Palynology of the Permian succession from the Ajabshir area (Azerbaijan, Central Iran): a preliminary report

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Abstract

Permian stratigraphic sequences are widely distributed throughout Iran, making this one of the best locations in the world to study this geological time interval. Nevertheless, some units lack detailed biostratigraphic characterization which is essential for palaeogeographic reconstructions. This preliminary study comprises a palynological assessment of a Permian stratigraphic section cropping out in the Ajabshir area (SW Azerbaijan, NW Iran). The continuous and relatively well-exposed Ajabshir section comprises Unit 3 of the Dorud Formation and the Ruteh and Nesen formations. In this area, the Dorud Formation starts with the Unit 3 unconformably overlying the Mila Formation, with its lower units missing. Unit 3 (48 m thick) is characterized by sandstones with siltstones and shale intercalations and an upward increase of limestones. The overlying Ruteh Formation (192 m thick) consists mainly of carbonates with scattered coarse sandstone intercalations and dolomitic limestones. The Nesen Formation (43 m thick) is characterized by dark, locally bituminous, bioclastic limestones with intercalations of sandstones, siltstones and shales. Due to the lack of fossil, Unit 3 of the Dorud Formation has been previously attributed to the Asselian-Sakmarian by correlation with the Bagh Vang Formation which crops out in the Central Iranian Basin and with the Vazhnan Formation in the Abadeh area. In the present study, we document for the first time well preserved and diverse palynological assemblages from Unit 3 of the Dorud Formation and from the Nesen Formation. The microflora from Unit3 mainly consists of sporomorphs which shows close morphological similarities with assemblages from the lower-middle Faraghan Formation (Zagros Basin, SW Iran) and with the OSPZ5 Biozone from the Upper Gharif Member in Oman (?Roadian-Wordian). The overlying Ruteh Formation proved barren in terms of palynomorph content. Studies on the foraminifer content are still in progress and will be the subject of a later publication. Sporomorphs from the Nesen Formation suggest a Capitanian-Wuchiapingian age. The results presented here constitute a good starting point for detailed studies in other areas of NW Iran in order to establish a palaeogeographical framework for the Permian of Northern Gondwana regions.

Keywords: *Northwestern Iran, Iranian Azerbaijan, palynology, Guadalupian-Lopingian.*

Introduction

In May 2017, a research group composed of an Italian team from the University of Perugia and an Iranian team from the Pars Geological Research Center (Arian Zamin) visited the Ajabshir section (Fig. 1), located north-east of Ajabshir City and north of Tapik-Darreh village (NW Iran). The main aim of this fieldwork was to sample in detail for palynomorphs and foraminifers the Permian stratigraphic interval from Unit 3 of the Dorud Formation (Assereto, 1963; Ghorbani, 2019), through the Ruteh Formation, into the Nesen Formation. In this short note, we report for the first time preliminary results on the microfloristic content from Unit 3 of the Dorud Formation and the Nesen Formation of this key area of NW Iran, together with biostratigraphic correlation to the Zagros Basin (SW Iran; Spina *et al*., 2018a) and the Arabian Peninsula (Stephenson *et al*., 2003; Stephenson, 2006; 2008). No palynomorphs were recorded from the Ruteh Formation. Notwithstanding the fact that the Permian succession of NW Iran is well known, having been sampled and analysed from the nineteen sixties up to very recently (e.g. Stepanov *et al*., 1969; Altiner *et al*., 1980; Partoazer, 1995; Baghbani, 1997; Shabanian and Bagheri, 2008; Garbelli *et al*., 2014; Ghaderi *et al*., 2014; Ebrahim-Nejad *et al*., 2015), we have still recorded important new biostratigraphic data mainly from Unit 3 of the Dorud Formation. Foraminiferal analyses and interpretations are still in progress and will be the subject of a later publication.

Geological setting

Iran is characterized by a complex assembly of several blocks grouped into three major structural units – Northern Iran (including the microstructural units of Kopeh-Dagh Range and of the South Caspian Depression), Central Iran (including the microstructural units of the Alborz Range of eastern Iran and of central Iran), and Southern Iran (mainly characterized by the microstructural unit of Zagros fold and thrust belt) units. These are separated by ophiolite suture zones (Alavi, 1991a; Stöcklin, 1968; Gaetani *et al*., 2009; Zanchi *et al*., 2009; Ghorbani, 2012).

The area studied is located on the Azerbaijan plateau of NW Iran, in the central part of the Arabian-Eurasian collision zone. It is located between the orogenic belt of the south Caucasus, eastern Alborz and the northern part of the Zagros (Mousavi *et al*., 2013; Fig. 1). There is no a general consensus concerning the geological setting of Azerbajian area. Stöcklin (1968) interpreted it as mostly part of Central Iran but with the north-eastern part included in the Alborz Basin and the south-eastern in the Sanadaj-Sirjan zone. In contrast, Nabavi (1976) described Azerbaijan as mostly part of the Alborz Basin, in a zone that he called 'Azerbaijan–Alborz', bounded to the north by the Alborz fault, to the west by the Tabriz–Urumiyeh fault, and to the south by the Semnan fault. Its eastern boundary with the Binaluod Zone is still controversial.

In this debate but in a broader context, Innocenti *et al*. (1982) designated two orogenic belts to describe the structural units of Azerbaijan as well as eastern and central Turkey.

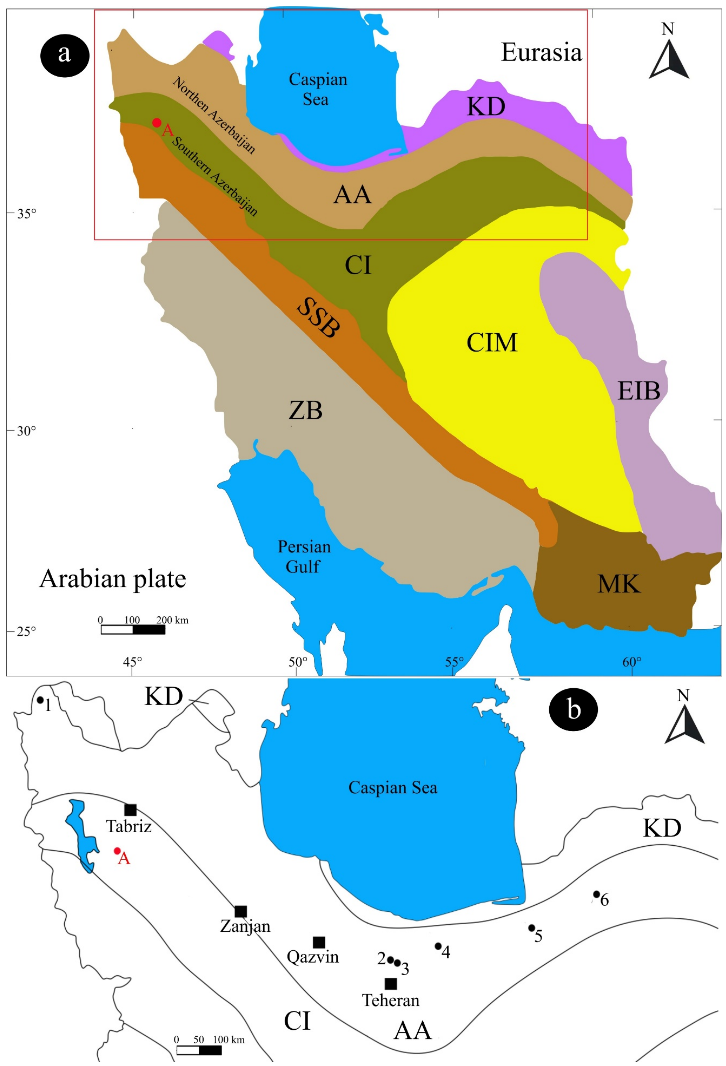

Figure 1. a) Location map and main substructural units of Iran (modified from Alavi, 1991b): Zagros Block (ZB), Sanandaj-Sirjan Block (SSB), Central Iran (CI), Alborz (AA), Kopeht Dagh (KD), Central Iranian Microcontinent (CIM), East Iran Belt (EIB) and Makran (MK). b) Index map of the Azerbaijan and Alborz Range areas with the location of the studied Ajabshir (A) section and and the cited sections in the text (black spots): Maku (1), Dorud (2), Ruteh (3), Emerat (4), Toyeh (5), Ghosnavi (6).

These are the Pontus, minor Caucasus, and Alborz Belt to the north and the Taurus–Central Iran Belt to the south. The north-eastern part of Azerbaijan comprises the Caucasus and Pontus Mountains in northern Turkey while south-western Azerbaijan belongs to the Taurus-Central Iran Belt (Innocenti *et al*., 1982; Ghorbani, 2013). South-western Azerbaijan was separated from north-eastern Azerbaijan during Early Devonian by the north Tabriz fault, which extends for about 600 km in a NW–SE direction from the Zanjan depression to the northern mountains of Tabriz (Mishu, Morou) and northwest of Azerbaijan and the Caucasus (Eftekharnejad, 1975; Darvishzadeh, 1991). Resulting from this faulting event, the northeast Azerbaijan block was characterized by subsidence and sedimentation from the Early Devonian times while the southwest Azerbaijan block remained as a structural high until late Carboniferous time (Innocenti *et al*., 1976).

The Ajabshir section is located in southwest Azerbaijan and it is consequently part of the Central Iran domain. This triangle-shaped structural unit is located in the middle of Iran and is one of the most important and complex structural zones. Precambrian to Quaternary rocks and episodes of orogenic activity, metamorphism, and magmatism characterized the Central Iran domain, the boundaries of which are strongly disputed in the literature. According to Stöcklin (1968), the Central Iran domain is bordered by the Alborz Mountains to the north, the Lut Block to the east, and Sanandaj–Sirjan to the south-southwest. However, Nabavi (1976) interpreted the northern part of the Lut Block as belonging to the Central Iran domain. Aghanabati (2004) included the Sanandaj-Sirjan and Alborz Range in the Central Iran domain.

Permian stratigraphy of Southwestern Azerbaijan

The Palaeozoic successions of NW Iran are generally characterized by a wide variety of sedimentary rocks (sandstones, limestones, dolostones, siltstones and shales) locally interrupted by gaps at several stratigraphic levels. The upper Palaeozoic succession cropping out in SW Azerbaijan rests unconformably on pre-Devonian formations (e.g. Ghorbani, 2019). The latter include the Lalun and Mila formations which crop out through much of Iran, from the Alborz Range to the Zagros Basin. The Lalun Formation is characterized by arkosic sandstones and minor siltstones and shales. Its depositional environment has been interpreted as fluvial to shallow marine and its age established as early to middle Cambrian (e.g. Setudehnia, 1975; Berberian & King, 1981; Ghorbani, 2019). The overlying Mila Formation consists of limestones, dolostones, marls, sandstones and shale intercalations deposited in shallow marine to offshore conditions. It is middle Cambrian to basal Ordovician in age (e.g. Geyer *et al*., 2014; Ghorbani, 2019). This formation was first defined in the Alborz mountains (Stöcklin *et al*., 1964) and was later elevated to the rank of Group in eastern Central Iran (e.g. Ruttner *et al*., 1968; Stöcklin & Setudehnia, 1991). The same rank was also proposed by Geyer *et al*. (2014) for the Mila Formation in the Alborz range. In western Central Iran, where the studied section crops out, the Mila is considered to be a formation, as in the Zagros basin.

The Dorud Formation crops out throughout the Alborz and Azerbaijan area. It consists of both carbonate and siliciclastic rocks (Assereto, 1963) and comprises three units (Gaetani *et al.*, 2009; Ghorbani, 2019). Jenny and Stampfli (1978) elevated the Dorud Formation to Group status in the Alborz Mountains and consequently, its three constituent units were considered to be formations. Unit 1 of the Dorud Formation is mainly siliciclastic, marked by a basal conglomerate grading up into sandstones intercalated by siltstones and shales. In the Alborz, it corresponds to the Toyeh unit (of the Dorud Group), 22 m to 90 m thick and deposited in an alluvial setting, from braided to alluvial plain, locally with marine to shoreface conditions. Brachiopods and foraminifers (Fusulinids) suggest a Gzhelian to earliest Asselian age (Gaetani *et al*., 2009). Unit 2 is characterized by limestones, locally dolomitized, deposited in inner to outer ramp settings. In the Alborz, this unit 2 corresponds to the Emerat and Ghosnavi units of the Dorud Group. The Emerat unit, mostly consists of carbonates including a basal section with oncolitic grainstone/packstone laterally interfingering with the Ghosnavi unit which mostly consists of locally dolomitized mudstone and wackestone (Gaetani *et al*., 2009). The total thickness of the Emerat unit is from 14 m to 120 m in the Dorud section. The depositional environment was interpreted as a carbonate ramp, spanning from inner and middle (Emerat unit) to outer (Ghosnavi unit) zone. This latter unit lacks fossils and the age attribution was based on its lateral correlation with the upper Emarat unit dated as Gzhelian to Sakmarian on the basis of brachiopods, fusulinids and palynomorph assemblages (Gaetani *et al.,* 2009).

Unit 3 of the Dorud Formation comprises cyclically alternating sandstones and siltstones with shale intercalations. Its depositional environment was interpreted as ranging from meandering fluvial-deltaic to shoreface settings (Shabanian and Bagheri, 2008). In southwest Azerbaijan, the thickness of this unit varies from 5 to 120 m. In the Alborz this unit was recognized only in the central part where it was designated the Shah Zeid unit of the Dorud Group. It reaches a thickness of 98 m in the Dorud and 160 m in the Emarat section (Fig. 1). The brachiopod fauna of the Shah Zeid unit in the central Alborz indicates an Asselian-Sakmarian age (Gaetani et al., 2009). In the Southwest Azerbaijan block, due to the absence of fossils, Shabanian and Bagheri (2008) assigned Unit 3 of the Dorud Formation to the Asselian-Sakmarian correlating it to the Bagh Vang unit of the Central Iranian Basin and with the Vazhnan unit in the Abadeh area (Baghbani, 1997). In SW Azerbaijan, the Dorud Formation is overlain by a mid and upper Permian succession including the Ruteh and Nesen formations. The Ruteh Formation consists of grey to dark-grey limestone, mainly characterized by bioclastic packstone/grainstone and mudstone, with scattered shaly and marly intercalations. Its depositional environment was interpreted as a mixed siliciclastic - carbonate ramp (Shabanian and Bagheri, 2008). The Ruteh Formation in Azerbaijan was correlated on the basis of lithology with the Jamal Formation in Central Iran, the Gnishik unit in the Julfa Mountains (northeastern Azerbaijan and Armenia) and the Surmaq Formation in the Abadeh area (Iranian-Japanese Group, 1981; Shabanian and Bagheri, 2008; Ebrahim-Nejad *et al*., 2015). The Ruteh Formation is one of the most fossiliferous units in Alborz-Azerbaijan containing foraminifers, brachiopods, corals, echinoderms and algae. In the Azerbaijan block, the Ruteh Formation is generally considered to be Roadian-Capitanian in age (e.g. Shabanian and Bagheri, 2008; Ebrahim-Nejad *et al*., 2015). A recent study on foraminifers in the Maku section (about 240 km north of Ajabshir; Ebrahim-Nejad *et al*., 2015) extended the stratigraphic range of this formation into the Wuchiapingian stage. The same conclusion was reached by Bozorgnia (1973) for the uppermost 25 metres of Ruteh Formation in the Alborz Basin. In the same area, Gaetani *et al*. (2009) assigned a middle Permian age (Wordian and Capitanian) to the Ruteh Formation, on the basis of foraminifers and brachiopods, and highlighted a gap between the base of the Ruteh Formation and the underlying Shah Zeid unit of the Dorud Group, spanning the late Sakmarian to Roadian. These authors did not record any evidence of a late Permian age for the uppermost Ruteh Formation.

The Nesen Formation is characterized by limestones showing different facies assemblages from northern to southern Azerbaijan. In the north, the Nesen Formation is mainly characterized by bituminous limestones with marly and shaly intercalations in the basal part. The limestones mainly consist of bioclastic wackestone and packstone with foraminifers, algae, brachiopods, crinoids and bryozoans and is assigned to the Capitanian-Wuchiapingian (e.g. Ghorbani, 2019). In the southern area, a thick igneous sill and bauxite layers are present at the base of the formation, overlain by shales, sandstones and clayey limestones with foraminifers attributed to the Wuchiapingian (Shabanian & Bagheri, 2008). The thickness of this unit varies from more than 400 m to 30 m. In its type area in the Alborz Range (Fig. 1), this formation reaches 130 m in thickness (Gaetani *et al*., 2009). Its depositional environment was interpreted as a mixed carbonate siliciclastic ramp (Shabanian and Bagheri, 2008). In the central and eastern Alborz, the Nesen Formation was subdivided in two members (Gaetani *et al*., 2009). The lower member contains a basal thin volcanic flow passing to siltstones, shales and marly limestone intercalations, thus showing similarities to the southern Azerbajan area. Limestone increases upwards, becoming dominant in the upper member. The fossil content of the latter is characterized by brachiopods, dasycladacean algae, small foraminifers and palynomorphs of Wuchiapingian and Changhsingian age (upper Permian). In the Abadeh area (Central Iran), the Nesen Formation corresponds to the Abadeh and lower Hambast formations (Ghorbani, 2019).

Lithostratigraphy of Ajabshir section

The Ajabshir stratigraphic section (N 37°31′06″; E 46°05′06″) is located in the north eastern of Ajabshir City and north of Tapik-Darreh village, Southwest Azerbaijan (Figs. 1 and 2; Plate 1). The Ajabshir stratigraphic section, about 813 m thick, includes, from bottom to top, the Cambrian Lalun and Mila formations and the upper Paleozoic Unit 3 of the Dorud Formation, overlain by Ruteh and Nesen formations.

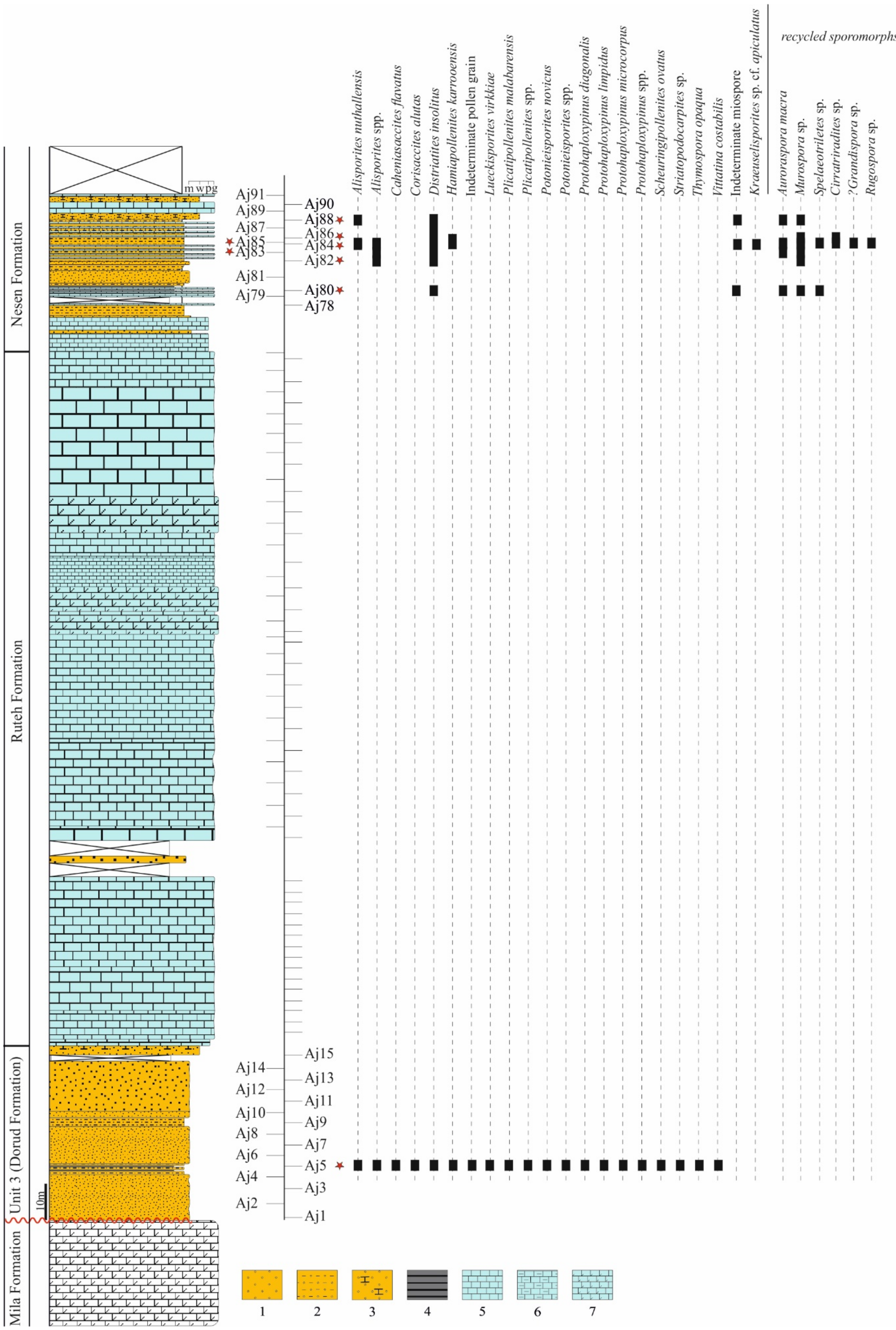

Figure 2. Lithology and sporomorph occurrences in the investigated section. Microflora assemblage from Unit3 of the Dorud Formation suggests a ?Rhodian-Wordian age; the microflora from Nesen Formation is attributed to Capitanian-Lopingian; on the right the recycled microflora assemblage assigned to the Late Devonian-early Carboniferous. 1. Sandstone; 2. Siltstone; 3. Siltstone with carbonate matrix; 4. Shale; 5. Limestone; 6. Marl; 7. Dolostone. Samples marked with red star are palynologically productive; samples from the Ruteh Formation (dash lines) are in progress for foraminiferal studies; m: mudstone; w: wackestone; p: packstone; g: grainstone

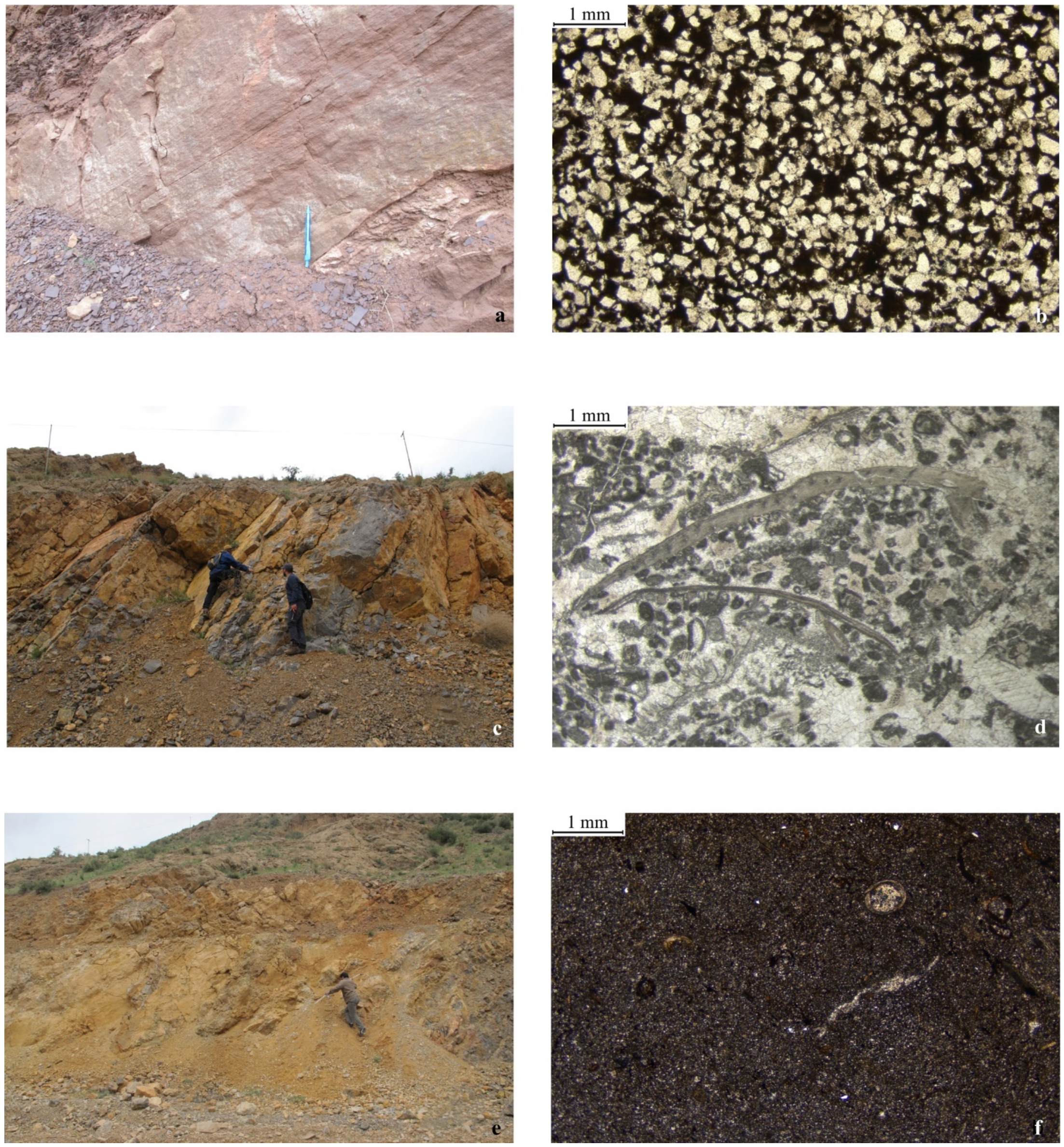

Plate 1. Facies and microfacies from Nesen Formation: a) marly limestones intercalated with marls; b) bioclastic wackestone (trilobites and ostracods among others) (Aj87); from Ruteh Formation: c) medium thicked fossiliferous limestones; d) peloidal and bioclastic grainstone (e.g brachiopods, foraminifers, echinoderms; Aj43); from Unit 3 of Dorud Formation: e) plane and cross bedded sandstones with shaly intercalations; f) quartzarenite with oxidised matrix (Aj1).

The Lalun Formation (210 m thick) is made up by intercalations of conglomerates, cross-bedded arkosic sandstones, dark grey shales, siltstones and limestones. The uppermost part of the formation contains a light fine grained quarzarenite known as the "Top-quarzite" (e.g. Ghorbani, 2019). The overlying Mila Formation (320 m thick) mostly consists of limestones, intercalated with dolostones and marls. In this area, the Dorud Formation lacks the lower units and starts with Unit 3 (48 m thick) unconformably overlying the Mila Formation. Unit 3 partially differs from the type facies of the Alborz sections (termed the Shah Zeid unit of the Dorud Group) in showing an upward increase of limestones intercalated with sandstones, dark grey shales, red-purple siltstones (Plate 1. a, b). The overlying mostly carbonate Ruteh Formation (192 m thick) displays scattered coarse sandstone intercalations and dolomitic limestones (Plate 1.c, d). The Nesen Formation (43 m thick) shows the typical facies of southern Azerbaijan composed of dark, locally bituminous, bioclastic limestones with sandstone, siltstone and shale intercalations (Plate 1.e, f). The upper Nesen Formation is not visible due to a cover of vegetation and recent debris.

Material and methods

Ninety-two samples (fifteen from the Dorud Formation, sixty-three from the Ruteh Formation and fourteen from the Nesen Formation) were processed. Of these samples, only one from Dorud Formation (Aj5) and seven from Nesen Formation (Aj80-86, Aj88) were productive. All the samples from the Ruteh Formation proved palynologically barren. The stratigraphic positions of the processed samples are given in Fig. 2.

The productive samples mainly consist of dark grey siltstones (Aj5 from Unit 3 of Dorud Formation and Aj82 and Aj88 from Nesen Formation) and grey calcareous shales (Aj80, Aj83, Aj84-86). The organic residue was concentrated using 20 g of sample soaked in hydrochloric (HCl, 37%) and hydrofluoric acid (HF, 50%) and sieved with a 10 µm filter. Light microscope observations were performed on palynological slides using Leica DM1000 microscope. Images were captured with a digital microscope camera and subsequently corrected for contrast and brightness using the open-source Gimp software. Palynological slides were processed and stored at the Sedimentary Organic Matter Laboratory of the Physics and Geology Department (University of Perugia, Italy). Authors of taxa identified are given in the species list of palynomorphs (Appendix) and in the plate descriptions.

Palynology

Unit 3 of the Dorud Formation

The productive sample (Aj5) yielded a quite well preserved and diverse microfloristic assemblage (Fig. 2; Plates 2 and 3). This mainly consists of bisaccate taeniate pollen grains such as *Distriatites insolitus* and *Hamiapollenites karrooensis* with few *Lueckisporites virkkiae* and *Corisaccites alutas*. *Protohaploxypinus* spp. (mainly *P. microcorpus*, *P. limpidus* and *P. diagonalis*) were also recorded. Non taeniates such as *Alisporites* spp. (mainly *A. nuthallensis*) and *Scheuringipollenites ovatus* also occur. *Vittatina costabilis* is abundant and was the only polyplicate pollen recorded. Of the monosaccate pollen grains, *Caheniasaccites flavatus*, *Potonieisporites* spp. and *Plicatipollenites* spp. are present. Monolete spore as *Thymospora opaqua* occurs quite commonly.

Nesen Formation

The seven productive samples (Aj80-86, Aj88; Fig. 2) yielded a microfloristic assemblage of restricted composition, mainly characterized by indeterminate monosaccate and bisaccate pollen grains. Bisaccate pollen included *Alisporites nuthallensis*, *Alisporites* sp., *Distriatites insolitus*, *Hamiapollenites karrooensis*, *Hamiapollenites* sp. and *Protohaploxypinus* sp.. Among the miospores, the monolete form *Thymospora opaqua* and the trilete form *Kraeuselisporites* sp. cf. *apiculatus* were recorded (Fig. 2; Plates 2 and 3). A few indeterminate acritarchs were also documented.

Abundant but poorly preserved miospores, consisting of radial, trilete miospore taxa as *Auroraspora macra*, *Cirratriradites* sp., ?*Grandispora* sp., *Murospora* sp., *Rugospora* sp. and *Spelaeotriletes* sp.. were also recorded (Fig. 2; Plate 4).

Previous palynological studies on the Permian of Iran

Palynological studies on the Permian of Iran are mainly confined geographically to the southern part of the country (i.e. Zagros Basin) and to a lesser extent to the central and eastern Alborz Mountains. This is the first palynological study in the Iranian Azerbaijan area.

In the eastern Alborz (Fig. 1), Chateauneuf and Stampfli (1979) described a lower Permian palynological assemblage, close to the base of the Dorud Formation, dominated by monosaccate pollen grains such as *Plicatipollenites malabarensis*, *P. indicus*, *Wilsonia vesicata*, bisaccates such as *Crucisaccites variosulcatus*, *C. monoletus*, *Lueckisporites singhii* and spores including *Pyramidosporites cyathodes* and *Densoisporites* sp.. In the Alborz area, Angiolini and Stephenson (2008) and Gaetani *et al*. (2009) documented a well-diversified Asselian - early Sakmarian assemblage from the Emarat stratigraphic unit of the Dorud section (Fig. 1), dominated by monosaccate pollen (*Potonieisporites* spp., ?*Barakarites* sp., *Cannanoropollis bilateralis*, *Plicatipollenites malabarensis*, *Potonieisporites* cf. *brasiliensis*, *Potonieisporites novicus*, bisaccates (*Alisporites indarraensis*, ?*Complexisporites* sp., *Corisaccites alutas*, *Hamiapollenites fusiformis*, *Protohaploxypinus amplus*, *Protohaploxypinus limpidus*, *Striasulcites tectus*, *Striatopodocarpites* spp.), but without *L. singhii* and *P. cyathodes.*

Plate 2. Sporomorphs from Dorud (Unit 3) and Nesen formations. Scale bar indicates 10 µm. 1. *Lueckisporites virkkiae* Potonié and Klaus 1954 (Aj5), 2, 5, 7, 9, 10. *Scheuringipollenites ovatus* (Balme and Hennelly) Foster 1979 (Aj5), 3. *Striatopodocarpites* sp. (Aj5), 4. *Protohaploxypinus diagonalis* Jansonius 1962 (Aj5), 6. *Alisporites* sp. (Aj84), 8. *Alisporites nuthallensis* Clarke 1965 (Aj5), 11. *Distriatites insolitus* Bharadwaj and Salujah 1964 (Aj5), 12, 14, 18. *Vittatina costabilis* Wilson 1962 (Aj5), 13. *Protohaploxypinus microcorpus* (Schaarchdmidt) Balme 1970 (Aj5), 15. *Caheniasaccites flavatus* (Bose and Kar) Azcuy and Di Pasquo 2000 (Aj5), 16, 17. *Hamiapollenites karrooensis* (Hart) Hart 1964 (Aj5), 19. *Corisaccites alutas* Venkatachala and Kar 1966 (Aj5)

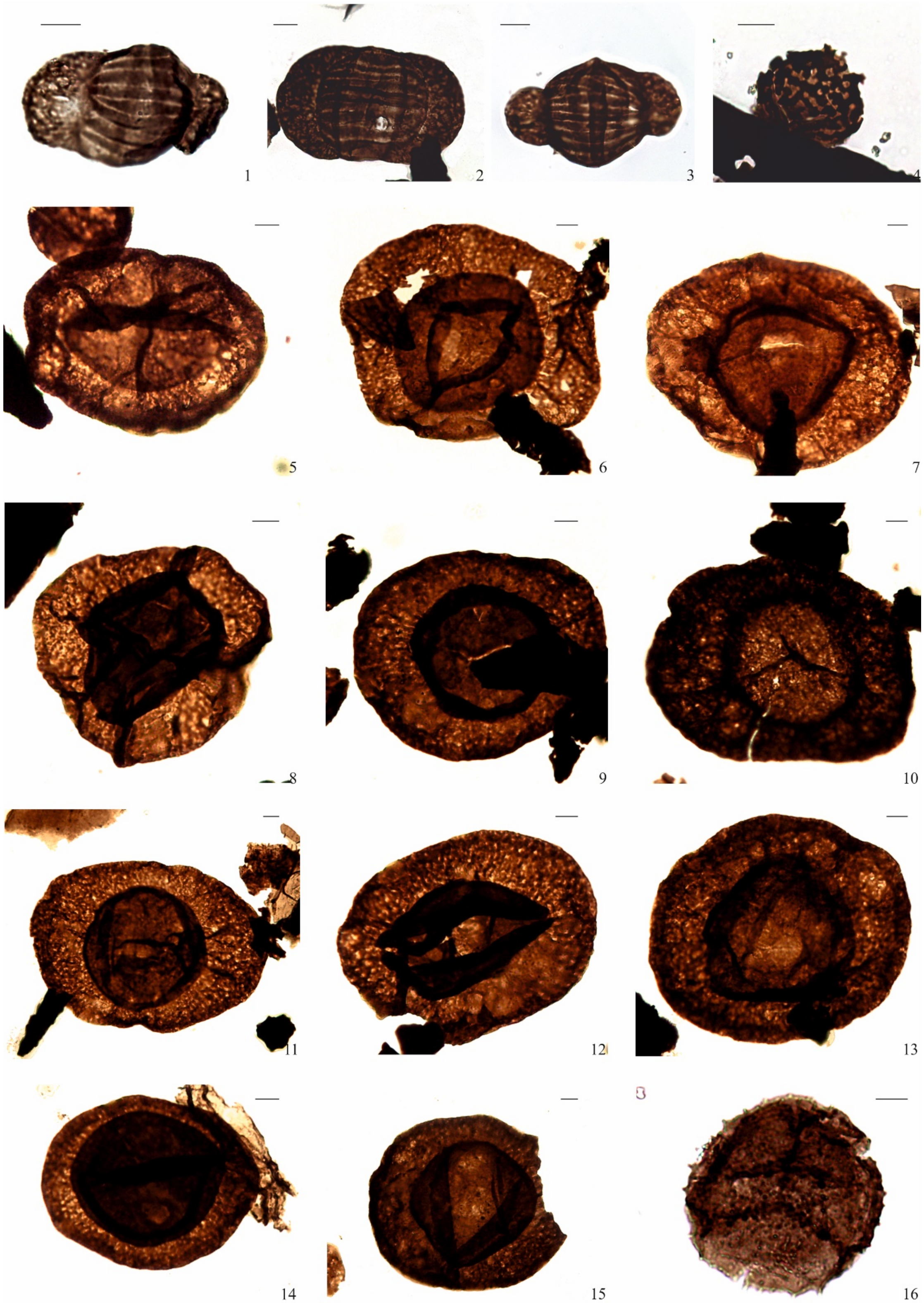

Plate 3. Sporomorphs from Dorud (Unit 3) and Nesen formations. Scale bar indicates 10 µm. 1, 3. *Hamiapollenites karrooensis* (Hart) Hart 1964 (Aj86), 2. *Distriatites insolitus* Bharadwaj and Salujah 1964 (Aj88), 4. *Thymospora opaqua* Singh 1964 (Aj5), 5, 8, 10. Indeterminate pollen grains (Aj5), 6. *Plicatipollenites* sp. (Aj5), 7, 9, 11, 13. *Potonieisporites novicus* Bharadwaj 1954 (Aj5), 14, 15. *Potonieisporites* spp. (Aj5), 16. *Kraeuselisporites* sp. cf. *apiculatus* Jansonius 1962 (Aj84)

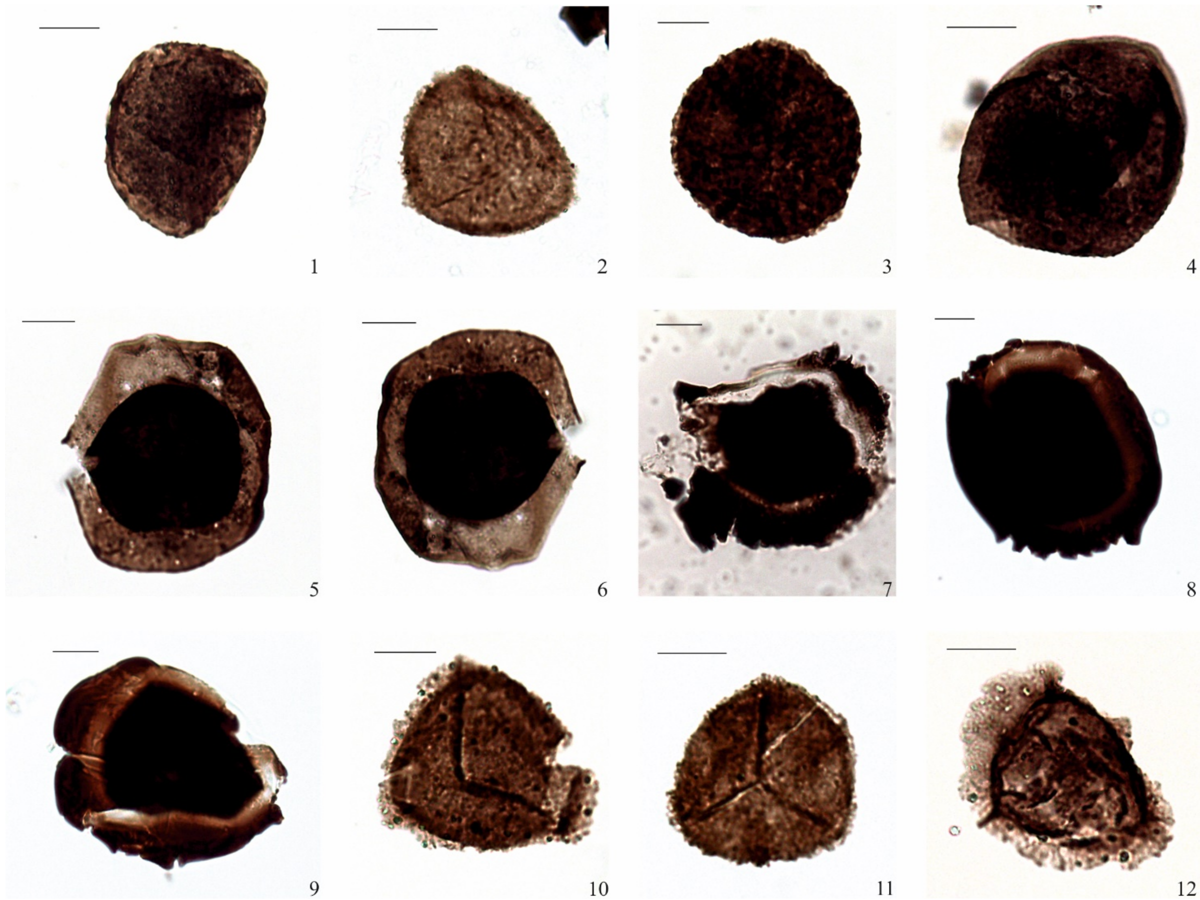

Plate 4. Upper Devonian-lower Carboniferous recycled miospores in the Nesen Formation. Scale bar indicates 10 μm. 1, 4. *Spelaeotriletes* sp. (Aj84), 2, 10, 11. ?*Grandispora* sp. (Aj84), 3. *Rugospora* sp. (Aj84), 5, 6. *Auroraspora macra* Sullivan 1968 (Aj80), 7, 8, 12. Indeterminate miospores (Aj88), 9. *Murospora* sp. (Aj86), 10. *Cirratriradites* sp. (Aj87)

According to these authors the assemblage is unlike those typical of the Asselian - early Sakmarian of the geographically close area of the Arabian Peninsula and other Gondwana areas (e.g. Antarctica, Australia, India and South America) assigned to the *Granulatisporites confluens* Oppel Zone of Foster and Waterhouse (1988). This zone is approximately equivalent to the OSPZ2 biozone of Stephenson *et al*. (2003) of Oman and Saudi Arabia. These are typically dominated by spores belonging to the genera *Microbaculispora* and *Horriditriletes*, by colpate pollen such as *Cycadopites cymbatus* and only few monosaccate pollen grains such as *Plicatipollenites malabarensis* and *Cannanoropollis* spp..

Ghavidel-syooki (1995), suggested a Gondwana affinity for his Pollen Assemblage VI dated as early Permian, from the base of the Dorud Formation, which consists of monosaccate such as *Potonieisporites granulatus*, *Plicatipollenites indicus* and *Nuskoisporites rotatus* and bisaccates including *Complexisporites polymorphus*, *Hamiapollenites perisporites* and *Striatopodocarpites cancellatus* in an assemblage with polyplicates such as *Vittatina costabilis.*

Southern Iran has also been extensively studied from a palynological point of view though there is not general consensus concerning the age of the Permian Faraghan Formation from which diversified assemblages have been recorded (e.g. Ghavidel-syooki, 1993; 1994; 1995; 1997; Spina *et al*., 2018a; Fig. 1). In the Chalisheh area, a microfloristic assemblage (Pollen Spore Assemblage IV) containing *Alisporites* sp., *Ephedripites ellipticus*, *Nuskoisporites triangularis*, *N. rotatus*, *Pityosporites giganteus*, *Protohaploxypinus diagonalis*, *Scheuringipollenites ovatus*, *Striatopodocarpites* sp., *Vittatina costabilis* and miospores such as *Horriditriletes ramosus*, *Punctatisporites gretensis* and *Thymospora parverrucosa* allowed dating of the Faraghan Formation as Cisuralian (Sakmarian to Kungurian).

The same Sakmarian to Kungurian age was also assigned to the Faraghan Formation of other Zagros areas on the basis of assemblages containing *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*, *Scheuringipollenites ovatus*, *Vittatina costabilis*, *V. lata* and *V. subsaccata* (Ghavidel-syooki 1994; 1995; 1997). Recently, a detailed study in the Zagros Basin provided new and different data to constrain the age of the Faraghan and the basal Dalan formations in the light of new biostratigraphic advances in the Arabian Peninsula (Spina *et al*., 2018a).

The stratigraphic sections (four outcrops and nine boreholes) located in several areas of the Zagros Basin (i.e. the Lorestan Domain, the NW High Zagros, the Fars Domain, the SE High Zagros and the Persian Gulf; Fig. 1) yielded well preserved and diverse palynological assemblages that permitted a good correlation with the biozone schemes for Oman (OSPZ biozones of Stephenson et al., 2003; Stephenson, 2006; 2008). The lower-middle Faraghan Formation was correlated to the OSPZ 5 Biozone, characterized overall by the presence of *Corisaccites alutas*, *Caheniasaccites flavatus*, *D. insolitus*, *Hamiapollenites dettamannae*, *H. karroensis*, *Hamiapollenites* spp., *Potonieisporites novicus*, *Potonieisporites* spp., *Plicatipollenites malabarensis*, *Plicatipollenites* spp., *Protohaploxypinus* spp., *Scheuringipollenites ovatus*, *T. opaqua* and *Vittatina costabilis*. The upper Faraghan and the lower Dalan formations were referred to the OSPZ6 Biozone, marked by the first occurrence of *Florinites*? *balmei* and *Indotriradites mundus* in assemblages also containing *A. nuthallensis*, *C. alutas*, *D. insolitus*, *H. dettamannae*, *H. karrooensis*, *Pyramidosporites cyathodes* and *T. opaqua*. On the basis of this correlation, the Faraghan Formation was assigned to the Guadalupian.

Discussion and conclusion

The present study of Unit 3 of the Dorud Formation and the Nesen Formation from the Azerbaijan area add important new stratigraphic constraints to the Permian succession of NW Iran on the basis of microfloral assemblages. Although just one sample from Unit 3 of Dorud Formation and seven samples from Nesen Formation were palynologically productive, the well preserved and diverse microflora recorded represents the first finding of palynomorphs from the Permian strata of Azerbaijan.

The occurrence of *Lueckisporites virkkiae* in Unit 3 of the Dorud Formation is very important, being one the most reliable age markers (e.g. Balme 1970; Mangerud 1994; Cirilli *et al*., 1998; Lazzarotto *et al*., 2003; Gaetani *et al*., 2005; 2013; Aldinucci *et al*., 2008; Stephenson 2008; Stolle *et al*. 2011; Spina *et al*., 2015; 2019). Utting *et al*. (1997) noted the first occurrence of this taxon in the lower part of the Kazanian (Wordian) in its type area in the Russian Platform. In China, along the Meishan section, ratified as the GSSP for base of the Triassic System (Yin *et al*., 2001), *L. virkkiae* was documented within the *Vittatina-Protohaploxypinus* Assemblage attributed to the Changhsingian-lower Induan on the basis of conodonts (Ouyang and Utting, 1990). In the Arabian Peninsula *L. virkkiae* was documented from the OSPZ5 Biozone of Stephenson *et al*. (2003), attributed to the? Roadian-Wordian age. This latter biozone is also marked by the occurrence in the upper Gharif Member in the north central Oman Barik fields (Stephenson, 2008; 2018) of two important elements which are present also in the present studied section, *Distriatites insolitus* and *Thymospora opaqua*. Other bisaccate pollen grains such as *Alisporites nuthallensis*, *Corisaccites alutas* and *Hamiapollenites karrooensis* are also present as well as in Unit 3 of the Dorud Formation studied here. A similar assemblage was also recorded from the lower-middle Faraghan Formation in the Zagros Basin, attributed to the OSPZ5 Biozone (Spina *et al*., 2018a). *Lueckisporites virkkiae* calso haracterizes the late Permian microfloristic content of other Northern Gondwana regions such as Southeast Turkey, where it was found from the Wuchiapingian of Kas Formation (e.g. Stolle, 2007; Stolle *et al*., 2011) in an assemblage with *Potonieisporites* spp., *Striatoabieites* spp., *Taeniaesporites* spp., *Protohaploxypinus* spp. and *Hamiapollenites* spp.. Polyplicates such as *Vittatina* are also present. Stolle (2007) recorded *L. virkkiae* from the Guadalupian and Lopingian Chia Zairi Formation (northern Iraq). This form was also documented from late Permian rocks of southern Gondwana (e.g. Galasso *et al*, 2019a; b). In a recent global overview of Permian palynostratigraphy, Stephenson (2018) described the bisaccate pollen grain *Lueckisporites virkkiae* as a Guadalupian-Lopingian 'bridging-taxon' occurring across different Permian phytogeographical provinces. Accordingly, on the basis of the microfloristic content here recorded from Unit 3 of the Dorud Formation, we could tentatively attribute the palynogical assemblage to the OSPZ 5 Biozone of ?Roadian-Wordian age. If this attribution is confirmed by other data, Unit 3 could be coeval with the Faraghan Formation. We are aware that this age attribution is derived from the analysis of only one productive sample. However, we consider these preliminary results promising, mainly because the palynomorphs studied were obtained from a formation previously considered to be palaeontologically barren and only attributed to the Asselian-Sakmarian on the basis of lithostratigraphical correlation with eastern and central Alborz. These results also form good starting point for future detailed studies of Unit 3 of the Dorud Formation that crops out in other areas of NW Iran, in order to establish a Permian palaeogeographical reconstruction of of Northern Gondwana. The ?Roadian-Wordian age of Unit 3 of the Dorud Formation in SW Azerbaijan area could be related to its paleogeographic position relative to the northern sector. This portion of the southern Azerbaijan block is separated from the northern part by the Soltanieh-Tabriz Fault and was an exposed structural high until late Carboniferous time, whereas the northern sector was the site of sedimentation and subsidence (Ghorbani, 2013). Sedimentation only resumed in southern Azerbaijan with the deposition of Unit 3 of the Dorud Formation unconformably overlying the Mila Formation. The Ruteh Formation did not yield palynomorphs, but a rich and diversified foraminifer assemblage was recorded which study is still in progress. The overlying Nesen Formation is marked by the occurrence of *Kraeuselisporites* sp. cf. *apiculatus,* a form mainly documented from the uppermost Permian-Lower Triassic of the Boreal Domain (e.g. Balme, 1980; Mangerud, 1994; Utting et al., 2004). However, *Distriatites insolitus* and *T. opaqua* also range up into Biozone OSPZ6 of Stephenson et al. (2003) and Stephenson (2006; 2008) which these authors assign to the Capitanian-Wuchiapingian. These palynomorphs were also recorded by Gaetani *et al.* (2009) from the Nesen Formation cropping out in the central and eastern Alborz, in assemblage with *Alisporites indarraensis*, *Indotriradites* spp., *Densoisporites/ Lundbladispora* spp., *Vesicaspora* spp., *Distriatites insolitus*, *Triquitrites proratus* and *Florinites*? *balmei*. Therefore, on the basis of the recorded microflora, the Nesen Formation can be dated as Capitanian-Wuchiapingian age.

In the Nesen Formation the group of poorly preserved miospores (*Auroraspora macra*, *Cirratriradite*s sp., ?*Grandispora* sp., *Murospora* sp., *Rugospora* sp. and *Spelaeotriletes* sp.; Fig. 2; Plate 4) includes taxa that have been widely recorded in the Late Devonian-?Mississippian of Central Iranian Basin (Aria-Nasab *et al*., 2016), Australia (Playford, 1990), Western Europe and Poland (Clayton *et al*., 1977; Turnau, 1978) Canada (Utting, 1987; Vecoli *et al*., 2011), North Africa (Massa *et al*., 1980; Coquel & Moreau-Benoit, 1986; Spina & Vecoli, 2009), Bolivia (Azcuy & Ottone, 1987), and Saudi Arabia (Clayton *et al*., 2000).

On the basis of this age attribution this group of miospores can be considered as recycled. This microflora highlights the presumed existence of nearby continental land masses where Devonian-Carboniferous rocks were exposed and the products of their erosion supplied the adjacent sedimentary basins. This topic is beyond the scope of the present paper, but provenance studies based on thermal history of "in situ" and recycled miospores (e.g. Spina *et al*., 2018b; Galasso *et al*., 2019a; Schito *et al*., 2017; 2019) and on the features of the recycled microfloristic assemblage are in progress in order to establish the possible sources areas.

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