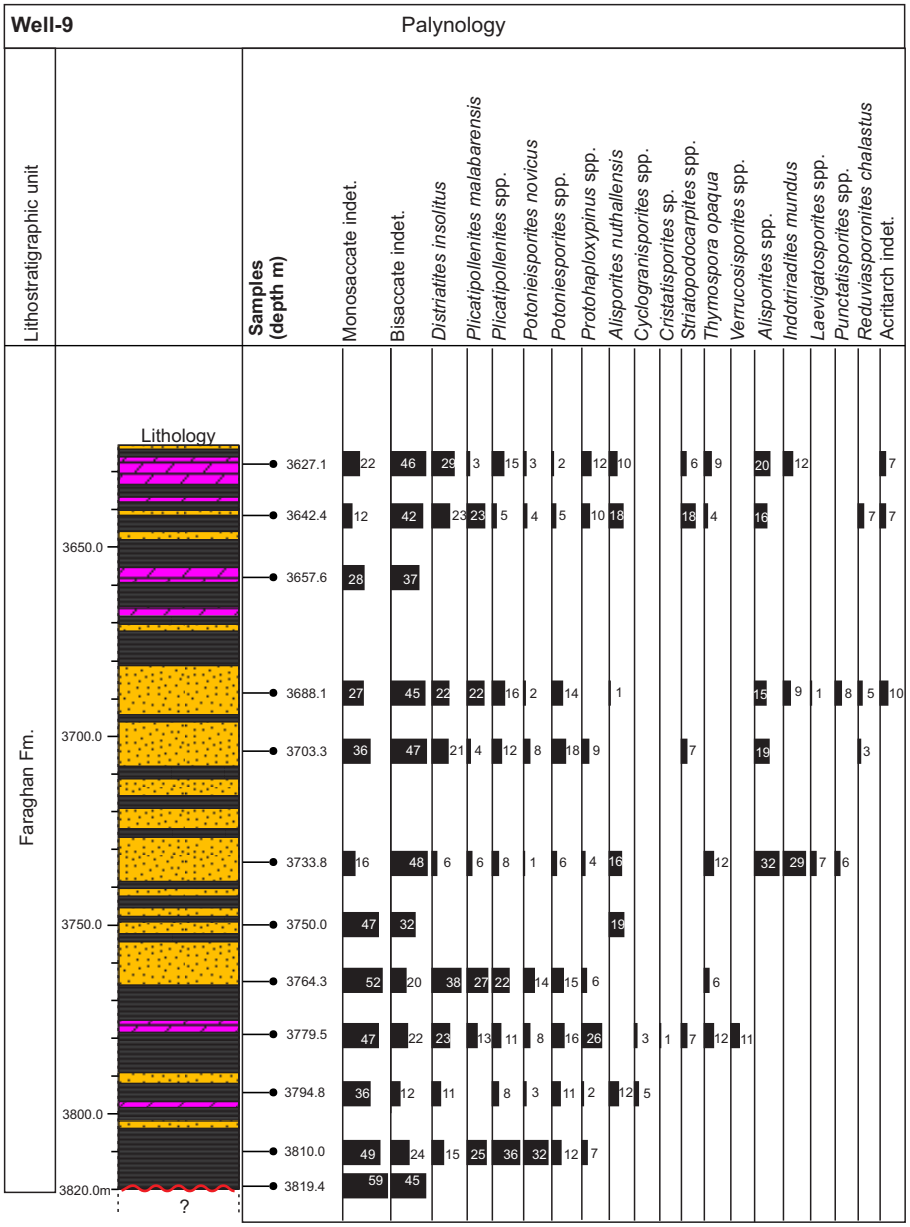

Fig. 15 - Well-9: stratigraphic log (for the legend see Fig. 16) and distribution chart of palynomorphs.

aquatic algal forms, for example *Botryococcus* spp. and *Tetraporina* spp., as well as rare marine indicators such as microforaminiferal test linings, scolecodonts, and spinose acritarchs. *Florinites*? *balmei* is common above 2620.3 m, occurring in almost all the samples. *Indotriradites mundus* occurs commonly above 2619 m.

The ranges of well-preserved assemblages in Barik-36 were used to improve understanding of the OSPZ5 and 6 biozones established by Stephenson et al. (2003) and Stephenson (2006). In particular it was possible to succinctly define the base of OSPZ5 and 6. The base of OSPZ5 was defined as the first appearance of the distinctive taxa *Distriatites insolitus*, *Hamiapollenites dettmannae*, *Indotriradites ater*, *Playfordiaspora cancellosa* and *Thymospora opaqua* (Stephenson 2006, 2008). The base of the OSPZ6 Biozone was defined as the first appearance of the distinctive monosaccate pollen *Florinites*? *balmei* (Stephenson 2006, 2008) with a recognition that the first appearance of *Indotriradites mundus* could also serve to indicate the base of OSPZ6. Palynomorphs recovered from Chal i Sheh, Darreh Yas, Kuh e Faraghan and Zard Kuh sections and from core-samples from Well-2, 3, 5, 6 and 8 allows the recognition two stratigraphic assemblages.

The lower assemblage, mostly from the lower-middle Faraghan Formation mainly consists of bisaccate pollen, both taeniate such as *Corisaccites alutas*, *Distriatites insolitus*, *Hamiapollenites dettmannae*, *H. fusiformis*, *H. karrooensis*, *H. saccatus*, *Hamiapollenites* spp., *Protohaploxypinus amplus*, *P. limpidus*, *Protohaploxypinus*

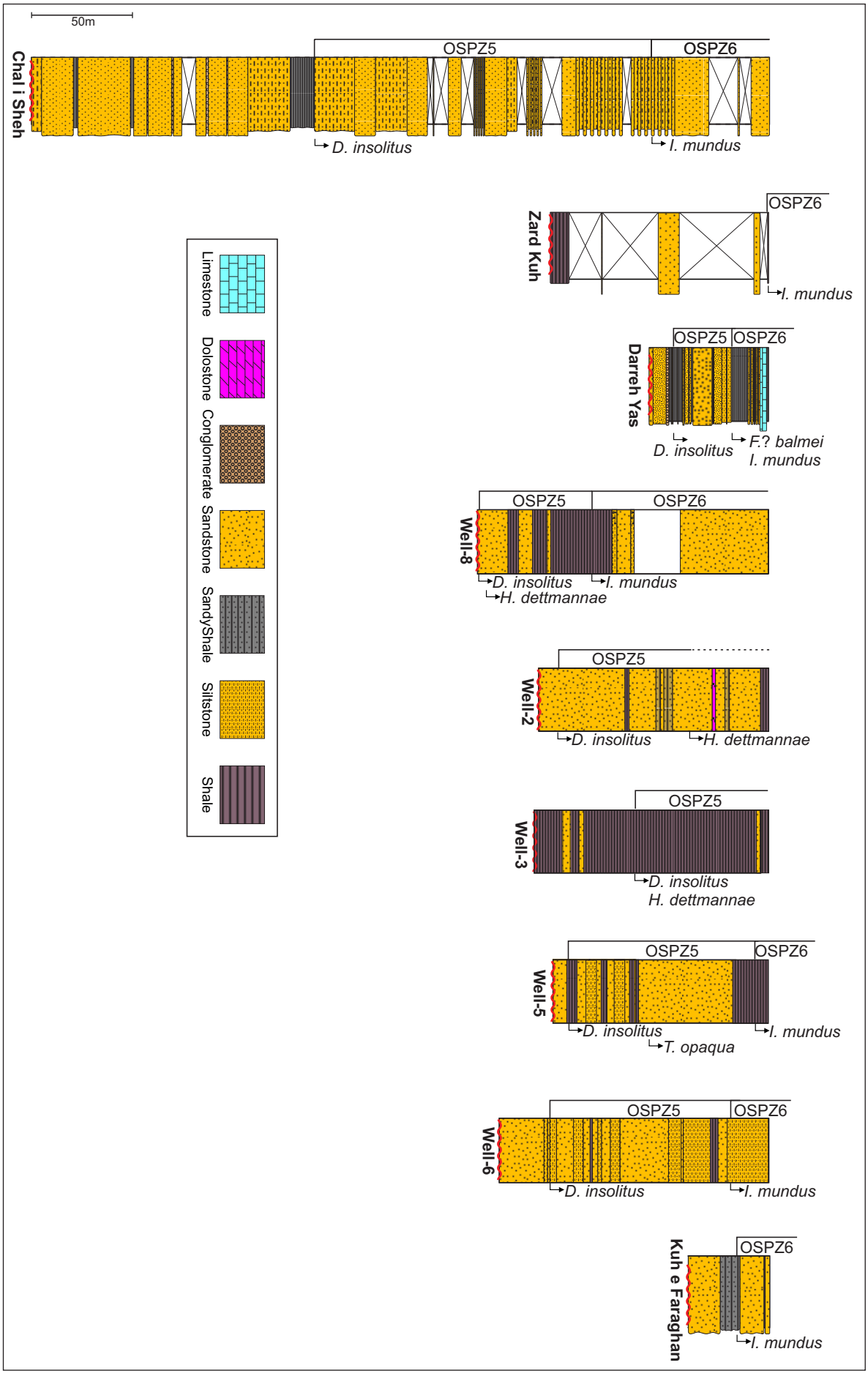

Fig. 16 - Distribution of OSPZ5 and 6 in the Faraghan Formation cropping out in Chal i Sheh, Darreh Yas, Kuh e Faraghan and Zard Kuh sections and in Well-2, 3, 5, 6 and 8.

This study	Section/well													OSPZ	
	1	2	3	4	5	6	7	8	9	10	11	12	13	5	6
A. nuthallensis	x	x		x	x	x	x		x	x	x	x	x	x	x
B. rotatus											x				
C. flavatus								x			x				
C. ovatus			x												
C. janakii							x					x			
C. polymorphus												x			
C. alutas			x						x			x		x	x
D. indicus												x		x	x
D. insolitus	x	x		x	x	x	x	x	x	x	x	x	x	x	x
F.? balmei				x											x
H. dettmannae	x			x		x	x	x	x			x		x	x
H. fusiformis		x					x			x	x	x		x	
H. karrooensis		x		x				x	x		x	x		x	x
H. saccatus								x	x						
I. mundus	x	x	x	x	x		x	x	x	x		x	x		x
L. callosus				x										x	x
P. fusus			x												
P. ovatus			x												
P. malabarensis	x	x	x			x	x	x	x	x	x	x	x		
P. novicus	x	x	x		x	x	x		x	x	x	x	x	x	
P. amplus										x				x	
P. limpidus	x	x	x	x	x	x	x		x	x	x	x	x	x	
P. indarraensis			x			x	x		x	x				x	
P. cyathodes									x						x
R. chalastus				x	x			x	x				x	x	x
S. cancellatus	x	x	x								x	x	x		
S. fusus	x										x	x	x		
S. ovatus		x	x			x	x	x				x		x	
T. opaqua				x				x	x		x		x	x	x
V. costabilis		x	x				x			x		x		x	
W. striatus				x											

Tab. 1 - Common occurrence of sporomorphs recorded in this study and in OSPZ5 and OSPZ6 biozones. 1: Chal i Sheh section; 2: Zard Kuh section; 3: Kuh e Faraghan section; 4: Darreh Yas section; 5: Well-1; 6: Well-2; 7: Well-3; 8: Well-4; 9: Well-5; 10: Well-6; 11: Well-7; 12: Well-8; 13: Well-9.

spp., *Striatopodocarpites* spp., and non-taeniate such as *Alisporites nuthallensis*, *Alisporites* spp., *Pteruchipollenites indarraensis*, *Sulcatisporites ovatus*. It also contains polyplicate pollen such as *Vittatina costabilis* and *Vittatina* spp. Monosaccate pollen also occur such as *Cannanoropollis janakii*, *Cannanoropollis* spp., *Densipollenites* sp., *Plicatipollenites malabarensis*, *Plicatipollenites* spp., *Potonieisporites novicus*, *Potonieisporites* spp. Spores such as *Camptotriletes* spp., *Cyclogranisporites* spp., *Indotriradites* spp. and *Thymospora opaqua* are also present.

The general character of the assemblage, the presence of *Distriatites insolitus*, *Hamiapollenites dettmannae*, *Thymospora opaqua,* and the absence of *Indotriradites mundus* and *Florinites*? *balmei* suggest that this lower assemblage correlates to OSPZ5, and to the Upper Gharif Member of Oman. Based on the most recent information (Stephenson 2006) this suggests that the assemblage is of possible Roadian-Wordian age. The upper assemblage, mostly coming from the upper Faraghan and lower Dalan formations, contains *Florinites*? *balmei* and *Indotriradites mundus,* which suggest correlation with OSPZ6. In Oman, the base of this biozone occurs a few meters below the base of the Khuff Formation carbonate beds within the 'Khuff transition section' and in Saudi Arabia within the 'basal Khuff clastics'. This suggests a possible age of Wordian-Capitanian based on Stephenson (2006, 2008) and close similarity between Iran and Oman stratigraphy. OSPZ6 was also documented in other areas of Northern Gondwana as the basal Khuff clastics (Saudi Arabia, Stephenson et al. 2003), the Sardhai Formation (Pakistan, Jan et al. 2009), the Kas Formation (SE Turkey) and the clastic base of the Chia Zairi Formation (Iraq; Stolle et al. 2007; Stolle 2010).

Conclusion

This paper clearly shows that palynology is an excellent tool for regional correlation. A different age for the Faraghan Formation than previously preposed, is here suggested on the basis of a detailed palynological study of sequences from nine boreholes and four outcrops in the Zagros Basin. The stratigraphic range of taxa recovered allows the use of the OSPZ palynostratigraphic scheme based in Oman and Saudi Arabia (e.g. Stephenson et al. 2003; Stephenson 2006, 2008). Assemblages mostly from the lower-middle Faraghan Formation are correlated to the ?Roadian-Wordian OSPZ5 Biozone. Assemblages mostly from the upper Faraghan Formation are correlated to the ?Wordian-Capitanian OSPZ6 Biozone (Fig. 16).

The Faraghan Formation is therefore considered in part to be the equivalent of Upper Gharif Member in Oman and in part to the 'basal Khuff clastics' (Saudi Arabia), 'Khuff transition section' (Oman), the Kas Formation (SE Turkey), the clastic base of the Chia Zairi Formation (Iraq) and the Sardhai Formation (Pakistan).

Acknowledgments. This study was mainly conducted during a researcher position of A. Spina at the Department of Physics and Geology (University of Perugia, Italy) in the framework, and with financial support, of the project "Paleontological Studies and Biozonation of Paleozoic Sediments in Central Iran and Zagros Basins" (coordinator R. Rettori). Material for study and permission for publishing were provided by NIOC (National Iranian Oil Company) and Arianzamin Pars Geological Center. The authors would like to thank NIOC and Arianzamin also for logistical support and unlimited access to analytical facilities. Two anonymous referees are thanked for their valuable comments that have led to significant improvements of this paper. Michael H. Stephenson publishes with permission of the Executive Director of BGS.References

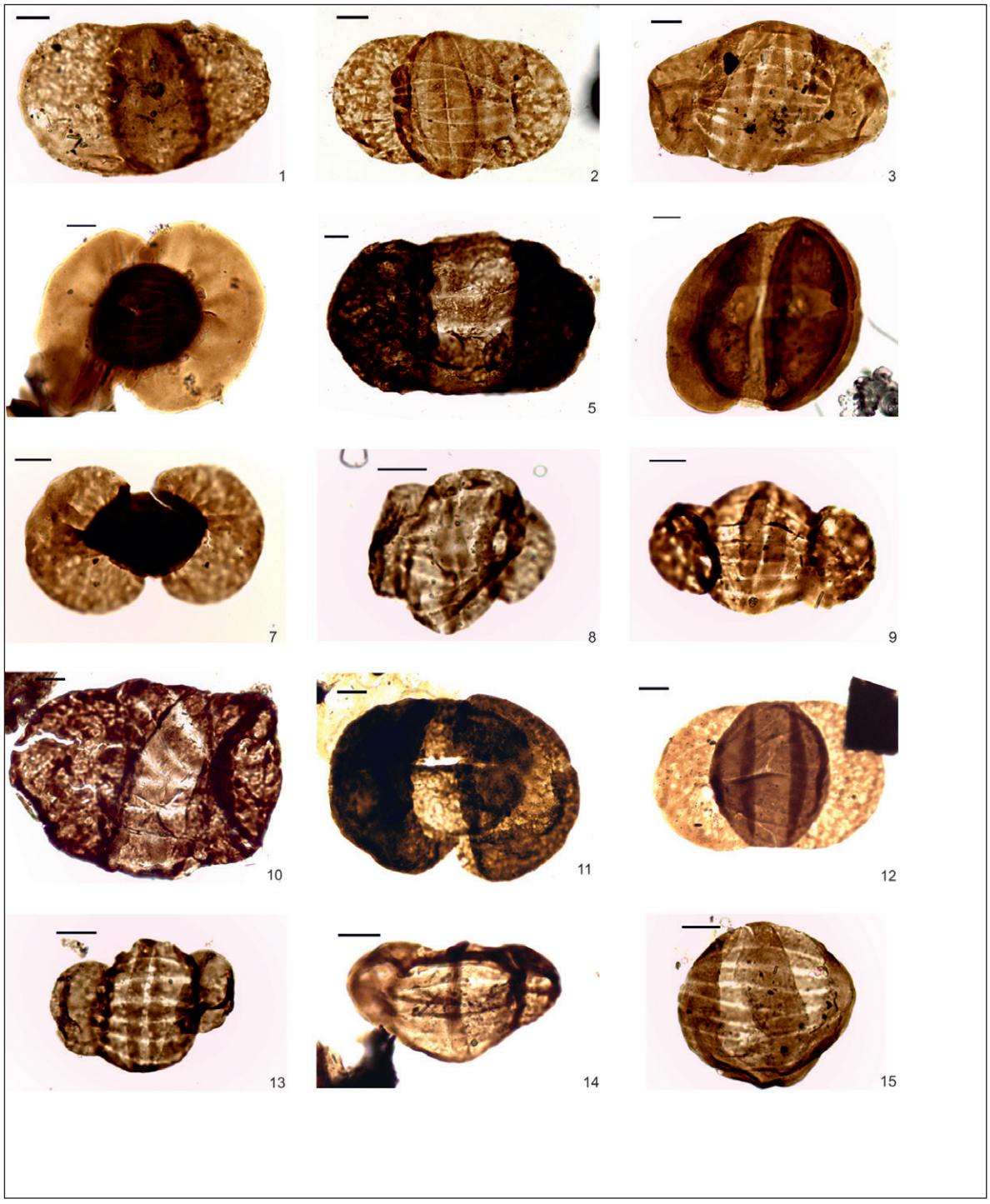

PLATE 1

Palynomorphs from the Faraghan Formation (scale bar indicates 10 μm).

1 - *Alisporites nuthallensis* Clarke 1965 (Well-9, 3733.8, W31/1);
2, 3 - *Distriatites insolitus* Bharadwaj and Salujha 1964 (2: Well-4, 3640-42, M45/1; 3: Well7, 788, P32/4);
4 - *Striatopodocarpites* spp. (Well-8, 14120-30, N37);
5 - *Taeniaesporites* sp. (Well-8, 14150-60, R40);
6, 11 - *Corisaccites alutas* Venkatachala and Kar 1966 (Well-8, 6: 14200-10, M45/4; 11: 14260-70, U21/2);
7- *Platysaccus* sp. (Kuh e Faraghan, 6655, P41/2);
8, 9, 13 - *Hamiapollenites karrooensis* (Hart) Hart 1964 (Well-4, 8: 3652-54, S36; 9: 3627-28, K42/4; 13: 3652-54, M36/1);
10, 12 - *Protohaploxypinus* spp. (Well-2, 11840, 10: T14/1; 12: P16/3);
14 - *Hamiapollenites dettmannae* Segroves 1969 (Chal i Sheh, 8619, O31);
15 - *Vittatina costabilis* Wilson 1962 (Well-8, 14170-80, V50/4).

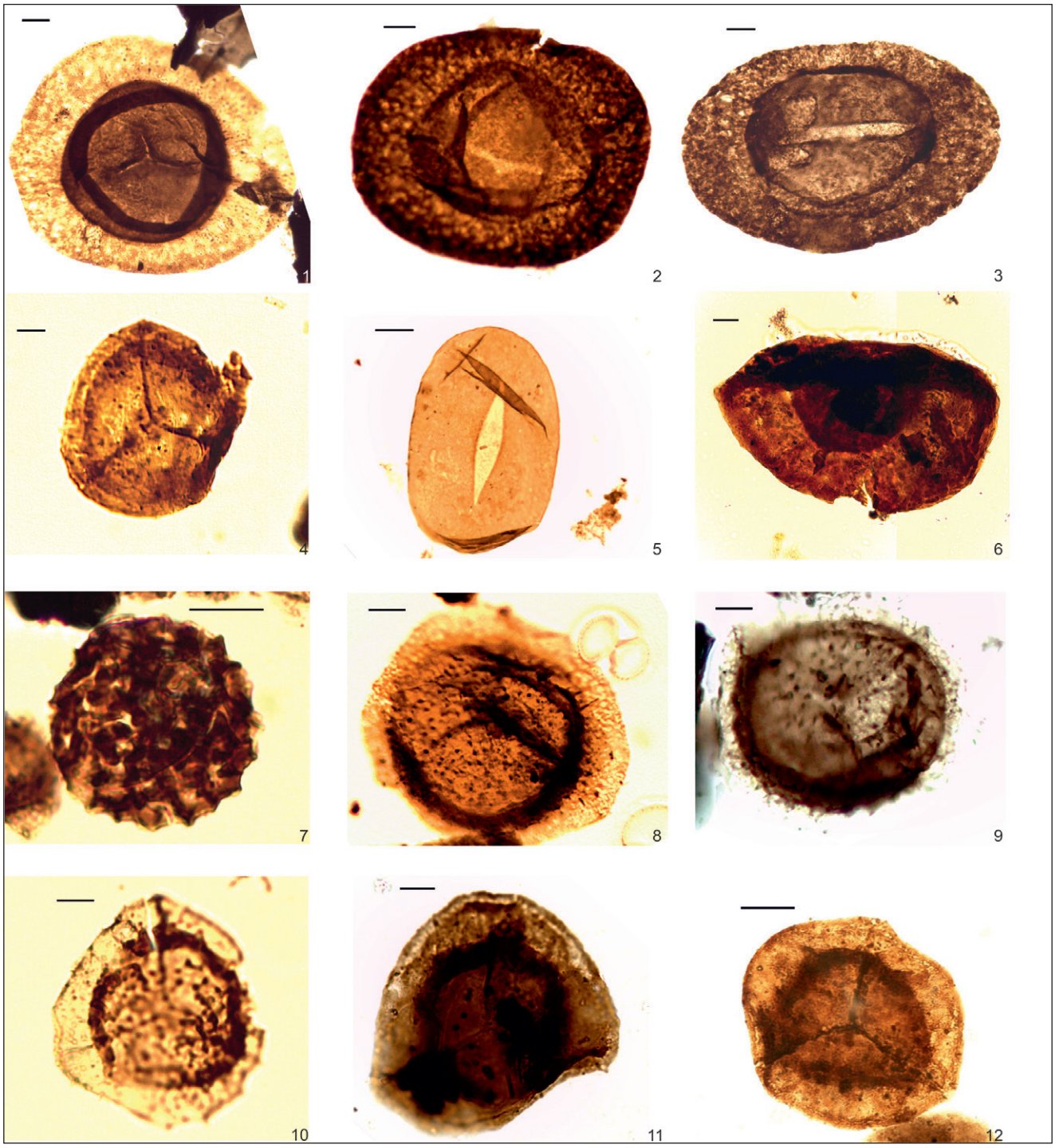

PLATE 2

Palynomorphs from the Faraghan Formation (scale bar indicates 10 μm).

1 - *Plicatipollenites malabarensis* (Potonié and Sah) Foster 1975 (Well-8, 14190-200, R50);
2, 3 - *Potonieisporite*s spp. (Well-8, 2: 14250-60, S38/1; 3: 14190-200, U22/1);
4 - *Densoisporites* spp. (Darreh Yas, 13266,106.1/62.1, P42);
5 - *Laevigatosporites* sp. (Well-3, 3888, O21);
6 - *Densipollenites indicus* Bharadwaj 1962 (Well-8, 14110-20, S36/4);
7 - *Thymospora opaqua* Singh 1964 (Darreh Yas, 13262, O33/3);
8, 9, 10 - *Indotriradites* spp. (Well-3, 8: 3888.0, I32/3; 9: 3907.0, J47/4; 10: Darreh Yas, 13262, U47/2);
11,12 - *Indotriradites mundus* Stephenson 2008 (11. Well-1, 9740, M45; 12: Well-5, 3198.0, M40/1)

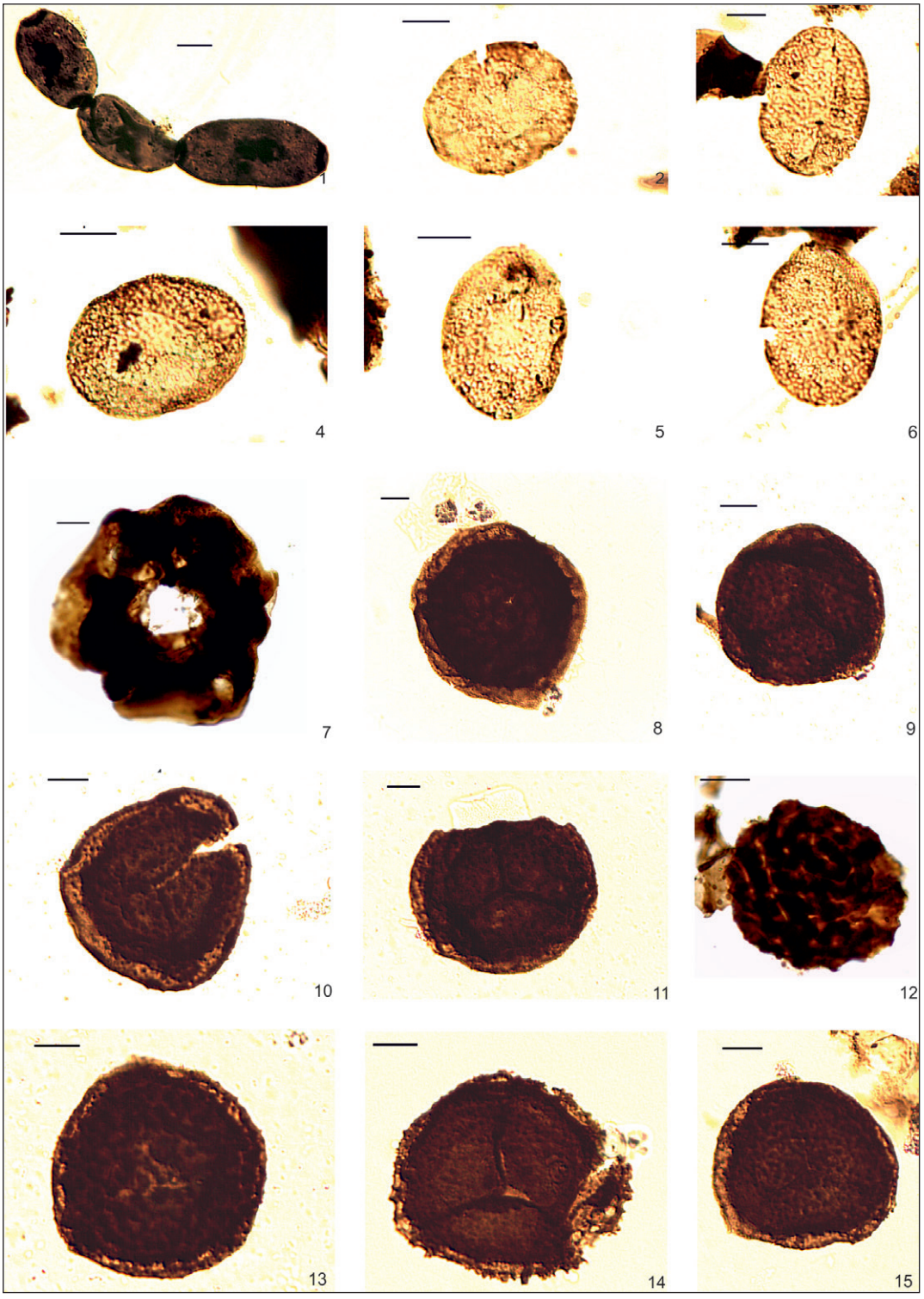

PLATE 3

Palynomorphs from the Faraghan Formation (scale bar indicates 10 μm).

1 - *Reduviasporonites chalastus* (Foster) Elsik 1999 (Well-1, 9740, P39/2);
2-6 - *Florinites? balmei* Stephenson and Filatoff 2000 (Darreh Yas, 13262, 2: O23/3; 3: P29/1; 4: Q20/3; 5: U39/2; 6: V23/3);
7 - *Pyramidosporites cyathodes* Segroves 1967 (Well-5, 3198.0, P38);
8-11, 13, 15 - *Densoisporites* spp. (Well-8: 14120-30, 8: L48, 9: E60/4; 14130-40 SL-2, 10: N28; 14140-50 SL-3, 11: P38/1, 13: P65; 14150-60 SL-2, 15: O23);
14 - *Kraeuselisporites* sp. (Well-8, 14150-60, K27/3);
12 - *Thymospora opaqua* Singh 1964 (Well-5, 3194.0, V50);

Appendix: Taxon list

?*Densipollenites* spp.
?*Falcisporites stabilis*
?*Indotriradites ater*
?*Indotriradites mundus* ?*Reduviasporonites* spp.
?*Retusotriletes* spp.
?*Vittatina* spp.
Alisporites nuthallensis Clarke, 1965
Alisporites cf. *nuthallensis* Clarke, 1965 *Alisporites* spp.
Barakarites rotatus (Balme & Hennelly) Bharadwaj & Tiwari, 1964
Barakarites spp.
Caheniasaccites flavatus Bose & Kar, 1966
Caheniasaccites ovatus Bose & Kar, 1966 *Caheniasaccites* spp.
Camptotriletes spp.
Cannanoropollis janakii Potonié & Sah, 1960 *Cannanoropollis* spp.
Complexisporites polymorphus Jizba, 1962 *Convolutispora* sp.
Corisaccites alutas Venkatachala & Kar, 1966 *Cristatisporites* spp.
Cycadopites sp.
Cyclogranisporites spp.
Densipollenites indicus Bharadwaj, 1962 *Densipollenites* spp.
Densoisporites spp.
Distriatites insolitus Bharadwaj & Salujha, 1964 *Distriatites* spp.
Florinites spp.
Florinites? halmei Stephenson & Filatoff, 2000
Hamiapollenites dettmannae Segroves, 1969
Hamiapollenites fusiformis Marques-Toigo, 1974
Hamiapollenites karrooensis (Hart) Hart, 1964
Hamiapollenites saccatus Wilson, 1962
Hamiapollenites spp.
Indotriradites mundus Stephenson, 2008
Indotriradites spp.
Kraeuselisporites sp.
Laevigatosporites callosus Balme,1970 *Laevigatosporites* cf. *callosus* Balme 1970 *Laevigatosporites* spp.
Leiotriletes spp.
Lophotriletes spp.
Microbaculispora spp.
Pakhapites fusus (Bose & Kar) Menéndez, 1971
Pakhapites ovatus (Bose & Kar) García, 1996 *Platysaccus* sp.
Plicatipollenites malabarensis (Potonié & Sah) Foster, 1975
Plicatipollenites spp.
Polarisaccites spp.
Potonieisporites novicus Bharadwaj, 1954 *Potonieisporites* spp.
Protohaploxypinus amplus (Balme & Hennelly) Hart, 1964 *Protohaploxypinus* spp.
Pteruchipollenites indarraensis (Segroves) Foster, 1979 *Punctatisporites* spp.
Pyramidosporites cyathodes Segroves, 1967 *Reduviasporonites chalastus* (Foster) Elsik, 1999 *Retusotriletes* sp.
Striatoabieites spp.
Striatopodocarpites spp.
Striomonosaccites spp.
Sulcatisporites ovatus (Balme & Hennelly) Bharadwaj, 1962
Taeniaesporites spp.
Thymospora opaqua Singh, 1964
Tumoripollenites sp.
Verrucosisporites spp.
Vesicaspora spp.
Vittatina costabilis Wilson, 1962
Vittatina spp.
Weylandites spp.
Weylandites striatus (Luber) Utting, 1994

References

Agard P., Omrani J., Jolivet L., Whitechurch H., Vrielynck B., Spakman W., Moni P., Meyer B. & Wortel R. (2011) - Zagros orogeny: a subduction-dominated process. *Geol. Mag.*, 148: 692-725.

Alavi M. (2004) - Regional stratigraphy of the Zagros fold-thrust belt of Iran and its proforeland evolution. *Am. J. Sci.*, 304: 1-20.

Al-Jallal I.A. (1995) - The Khuff Formation: Its regional reservoir potential in Saudi Arabia and other Gulf countries, depositional and stratigraphic approach. In: Al-Husseini, M.I. (Ed.) - Geo-94 Middle East petroleum geosciences conference 1: 103-119. Gulf PetroLink, Bahrain. Bahroudi, A., & Talbot, C. J. (2003). The configuration of the basement beneath the Zagros basin. *J. Petroleum Geol.*, 26: 257-282.

Angiolini L., Balini M., Garzanti E., Nicora A., Tintori A., Crasquin-Soleau S. & Muttoni G. (2003) - Permian climatic and palaeogeographic changes in northern Gondwana: The Khuff Formation of Interior Oman. *Palaeogeogr., Palaeoclimatol., Palaeoecol.,* 191, 3-4: 269-300.

Angiolini L.**,** Balini M., Garzanti E., Nicora A. & Tintori A. (2003) - Gondwanan deglaciation and opening of Neotethys: the Al-Khlata and Saiwan formations of Interior Oman. *Palaeogeogr., Palaeoclimatol., Palaeoecol.,* 196, 1-2, 99-123.

Berberian M., & King G.C.P. (1981) - Towards a paleogeography and tectonic evolution of Iran. *Canadian J. Earth Sci.*, 18: 210-265.

Beydoun Z.R. (1988) - The Middle East: Regional Geology and Petroleum Resources. Scientific Press, Beaconsfield, U.K., 292 pp.

Cavazza W., Roure F. & Ziegler P.A. (2004) - The Mediterranean area and the surrounding regions: active processes, remnants of former Tethyan oceans and related thrust belts. *The TRANSMED Atlas*: 1-29.

Davydov V.I. & Arefifard S. (2013) - Middle Permian (Guadalupian) fusulinid taxonomy and biostratigraphy of the mid-latitude Dalan Basin, Zagros, Iran and their applications in paleoclimate dynamics and paleogeography. *GeoArabia*, 18: 17-62.

Esrafili-Dizaji B. & Rahimpour-Bonab H. (2013) - A review of Permo-Triassic reservoir rocks in the Zagros area, SW Iran: influence of the Qatar-Fars arch. *J. Petroleum Geol.* 36: 257-279.

Fakhari M. D., Axen G. J., Horton B. K., Hassanzadeh J. & Amini A. (2008) - Revised age of proximal deposits in the Zagros foreland basin and implications for Cenozoic evolution of the High Zagros. *Tectonophysics*, 451: 170-185.

Ghavidel-syooki M. (1984) - Palynological study and age determination of Faraghan in Kuhe-Faraghan, southeast of Iran. *J. Sci.*, University of Tehran: 41-50.

Ghavodel-syooki M. (1988) - Palynostratigraphy and paleoecology of the Faraghan Formation of Southeastern Iran. Ph.D. Thesis, Michigan State University, 279 pp.

Ghavidel-syooki M. (1993) - Palynological study of Palaeozoic sediments of the Chal-i-sheh area, southwestern Iran. *J. Sci., Islamic Republic of Iran*, 4: 32-46.

Ghavidel-syooki M. (1994) - Biostratigraphy and Paleo-biogeography of some Paleozoic rocks at Zagros and Albors mountains. In: Hushmandzadeh A. (Ed.) - Treatise on the Geology of Iran. Ministry of Mines and Metals :1-169, Geological Survey of Iran.

Ghavidel-syooki M. (1995) - Palynostratigraphy of Sarchahan (lower Silurian) and Faraghan Formations (Devonian and Lower Permian) in Kuh-e-Gahkum, Zagros Basin. *Geological Survey of Iran, Geosciences, Sci. Quart. J.*, 4: 74-79 [in Persian with English abstract].

Ghavidel-syooki M. (1996) - Acritarch biostratigraphy of the Palaeozoic rock units in the Zagros Basin, Southern Iran. *Acta Universitatis Carolinae Geologica*: 385-412.

Ghavidel-syooki M. (1997) - Palynostratigraphy and palaeogeography of Early Permian strata in the Zagros Basin, Southeast-southwest Iran. *J. Sci. Islamic Republic of Iran*, 8: 243-261.

Ghavidel-syooki M. (2003) - Palynostratigraphy of Devonian sediments in the Zagros Basin, southern Iran. *Rev. Palaeobot. Palynol.*, 127: 241-268.

Ghavidel-syooki M., Hassanzadeh J. & Vecoli M. (2011) - Palynology and isotope geochronology of the Upper Ordovician–Silurian successions (Ghelli and Soltan Maidan Formations) in the Khoshyeilagh area, eastern Alborz Range, northern Iran; stratigraphic and palaeogeographic implications. *Rev. Palaeobot. Palynol.*, 164: 251-271.

Ghavidel-syooki M., Popov L.E., Alvaro J.J., Ghobadi Pour M., Tolmacheva T.Y. & Ehsani M. H. (2014) - Dapingian–lower Darriwilian (Ordovician) stratigraphic gap in the Faraghan Mountains, Zagros Ranges, south-eastern Iran. *Bull. Geosci.*, 89: 679-706.

Ghobadi Pour M., Ghavidel-syooki M., Álvaro J.J., Popov L.E. & Ehsani M.H. (2015) - First reported Late Ordovician trilobites from the High Zagros Ranges, Iran: a biogeographic link between Gondwanan Chinese and Mediterranean faunas. *Geobios*, 48: 351-369.

Glennie K.W. (2001) - Evolution of the Emirates' land surface: an introduction. United Arab Emirates, a new perspective. London, Trident Press Ltd.: 9-27.

James G.A. & Wynd J.G. (1965) - Stratigraphic nomenclature of Iranian oil consortium agreement area. *AAPG Bulletin*, 49: 2182-2245.

Jan I.U., Stephenson M.H., & Khan F.R. (2009) - Palynostratigraphic correlation of the Sardhai Formation (Permian) of Pakistan. *Rev. Palaeobot. Palynol.*, 158(1-2): 72-82.

Kashfi M.S. (1976) - Plate tectonics and structural evolution of the Zagros geosyncline, southwestern Iran. *Geol. Soc. America Bull.*, 87: 1486-1490.

Kashfi M.S. (1992) - Geology of the Permian 'supergiant' gas reservoirs in the greater Persian Gulf area. *J. Petroleum Geol.* 15: 465-480.

Konert G., Afifi A.M., Al-Hajri S.A., De Groot K., Al Naim A.A. & Droste H.J. (2001) - AAPG Memoir 74, Chapter 24: Paleozoic stratigraphy and hydrocarbon habitat of the Arabian Plate, 483-515.

Koop W.J. & Stoneley R. (1982) - Subsidence history of the Middle East Zagros Basin. *Phil. rans. Royal Soc. London*, Series A 305: 149-168.

Insalaco E., Virgone A., Courme B., Gaillot J., Kamali M., Moallemi A., Lotfpour M. & Monibi S. (2006) - Upper Dalan Member and Kangan Formation between the Zagros Mountains and offshore Fars, Iran: depositional system, biostratigraphy and stratigraphic architecture. *GeoArabia*, 11: 75-176.

Madani-Kivi M., & Zulauf G. (2015) - Tectono-sedimentary evolution of the Permian–Triassic extension event in the Zagros basin (Iran): results from analogue modelling. *J. Geol. Soc.*, 172: 237-250.

Motiei H. (1993) - Stratigraphy of Zagros. Treatise on the Geology of Iran No. 1. Ministry of Mines and Metals, Geological Survey of Iran, Tehran. 536 pp.

Parvizi T., Rashidi K. & Vachard D. (2013) - Middle Permian calcareous algae and microproblematica (Dalan Formation, Dena Mountain, High Zagros, SW Iran). *Facies*, 59: 149-177.

Saberi M.H., Rabbani A.R. & Ghavidel-syooki M. (2016) - Hydrocarbon potential and palynological study of the Latest Ordovician–Earliest Silurian source rock (Sarchahan Formation) in the Zagros Mountains, southern Iran. *Mar. Petroleum Geol.* 71: 12-25.

Sabouri J., Mahmoudi M., Sabbaghiyan H. & Aria-Nasab M. (2014) - The first evidences of Carboniferous (Middle-? Late Mississippian) sediments in Zagros Basin, Iran and its palaeogeographic implications. In: Abstract Volume and Proceedings of The Third International Symposium of the IGCP-589, Development of the Asian Tethyan Realm: Genesis, Process and Outcomes: 29-30.

Sampo M. (1969) - Microfacies and microfossils of the Zagros area southwestern Iran (from pre-Permian to Miocene). E.J. Brill, Leiden, 102 pp.

Şengör A.M.C. (1990) - A new model for the late Palaeozoic-Mesozoic tectonic evolution of Iran and implications for Oman. *Geol. Soc., London, Spec. Publ.*, 49: 797831.

Sepehr M. & Cosgrove J.W. (2004) - Structural framework of the Zagros fold–thrust belt, Iran. *Mar. Petroleum Geol.*, 21: 829-843.

Setudehnia A. (1972) - Stratigraphic Lexicon of Iran. Union International des Sciences Geologiques, vol. 3. ASIE, South-West Iran.

Stephenson M.H. (2006) - Stratigraphic Note: Update of the standard Arabian Permian 483 palynological biozonation; definition and description of the OSPZ5 and 6. *GeoArabia*, 11: 484 173-178.

Stephenson M.H. (2008) - Spores and pollen from the middle and upper Gharif members (Permian) of Oman. *Palynology*, 32: 157-182.

Stephenson M.H., Osterloff P.L. & Filatoff J. (2003) - Palynological biozonation of the Permian of Oman and Saudi Arabia: progress and challenges. *GeoArabia*, 8: 467-496

Stern R.J. & Johnson P.R. (2010) - Continental lithosphere of the Arabian Plate: a geologic, petrologic, and geophysical synthesis. *Earth Sci. Rev.*, 101: 2967.

Stöcklin J. (1968) - Structural history and tectonics of Iran: a

review. *AAPG Bulletin*, 52: 12291258.

Stolle E. (2007) - Regional Permian palynological correlations: Southeast Turkey-Northern Iraq. *Comun. Geol.*, 94: 125-143.

Stolle E., Yalçin M.N. & Kavak O. (2011) - The Permian Kas Formation of SE Turkey - palynological correlation with strata from Saudi Arabia and Oman. *Geol. J.*, 46(6): 561-573.

Szabo F. & Kheradpir A. (1978) - Permian and Triassic Stratigraphy, Zagros Basin, SouthWest Iran. *J. Petroleum Geol.*, 1: 57-82.

Zamanzadeh S.M. (2008) - Sedimentary petrology/environment and sequence stratigraphy of Zakeen and Faraghan Formations in their type section (Bandar-Abbas area), PhD Thesis, University of Tehran, Iran, 280 pp.

Zamanzadeh S.M., Amini A. & Ghavidel-syooki M. (2009a) - Sequence stratigraphic controls on earlydiagenetic carbonate cementation of shallow marine clastic sediments (the Devonian Zakeen Formation, southern Zagros, Iran). *Geosci. J.*, 13: 31-57.

Zamanzadeh S.M., Amini A. & Rahimpour Bonab H. (2009b) - Eogenetic dolomite cementation in Lower Permian reservoir sandstones, southern Zagros, Iran. *Geol. J.*, 44: 501- 525.

Zanchi A., Zanchetta S., Garzanti E., Balini M., Berra F., Mattei M., & Muttoni G. (2009) - The Cimmerian evolution of the Nakhlak–Anarak area, Central Iran, and its bearing for the reconstruction of the history of the Eurasian margin. *Geol. Soc., London, Spec. Publ.*, 312: 261-286.

Zharkov M.A. & Chumakov N.M. (2001) - Paleogeography and sedimentation settings during Permian-Triassic reorganizations in biosphere. *Stratigr. Geol. Correl.*, 9: 340-363.

Zoleikhaei Y., Amini A. & Zamanzadeh S.M. (2015) - Integrated provenance analysis of Zakeen (Devonian) and Faraghan (early Permian) sandstones in the Zagros belt, SW Iran. *J. African Earth Sci.* 101: 148-161.