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Middle–late Cambrian acritarchs of the Zagros Basin, southwestern Iran

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ABSTRACT
A detailed palynological study was conducted in the lower Palaeozoic of the Zagros Basin (southwestern Iran) where the Mila and Ilbeyk formations are present in several areas. The Mila Formation mainly consists of dolostones, limestones and shales deposited in a shallow marine to outer ramp environment. It is conformably overlain by the Ilbeyk Formation, characterised by shales and sandstones with scattered limestone intervals deposited in a setting extending from shoreface to low-energy offshore environments. The palynological investigation of the Mila and Ilbeyk formations from the Chalisheh, Ghalikuh and Oshtorankuh areas allows the establishment of three palynozones. These can be well correlated with the palynozonations from adjacent areas and/or with middle–late Cambrian sections independently dated with trilobites. These correlations are useful for the age determination of the Cambrian successions from southern Iran. The Cambrian assemblages exhibit close affinities with microfloras from peri-Gondwana (including the countries belonging to the Avalonia microcontinent in the Early Ordovician) and Baltica, confirming that these palaeogeographical domains were part of the same large bioprovince, as shown in current palaeogeographical maps.

KEYWORDS
palynostratigraphy; acritarchs; Miaolingian; Furongian; Iran; Gondwana

1. Introduction

The Zagros Basin (Figure 1a, b) is one of the major oil-producing provinces in the world. Almost all of the geological investigations of the Palaeozoic successions in the Zagros Basin have been focused on petroleum geology, sedimentology and structural geology (e.g. Sampo 1969; Setudehnia 1972; Kashfi 1976; Bahroudi and Talbot 2003; Alavi 2004; Sepehr and Cosgrove 2004; Insalaco et al. 2006; Fakhari et al. 2008; Zamanzadeh, Amini, and Ghavidel-Syooki 2009; Zamanzadeh, Amini, and Rahimpour-Bonab 2009; Agard et al. 2011; Esrafili-Dizaji and Rahimpour-Bonab 2013; Ghorbani 2019). On the other hand, biostratigraphical studies are limited in this area so far and have mainly focused on the palynology of the Late Ordovician, Devonian and Permian (e.g. Ghavidel-Syooki 1984, 1988, 1993, 1994, 1996, 1997, 2001, 2003; Ghavidel-Syooki et al. 2011; Spina, Stephenson, et al. 2018). Recent palynological data, obtained by Ghavidel-Syooki and Vecoli (2008), Ghavidel-Syooki (2019) and an Italian–Iranian bilateral project between the Arianzamin Pars Geological Centre (Tehran, Iran) and the University of Perugia (Italy) focused on the Zagros Basin, have improved the knowledge of the stratigraphy of the lower Palaeozoic successions, mainly of the Miaolingian and Furongian (middle-upper Cambrian), Mila and Ilbeyk formations cropping out over large areas in southern Iran.

The present study provides new palynological data based on acritarch assemblages from the Mila and Ilbeyk formations, well exposed in the Chalisheh, Ghalikuh and Oshtorankuh localities along the High Zagros Thrust (Figure 1a, b). These well-preserved and diverse palynological assemblages are evaluated in terms of their chronostratigraphical significance, providing – together with the palynozones proposed by Ghavidel-Syooki and Vecoli (2008) and Ghavidel-Syooki (2019) in other coeval sections – a detailed lower Palaeozoic biostratigraphy of the Zagros Basin and improving the understanding of palaeobiogeographical value of the Miaolingian and Furongian acritarch microflora.

2. Geological setting

The Palaeozoic Middle East terranes, according to most authors (e.g. Cocks and Torsvik 2002; Gaetani et al. 2005, 2013; Ruban et al. 2007), are characterised by different major tectonic units. Among these are the Alborz Range, Central Iran and the Sanandaj–Sirjan Block (Figure 1a). This latter was separated from the Zagros Basin by a branch of the Permian Neotethys oceanic basin (e.g. Zanchi et al. 2009). The Zagros Basin (about 2000 km in length and 250 km in width; see Figure 1a, b) extends from southeastern Turkey through northern Syria and Iraq to western and southwestern Iran. During the Precambrian and through the Palaeozoic, it was part of the Arabian Plate (Beydoun 1988; Ghorbani 2019). This basin displays outcrops of late Precambrian to Neogene sedimentary successions. Palaeozoic to Cretaceous successions reach a thickness of more than

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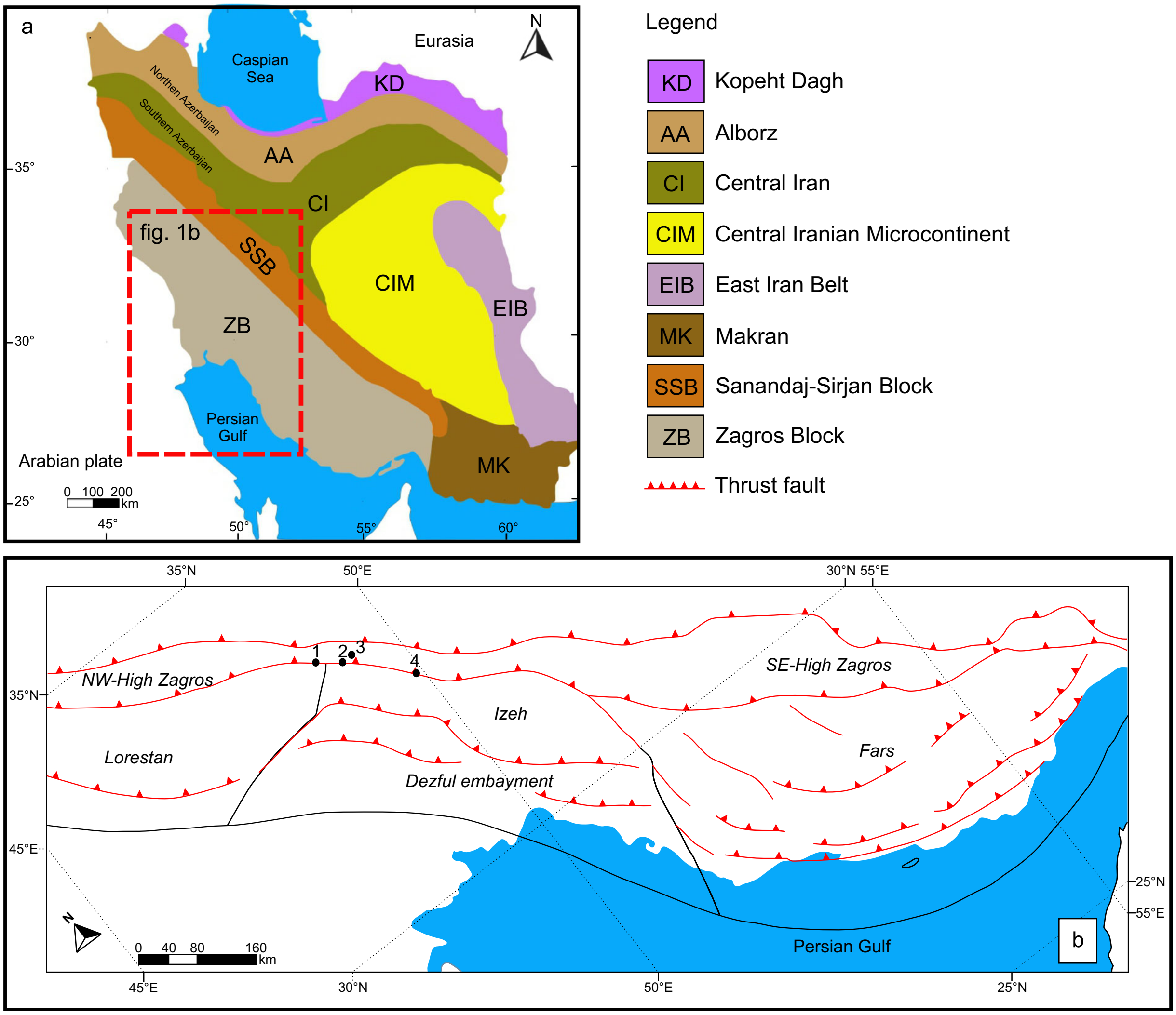

Figure 1. Figure 1. (a) Location map and main substructural units of Iran (modified and redrawn from Alavi 1991). (b) Location map with structural domains in the Zagros Basin (modified and redrawn from Madani-Kivi and Zulauf 2015) of the (1) Oshtorankuh, (2) Chalisheh and (3) Ghalikuh stratigraphical sections studied herein, and (4) the Tang-e-Ilbeyk stratigraphical section studied by Ghavidel-Syooki and Vecoli (2008) and Ghavidel-Syooki (2019).

14 km in the Zagros part of the Arabian Plate, deposited over the Neoproterozoic igneous and metamorphic rocks of the basement. This considerable thickness could be the result of a long phase of rifting and subsidence of the Afro-Arabian plate margin (Berberian and King 1981; Motiei 1993; Bahroudi and Talbot 2003; Stern and Johnson 2010). The Palaeozoic stratigraphy (Figure 2a) of the Zagros area has been described in detail in the geological literature (e.g. James and Wynd 1965; Setudehnia 1972; Koop and Stoneley 1982; Motiei 1993; Ghavidel-Syooki 2003; Alavi 2004; Ghavidel-Syooki et al. 2011; Zoleikhaei et al. 2015; Spina, Stephenson, et al. 2018). The oldest sedimentary succession is the Hormuz Formation of late Precambrian age, deposited in a syn-rift evaporitic basin. The Terreneuvian to Series 2 (lower Cambrian; Soltanieh, Barut, Zaigun and Lalun) formations consist of transgressive shallow marine (Soltanieh and Barut formations) to post-rifting transitional and continental (fluvial) siliciclastic deposits (Zaigun and Lalun formations; Heydari 2008; Ghorbani 2019). The red arkosic sandstones of the Lalun Formation extend across most of the Iranian Plateau and are overlain by the Miaolingian to Furongian (middle to upper Cambrian) marine deposits of the Mila Formation. This latter is characterised by dolostones, shales and limestones, and reaches a thickness of 585 m in its type section, close to Mila Kuh area in the eastern Alborz range (Stöcklin et al. 1964). The Mila Formation is well exposed in the Lorestan domain of the Zagros Basin (Figure 1a, b) where it has been divided into three members: A, B, and C (Setudehnia 1975). Member A is barren of fossils and in general characterised by dolostones with interbedded shales. Member B is also unfossiliferous and mainly consists of shales and siltstones with dolostone interlayers in the middle part. The overlying Member C is abundantly fossiliferous and characterised by shales, sandstones and limestones. Setudehnia (1975) attributed this member to the late Cambrian on the basis of brachiopod and trilobite faunas. Ghavidel-Syooki and Vecoli (2008) assigned a Miaolingian to early Furongian (middle to early late Cambrian) age on the basis of acritarch assemblages. Despite the absence of fossils, the members A and B were attributed, respectively, to the

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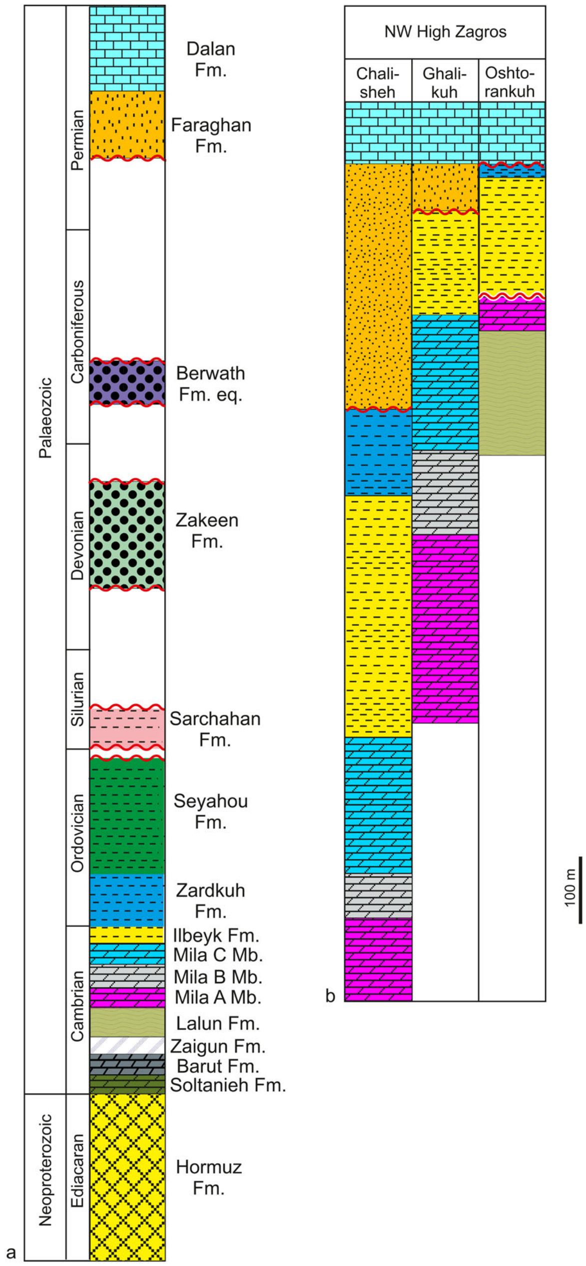

Figure 2. (a) General lithostratigraphical chart for the Palaeozoic successions belonging to the Zagros Basin (modified and redrawn from Spina et al. 2018a). (b) Lithostratigraphical logs of the studied Palaeozoic successions.

'early-middle Cambrian' and 'middle Cambrian' based on their stratigraphical position below member C (Setudehnia 1975; Ghavidel-Syooki and Vecoli 2008; Ghavidel-Syooki 2019; Ghorbani 2019). According to Lasemi (2001), the Mila Formation was deposited in a shallow marine to outer ramp environment. The conformably overlying Ilbeyk Formation consists of shales and sandstones with scattered limestone intervals and it was deposited in a setting spanning from a shoreface to a low-energy offshore environment. This formation was assigned to the Furongian (Setudehnia 1975; Ghavidel-Syooki and Vecoli 2008). It is conformably overglain by the Zardkuh Formation. In its type section (Tang-e-Ilbeyk in the Zardkuh area), the Zardkuh Formation comprises a lower member made up of shales and sandstones and an upper member dominated by shales with scattered sandstone intercalations. The Zardkuh Formation has been dated as early Tremadocian (Early Ordovician; Setudehnia 1975; Ghavidel-Syooki and Vecoli 2008). The lithology and sedimentary structures of the Zardkuh Formation point to a siliciclastic shoreface environment, deposited during sea-level lowstand conditions (Ghavidel-Syooki et al. 2014; Ghorbani 2019).

3. Stratigraphy of the studied successions

The studied Chalisheh, Galikuh and Oshtorankuh successions crop out along the High Zagros Thrust in the Lorestan Domain (Figure 1b). Here, the lower Palaeozoic rocks were distinguished as the Lalun, Mila, Ilbeyk and Zardkuh formations (Figure 2b). The latter crops out only in the Chalisheh and Oshtorankuh sections. The Faraghan Formation, recently attributed to mid-Permian age (Guadalupian; Spina, Stephenson, et al. 2018) unconformably overlies the lower Palaeozoic units in the Chalisheh and Galikuh sections. In the Oshtorankuh section, the Faraghan Formation is absent and lower Palaeozoic units are unconformably overlain by the Guadalupian–Lopingian (mid—upper Permian) Dalan Formation. The Chalisheh, Galikuh and Oshtorankuh sections as well as all the Palaeozoic sequences of the Zagros Basin are generally distinguished by different major unconformities associated with hiatuses. They resulted from: (i) major sea-level drops linked to the end-Ordovician glaciation event (Ghavidel-Syooki 2011) and to the Carboniferous Southern Hemisphere glaciation (Golonka 2000); (ii) the mid-Silurian to Middle Devonian uplift of the northern Arabian Plate margin (a middle Palaeozoic event but not the Caledonian Orogeny), where the uplift may have taken place along the Palaeo-Tethys Ocean prior to, during or, probably, after the rifting (Ruban et al. 2007); (iii) the impact of the Hercynian orogeny occurring from the Late Devonian to the Carboniferous (Faqira et al. 2009). Nevertheless, in the Chalisheh, Galikuh and Oshtorankuh sections, only the pre-Permian unconformity is evident (Figure 2b).

3.1. Chalisheh section

The studied section is located to the north of Baznavid village (Aligoodarz area; 32°55′39″N, 49°31′18″E; Figures 1c, 2b, 3). In this area, the Mila Formation includes the Mila A, Mila B and Mila C members. The Mila A Member (123 m thick) consists of limestones (mainly mudstone and wackestone), micaceous shales, marly limestones and dolostones. The overlying Mila B Member (about 60 m thick), along the section, is covered by vegetation and its thickness can only be broadly estimated. Dolostones, shales, limestones (locally dolomitised) and sandy limestones characterise Member C. The Mila Formation is overlain by the Ilbeyk Formation, which is about 359 m thick and characterised by a sharp increase of shales; tabular thin-bedded and parallel laminated sandstones, locally with calcite cement (calcareous sandstones); and minor limestones with brachiopods.

The Ilbeyk Formation passes upwards to the Zardkuh Formation, which is about 128 m thick and the basal horizon

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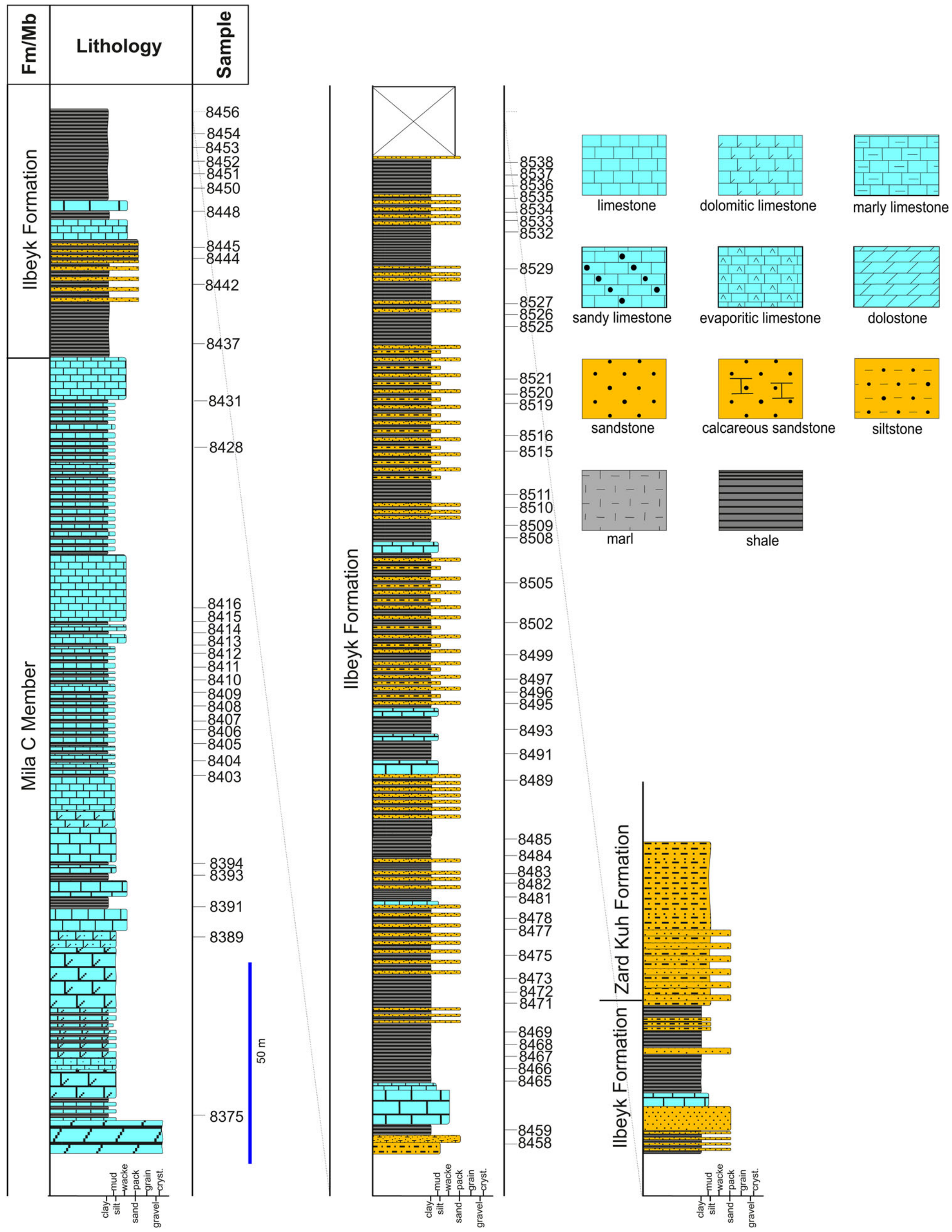

Figure 3. Lithostratigraphical log of the Chalisheh section. Only the palynologically productive samples were plotted.

of which consists mostly of siltstones, sandstones and rare shales. In the Chalisheh section, this horizon had been included previously in the Ilbeyk Formation (e.g. Ghavidel-Syooki 1993). Nevertheless, because it is dominated by sandstones and siltstones, it has recently been considered to be the basal part of the overlying Zardkuh Formation (Figure 2b; Ghorbani 2019).

3.2. Ghalikuh section

The studied succession is located in the Aligoodarz area near the Absefid waterfall (32°58′45.8″N, 49°36′48.8″E; Figures 1c, 2b, 4). In this area the Mila Formation includes all three members. The Mila A Member (280 m) is composed of dolostones and locally dolomitic limestones, muddy limestones, marls and minor marly limestones. Rare carbonate evaporitic levels are present in the basal portion. The Mila B Member (125 m) consists of a thick basal marly interval passing upwards to marls and muddy limestones. The Mila C Member (201 m) is characterised by an increase in marls and marly limestones alternating with mud-supported limestones with fine-grained siliciclastic intercalations. The Mila Formation passes upwards to the Ilbeyk Formation (about 156 m), showing an abrupt increase of siliciclastics composed of shales and sandstones, alternating with a few levels of calcareous sandstones, and limestones (mostly wackestone and packstone).

3.3. Oshtorankuh section

The studied section (33°13′25.7″N, 49°23′35.8″E; Figures 1c, 2b, 5) is located in the southwestern Aligudarz and

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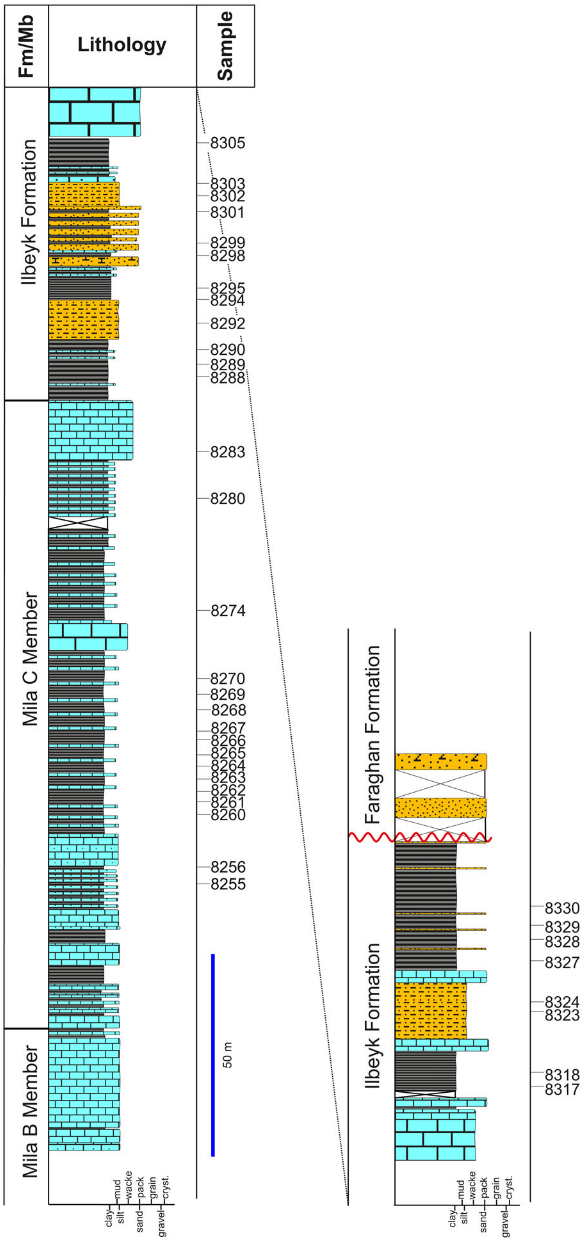

Figure 4. Lithostratigraphical log of the Galikuh section. Only the palynologically productive samples were plotted (for the legend see Figure 3).

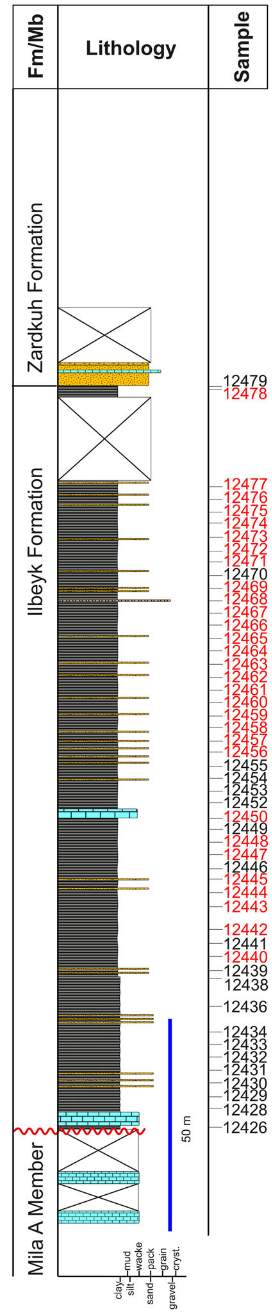

Figure 5. Lithostratigraphical log of the Oshtorankuh section. The palynologically unproductive samples are marked in red (for the legend see Figure 3).

northeastern Firuzabad villages. The stratigraphy of Palaeozoic successions in the Zagros Basin highlights different levels of erosion. In the Oshtorankuh area, a sedimentary hiatus has been recognised at the top of the Mila A Member which is unconformably overlain by the Ilbeyk Formation (Setudehnia 1975). The Mila A Member (52 m), overlying the red arkosic sandstones of the Lalun Formation (lower Cambrian), mainly consists of dolostones, subordinate limestones and very rare thin marly intervals. The overlying Ilbeyk Formation (176 m) is characterised mostly by shales with thin intercalations of sandstones and minor calcareous sandstones and rare limestones. The overlying Zardkuh Formation is almost entirely covered with vegetation and consists of a succession of only about 18 m, mostly composed of sandstone.

4. Material and methods

A total of 138 samples of 20 g each were studied. Samples 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-µm filter. No oxidation by Schultze's solution was performed to avoid modifying the thermal maturity of the organic matter (e.g. Spina, Vecoli, et al. 2018; Galasso et al. 2019; Schito et al. 2017; 2019). Organic residue rich in amorphous organic matter (AOM) was sieved 2–3 times with a 10-µm filter. Light microscope observations were performed on palynological slides using a Leica DM1000 microscope with differential interference

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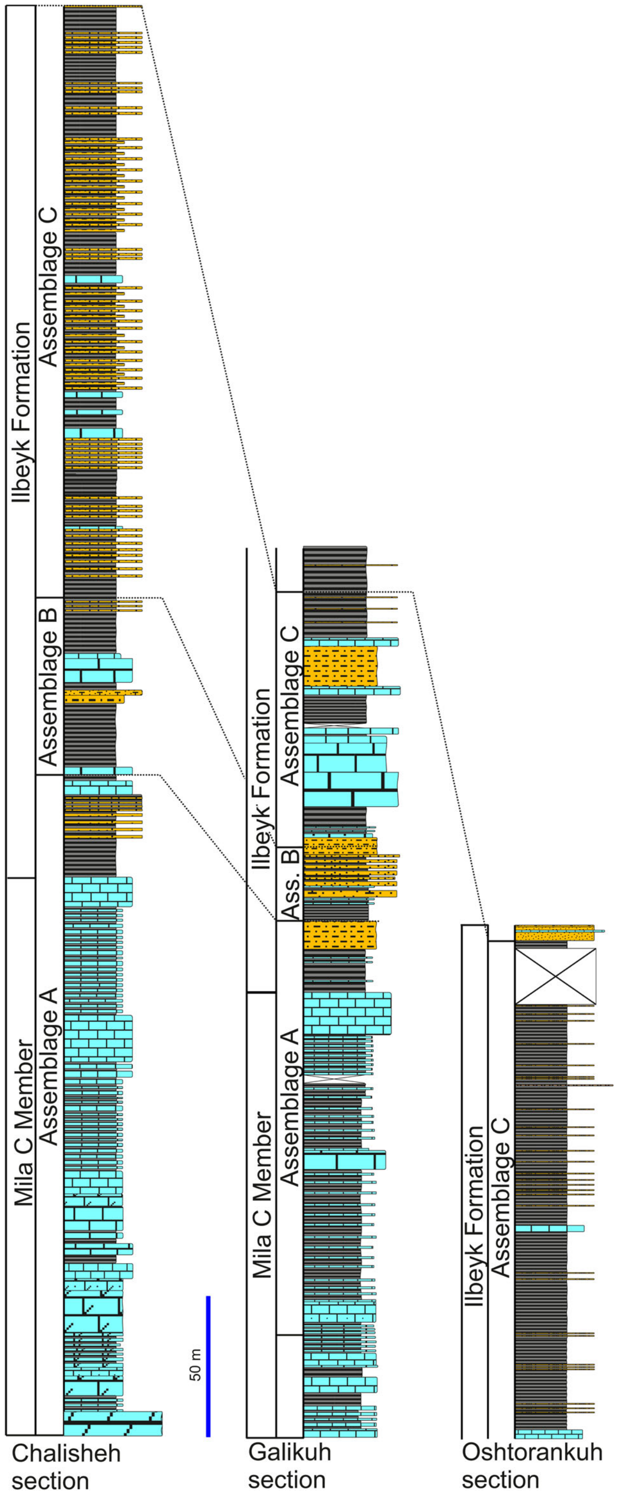

Figure 6. Correlations between the Chalisheh, Galikuh and Oshtorankuh sections, on the basis of the present palynozones.

contrast (DIC) techniques in transmitted light. The slides are stored in the palynological laboratories of the National Iranian Oil Company (NIOC, Rey Storage of Exploration Directorate, Hafez crossing, Taleghani Avenue, Tehran, Iran). Authors of the species names are given in the list of palynomorph species (Appendix 1) and in the plate descriptions. A short description of the palynomorph contents from each section is given in the following biostratigraphy section.

5. Biostratigraphy

5.1. Chalisheh section

The Mila members A and B are palynologically barren, while the Mila C Member and Ilbeyk Formation yielded a well-preserved and diverse microflora. Seventy-seven samples were palynologically productive: 22 from the Mila C Member and 55 from the Ilbeyk Formation (Table 1; Plates 1, 2). The microflora is generally well preserved and diverse. *Cristallinium dubium*, *Retisphaeridium ovillense*, *Symplassosphaeridium cambriense*, *Vulcanisphaera spinulifera* and *V. turbata* mark the lowest sampled level of the Mila C Member. These forms are recorded together with *Timofeevia lancariae*, *T. pentagonalis* and *T. phosphoritica*, which occur also in the middle and upper Mila C Member in an assemblage with *Cristallinium cambriense*. Other acritarchs, such as *Comasphaeridium silesiense*, *Granomarginata squamacea*, *Retisphaeridium dichamerum*, *R. lechistanium*, *Solisphaeridium flexipilosum* and *S. multiflexipilosum*, are also recognised. Several forms recorded from the Mila C Member, such as *T. pentagonalis*, *T. lancariae*, *T. phosphoritica* and *V. turbata*, range into the overlying Ilbeyk Formation. The lower part of the Ilbeyk Formation is marked by the first occurrence of *Leiofusa stoumonensis*. Moving upwards to the middle part of the Ilbeyk Formation, *C. randomense* and *Vulcanisphaera africana* first occur. Forms such as *C. cambriense* and *T. microretis* are present also in this part of the Ilbeyk Formation. In the upper part of the formation, *Cymatiogalea aspergillum*, *C. membranisipina*, *Dasydiacrodium obsonum*, *Dorsennidium mutabile*, *Impluviculus multiangularis*, *Lusatia dendroidea*, *Ninadiacrodium dumontii*, *Stelliferidium magnum* and *Trunculumarium revinium* occur. Almost all of these forms continue to be present also in the topmost Ilbeyk Formation.

5.2. Galikuh section

The Mila A and B members did not yield palynomorphs, but in the Mila C Member (16 samples) and the Ilbeyk Formation (20 samples) well-preserved palynological assemblages were found (Table 2; Plate 2). The basal part of the Mila C Member proved to be barren. In the middle part, *Solisphaeridium flexipilosum* is recorded only in one level. Other forms, such as *Timofeevia phosphoritica*, *T. lancariae* and *T. pentagonalis*, are also recognised in the middle-upper part of the Mila C Member and in the basal-middle Ilbeyk Formation where *Cristallinium cambriense*, *Stelliferidium* sp. cf. *gautieri*, *T. microretis*, *Trunculumarium revinium* and *Vulcanisphaera africana* first occur. The upper Ilbeyk Formation is marked by the presence of *Actinotodissus* spp., *A. ubui*, *Lusatia dendroidea*, *Ninadiacrodium caudatum* and *N. dumontii*.

5.3. Oshtorankuh section

The Mila A Member is palynologically barren, while of the 49 samples collected from the Ilbeyk Formation, 20 yielded well-preserved palynomorphs (Table 3; Plates 1, 2). *Cristallinium cambriense*, *C. randomense*, *Dorsennidium mutabile*, *Lusatia dendroidea*, *Ninadiacrodium dumontii*, *Retisphaeridium ovillense*,

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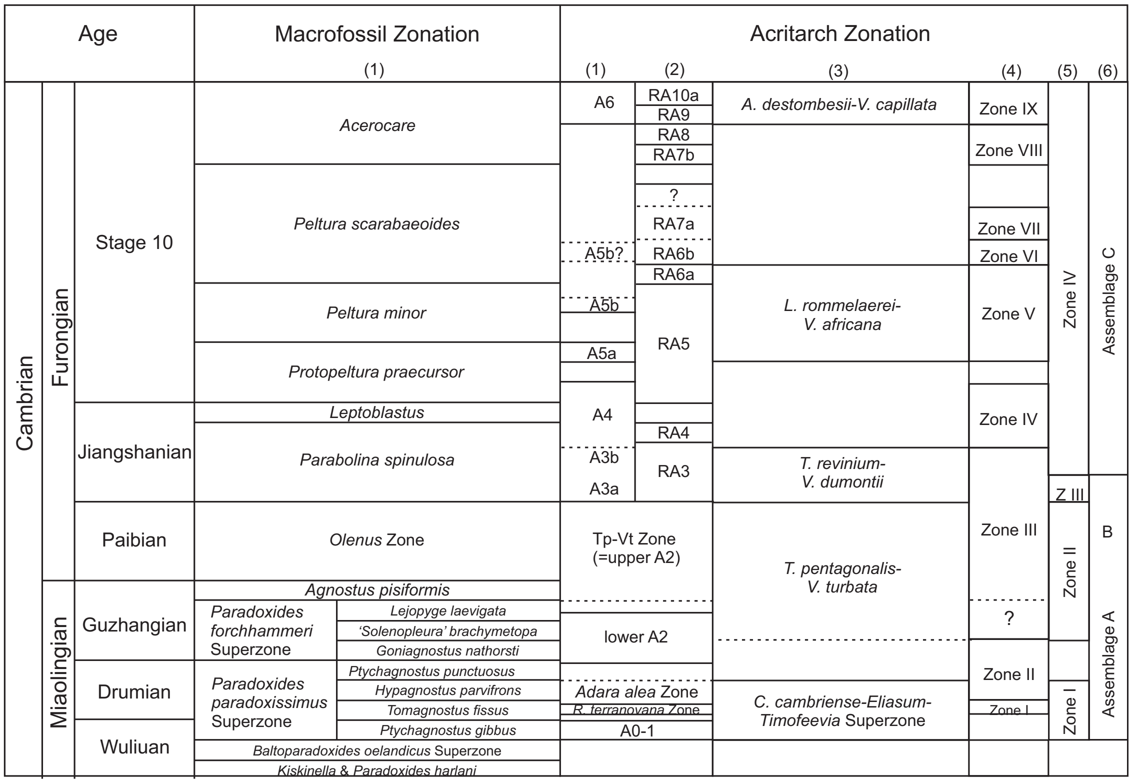

Figure 7. Chronostratigraphical correlation of the acritarch assemblages (modified from Rushton and Molyneux 2011) documented in the present study with the palynozones of Ghavidel-Syooki and Vecoli (2008) and Ghavidel-Syooki (2019), macrofossil zonation and previously described middle–upper Cambrian acritarch zonations. 1, Martin and Dean (1988); 2, Parsons and Anderson (2000); 3, Vanguestaine and Van Looy (1983); 4, Ghavidel-Syooki (2019); 5, Ghavidel-Syooki and Vecoli (2008); 6, this study.

Timofeevia phosphoritica, *Trunculumarium revinium* and *Vulcanisphaera africana* occur from the basal part of the formation upwards. Some of the forms are also recorded in the middle Ilbeyk Formation in an assemblage that includes *Cymatiogalea membranispina*, *Timofeevia microretis* and *Stelliferidium* sp. The occurrence of *Dasydacrodium obsonum* and *Ninadiacrodium caudatum* marks the top of the Ilbeyk Formation.

6. Discussion

The palynofloras recorded from the Mila C Member and from the Ilbeyk and Oshtorankuh formations in the Chalisheh, Galikuh and Oshtorankuh sections are well preserved and diverse, allowing some chronostratigraphical and palaeobiogeographical considerations.

6.1. Chronostratigraphical significance

Based on the vertical distribution of the recognised taxa, three acritarch assemblages are recognised (Figures 6, 7). Assemblage A occurs in the Mila C Member and in the basal part of the Ilbeyk Formation in both the Chalisheh and Galikuh sections. Assemblage B is recorded from the Ilbeyk Formation *pro parte (p.p.)*. in both the Chalisheh and Galikuh sections, whereas Assemblage C is present in the upper Ilbeyk Formation in all three sections. In the Oshtorankuh section, due to the hiatus between the Mila and Ilbeyk formations, marked by the absence of the Mila B and Mila C members and parts of the Ilbeyk Formation, only Assemblage C is recognised. The three acritarch assemblages are described below (Figure 7; Tables 1–3; Plates 1, 2).

6.1.1. Assemblage A

Occurrence: Chalisheh section: Mila C Member and Ilbeyk Formation *p.p.* (samples from the interval 8375 to 8448, extending through a thickness of 212 m). Galikuh section: Mila C Member and Ilbeyk Formation *p.p.* (samples from the interval 8255 to 8294, covering a thickness of 145 m).

Description: Assemblage A is characterised by the co-occurrence of *Timofeevia* spp. (i.e. *T. lancariae*, *T. pentagonalis*, *T. microretis* and *T. phosphoritica*) and *Comasphaeridium silesiense*, *Cristallinium cambriense*, *C. dubium*, *Granomarginata squamacea*, *Retisphaeridium dichamerum*, *R. lechistanium*, *R. ovillense*, *Solisphaeridium flexipilosum*, *S. multiflexipilosum*, *Symplassosphaeridium cambriense*, *Vulcanisphaera spinulifera* and *V. turbata*. The top of this zone coincides with the base of the succeeding Assemblage B.

Distribution: Assemblage A shows close similarities to the Miaolingian Acritarch Assemblage Zones I and II of Ghavidel-Syooki and Vecoli (2008) in the Mila C Member, cropping out in the Zardkuh area (Tang-e-Ilbeyk section) of the Zagros Basin and attributed to the Wuliuan–Drumian and Guzhangian–Paibian, respectively (Figure 7). Assemblage A shares acritarchs such as *Retisphaeridium dichamerum* with Acritarch Assemblage Zone I and *Timofeevia lancariae*, *T. pentagonalis*, *T. microretis*, *T. phosphoritica* and *Vulcanisphaera*

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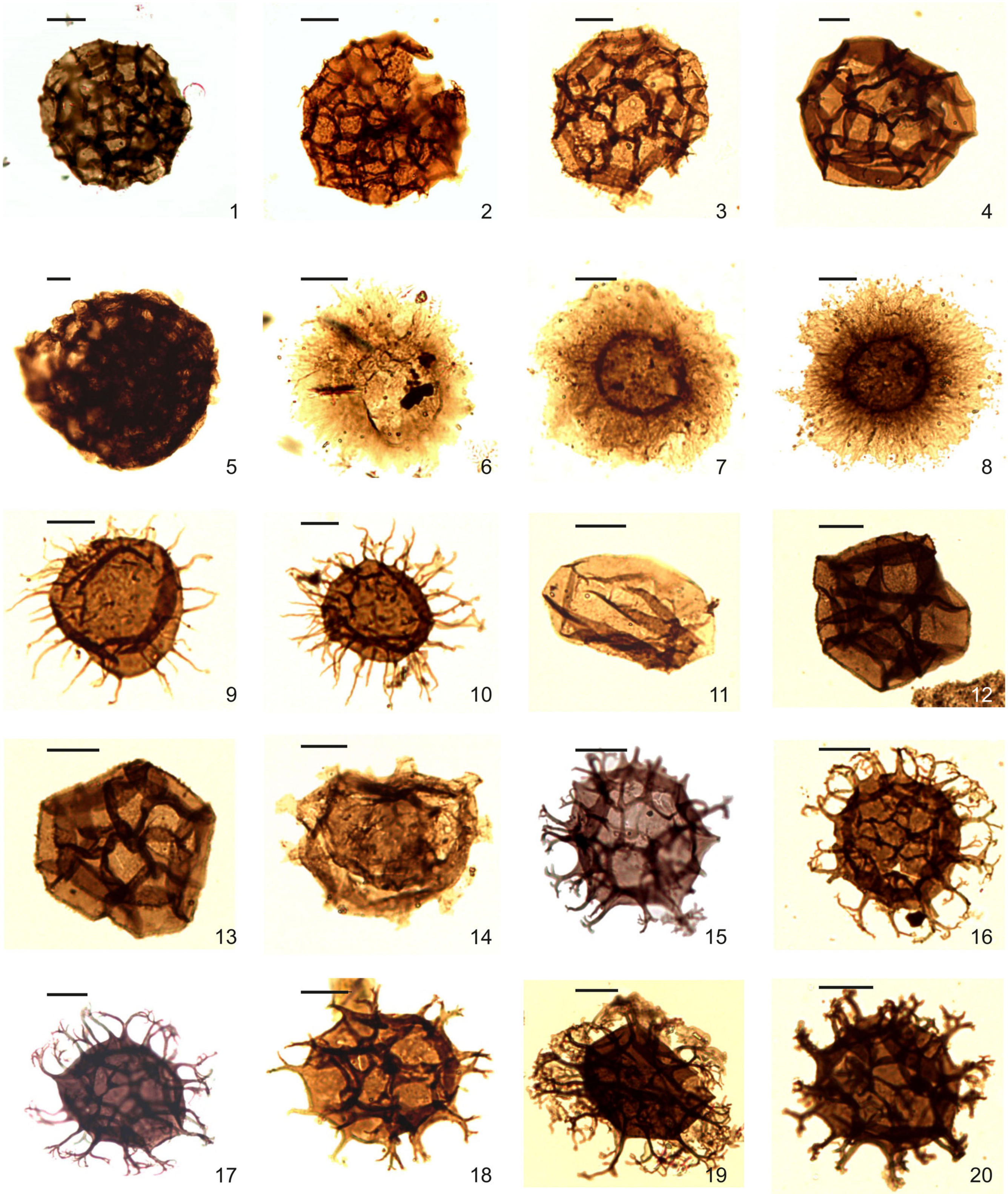

Plate 1. Acritarchs from the studied sections. Scale bars: 10 µm. 1. *Retisphaeridium ovillense* (Cramer & Díez 1972) Vanguestaine 2002 (Chalisheh section, slide 8375), 2. *Cristallinium dubium* Volkova 1990 (Chalisheh section, slide 8375), 3. *Cristallinium randomense* Martin in Martin & Dean 1981 emend. Martin in Martin & Dean 1988 (Chalisheh section, slide 8508), 4, 12, 13. *Cristallinium cambriense* (Slavíková 1968) Vanguestaine 1978 (Chalisheh section, 4: slide 8499; 12: slide 8391; 13: slide 8403), 5. *Symplassosphaeridium cambriense* (Slavíková 1968) Palacios 2015 (Chalisheh section, slide 8375), 6. *Comasphaeridium strigosum* (Jankauskas & Posti 1976) Downie 1982 (Chalisheh section, slide 8391), 7. *Granomarginata squamacea* Volkova 1968 (Chalisheh section, slide 8391), 8. *Comasphaeridium silesiense* Moczydłowska 1998 (Chalisheh section, slide 8393), 9. *Solisphaeridium flexipilosum* Slaviková 1968 emend. Moczydłowska 1998 (Chalisheh section, slide 8403), 10. *Solisphaeridium multiflexipilosum* Slaviková 1968 emend. Moczydłowska 1998 (Chalisheh section, slide 8403), 11. *Eliasium* sp. (Chalisheh section, slide 8391), 14. *Multiplicisphaeridium* sp. cf. *eopiriferum* Fombella 1978 (Chalisheh section, slide 8452), 15, 18. *Timofeevia phosphoritica* Vanguestaine 1978 (Chalisheh section, 15: slide 8375; 18: slide 8416), 16. *Timofeevia lancariae* (Cramer & Díez 1972) Vanguestaine 1978 (Chalisheh section, slide 8393), 17. *Timofeevia pentagonalis* (Vanguestaine 1974) Vanguestaine 1978 (Chalisheh section, slide 8375), 19. *Timofeevia microretis* Martin in Martin & Dean 1981 (Chalisheh section, slide 8456), 20. *Timofeevia* sp. (Chalisheh section, slide 8450).

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Plate 2. Acritarchs from the studied sections. Scale bars: 10 µm. 1. *Vulcanisphaera spinulifera* (Volkova 1990) Parsons & Anderson 2000 (Chalisheh section, slide 8375), 2, 3. *Vulcanisphaera turbata* Martin in Martin & Dean 1981 (2: Chalisheh section, slide 8375; 3: Oshtorankuh section, slide 12428), 4, 5. *Vulcanisphaera africana* Deunff 1961, (4: Chalisheh section, slide 8489; 5: Oshtorankuh section, slide 12426), 6. *Stelliferidium magnum* Palacios in Palacios et al. 2009 (Chalisheh section, slide 8526), 7. *Trunculumarium revinium* (Vanguestaine 1973) Loeblich & Tappan 1976 (Chalisheh section, slide 8499), 8. *Impluviculus multiangularis* (Umnova in Umnova & Fanderflit 1971) Volkova 1990 (Chalisheh section, slide 8496), 9. *Ninadiacrodium dumontii* (Vanguestaine 1973) Raevskaya & Servais 2009 (Chalisheh section, slide 8499), 10. *Dorsennidium mutabile* (Di Milia et al. 1989) Sarjeant & Stancliffe 1994 (Chalisheh section, slide 8511), 11. *Dasydiacrodium obsonum* (Chalisheh section, slide 8505), 12. *Cymatiogalea aspergillum* Martin in Martin & Dean 1988 (Chalisheh section, slide 8512), 13. *Leiofusa stoumonensis* Vanguestaine 1973 (Chalisheh section, slide 8453), 14. *Lusatia dendroidea* Burmann 1970 emend, Albani et al. 2007 (Chalisheh section, slide 8508), 15, 17. *Actinotodissus achrasii* (Martin 1972) Yin 1986 (Oshtorankuh section, slide 12433; Chalisheh section, slide 8510), 16. *Actinotodissus ubui* (Martin 1969) Fensome, Williams, Barss, Freeman & Hill 1990 (Oshtorankuh section, slide12439), 18. *Cymatiogalea membranispina* Deunff 1961 (Chalisheh section, slide 8496), 19. *Vulcanisphaera* sp. (Galikuh section, slide 8298).

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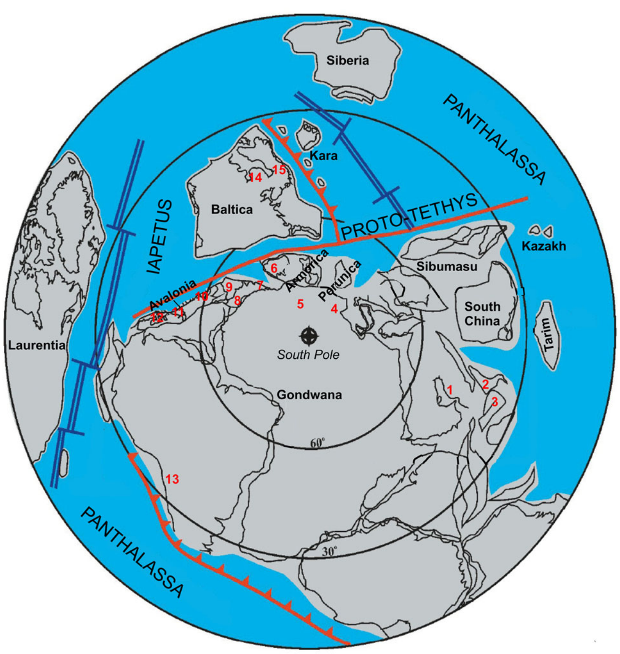

Figure 8. Global palaeogeographical map of late Cambrian (modified and redrawn from Cocks and Torsvik 2002; Berra and Angiolini 2014): 1, study area (Zagros Basin); 2, Alborz; 3, central Iran; 4, Tunisia; 5, Algeria; 6, Spain; 7, Poland; 8, Belgium and northern France; 9, England and Wales; 10, Ireland; 11, eastern Newfoundland; 12, New Brunswick; 13, Eastern Cordillera (northwestern Argentina); 14, Sweden; 15, northern Norway.

turbata with Acritarch Assemblage Zone II. In a recent palynological study from the Mila C Member in the same Tang-e-Ilbeyk section, Ghavidel-Syooki (2019) observed that Acritarch Assemblage Zone I from the basal Mila C Member is marked by the first appearance datum (FAD) of *R. ovillense*, *R. dichamerum* and *T. lancariae* and that Acritarch Assemblage Zone II from the middle–upper Mila C Member is characterised by the FAD of *C. cambriense* and *S. cambriense*. The acritarch assemblage zones were attributed to the early Drumian and Drumian–early Guzhangian. Moreover, Ghavidel-Syooki (2019) recorded the FAD of *T. phosphoritica* and *T. pentagonalis* as marking the base of Acritarch Assemblage Zone III, obtained from the topmost Mila C Member and the basal Ilbeyk Formation and attributed to the Guzhangian–early Jiangshanian. Acritarch taxa recorded from Assemblage A of the present study share some characteristics with Miaolingian and Furongian acritarch suites documented from several localities worldwide, such as North Africa (e.g. Vanguestaine and Van Looy 1983; Albani et al. 1991; Vecoli 1999), Belgium and France (Ribecai and Vanguestaine 1993), the East European Platform (Volkova 1990), Spain (Palacios 2015) and Canada (Martin and Dean 1988; Parsons and Anderson 2000; Palacios et al. 2017). Acritarchs such as *C. cambriense*, *T. lancariae* and *T. phosphoritica* were recorded in the *Cristallinium cambriense–Eliasium/Timofeevia* Superzone (Cc-ET) of late Wuliuan–middle Drumian age, and taxa such as *T. pentagonalis*, *T. microretis* and *V. turbata* occurred in the *Timofeevia pentagonalis–Vulcanisphaera turbata* (Tp-Vt) Zone of Guzhangian–Paibian age, documented in a section that was independently dated with trilobites, in the High Atlas Mountains of Morocco (Vanguestaine and Van Looy 1983; Figure 7).

Other species recorded in the Iranian Assemblage A, such as *Retisphaeridium dichamerum*, occur in Miolingian deposits of Canada, in eastern Newfoundland (Martin and Dean 1988), in western Canada including southern Alberta (Staplin et al. 1965) and in Furongian strata of Nova Scotia (Palacios et al. 2012). *Comasphaeridium silesiense* was documented in the Miolingian of Baltica, with its first appearance in the *Paradoxides oelandicus* Zone (e.g. Moczydłowska 1998; Jachowicz-Zdanowska 2013), in Spain (Palacios 2008), and in New Brunswick, Canada (Association 2 of Palacios et al. 2017). *Retisphaeridium lechistanium* was reported from the Miaolingian of Poland (Jachowicz-Zdanowska 2013) and of Canada in an assemblage that also includes *R. dichamerum* (Association 3 in Palacios et al. 2017). This latter form occurs with *C. silesiense* in the IMC 1 (Iberian Middle Cambrian) Zone, along the *Paradoxides asturianus* Zone and the base of the *Badulesia tenera* Zone, defined in the Vallehondo Formation, southern Spain (Palacios et al. 2006; Palacios 2008, 2015). The IMC1 Zone has been considered to have great potential to globally establish the lower boundary of the Wuliuan (Mialongian; Palacios 2015). The overlying IMC2 Zone is marked by the first occurrence of *C. cambriense*, in an assemblage that contains *Solisphaeridium flexipilosum* and *S. multiflexipilosum* (Palacios 2015). This zone partially corresponds to the *Badulesia* Zone, which base has been correlated by the author with the FAD of *Ptychagnostus atavus* in the Drumian Global Stratotype Section and Point (GSSP; e.g. Fletcher 2006; Babcock et al. 2007; Palacios 2015). The long-ranging species *Cristallinium cambriense* also occurs together with *Granomarginata squamacea* within the *Cristallinium cambriense–Heliosphaeridium nodosum–Globosphaeridium cerinum* Zone from the Kaili Formation (China) in the GSSP section for the Miaolingian Series and Wuliuan Stage, belonging to the *Oryctocephalus indicus* and *Perononpsis taijiangensis* trilobite zones (Yin et al. 2010; Zhao et al. 2019).

On the basis of the acritarch occurrences, the Iranian Assemblage A belonging to the Mila C Member and to the basal Ilbeyk Formation can tentatively be attributed to the Miaolingian (late Wuliuan–Guzhangian; Figure 7).

6.1.2. Assemblage B

Occurrence: Chalisheh section: Ilbeyk Formation *p.p.* (samples from the interval 8450 to 8471, extending through a thickness of 112 m). Galikuh section: Ilbeyk Formation *p.p.* (samples from the interval 8295 to 8302, covering a thickness of 34 m).

Description: Assemblage B is marked by the first occurrence of *Leiofusa stoumonensis* and *Multiplicisphaeridium* sp. cf. *eopiriferum*. Several forms present in the underlying Assemblage A, identified as *Symplassosphaeridium cambriense*, *Timofeevia lancariae*, *Timofeevia phosphoritica*, *Timofeevia microretis* and *Timofeevia* spp., are also abundantly recorded in Assemblage B. *Cristallinium cambriense*, *Retisphaeridium ovillense* and *Timofeevia pentagonalis* are documented only in the lower part of the assemblage. However, other taxa present in Assemblage A, identified as *Comasphaeridium silesiense*, *Granomarginata squamacea*, *Retispaheridium dichamerum*, *R. lechistanium*, *Solisphaeridium*

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flexipilosum, *S. multiflexipilosum*, *Vulcanisphaera spinulifera* and *V. turbata*, disappear. The top of this zone corresponds to the base of the overlying Assemblage C.

Distribution: Assemblage B is rather similar in composition to Acritarch Assemblage Zone III of Ghavidel-Syooki and Vecoli (2008), attributed to the early Furongian. Recently, Ghavidel-Syooki (2019) documented the FAD of *L. stoumonensis* at the base of Acritarch Assemblage Zone III in an assemblage with *V. turbata*, *T. pentagonalis*, *T. phoshoritica* and *Trunculumarium revinium*, from the last 55 m of the Mila C Member and the basal Ilbeyk Formation. The interval contains abundant skeletonised invertebrate fauna of late Cambrian age (Ghavidel-Syooki 2019). In the text (p. 339–340) the author claimed that Acritarch Assemblage Zone III is probably correlatable, at least in part, with the upper A2 to A3 (Martin and Dean 1988; Parson and Anderson 2000), the VK I to VK 2B acritarch zone of Russian workers (Molyneux et al. 1996; Volkova 1990; Volkova and Kirjanov 1995) and *V. turbata–T. phosphoritica* to *N. dumontii–T. revinium* assemblage zones of Newfoundland in Canada (Vanguestaine and Van Looy 1983), Russia and Morocco, respectively.

Accordingly, on the basis of the above-mentioned correlations, Ghavidel-Syooki (2019) attributed Acritarch Assemblage Zone III to the early Furongian. On the other hand, in his Table 3, Ghavidel-Syooki (2019, p. 338) placed the base of Zone III within the upper Lower A2 Zone of Martin and Dean (1988), consequently considering the FAD of *L. stoumonensis* to be of Guzhangian age.

Nevertheless, the stratigraphical range of *L. stoumonensis* is generally confined to the Furongian. This species occurs in eastern Newfoundland from the uppermost part of the upper A2 Zone along the *Olenus* to *Parabolina spinulosa* trilobite zones (Martin and Dean 1988; Parsons and Anderson 2000; Figure 7), and in levels of probably similar age in Belgium (Ribecai and Vanguestaine 1993) and Spain (Palacios 2015). Additionally, *L. stoumonensis* was recorded in an assemblage with *Multiplicisphaeridium* sp. cf. *eopiriferum*, *Cymatiogalea aspergillum*, *V. turbata*, *T. pentagonalis* and *T. phoshoritica* from the Furongian (close to the Paibian–Jiangshanian boundary) of the Ffestiniog Flags Formation in North Wales (UK; Young et al. 1994). A similar microflora marked by the occurrence of *L. stoumonensis* associated with *Multiplicisphaeridium* sp. cf. *eopiriferum*, *Ninadiacrodium dumontii* and *Timofeevia* spp. was documented in the Furongian of Oman (Molyneux et al. 2006). Other acritarch taxa, such as *Cristallinium cambriense* and *Timofeevia* spp., are abundant in Assemblage B. They are cosmopolitan and long ranging, spanning from the Cambrian to the Early Ordovician (e.g. Martin and Dean 1988; Moczydłowska 1998; Vecoli 1996, 1999; Vanguestaine 2002). Assemblage B is here considered coeval with Acritarch Assemblage Zone III of Ghavidel-Syooki and Vecoli (2008) and consequently attributed to the early Furongian (Jiangshanian; Figure 7).

6.1.3. Assemblage C

Occurrence: Chalisheh section: Ilbeyk Formation *p.p.* (samples from the interval from 8472 to 8536, extending through a thickness of 200 m). Galikuh section: Ilbeyk Formation *p.p.* (samples from the interval from 8303 to 8330, covering a thickness of 82 m). Oshtorankuh section: Ilbeyk Formation *p.p.* (samples from the interval from 12426 to 12479, covering a thickness of 178 m).

Description: Cristallinium randomense, *Vulcanisphaera africana*, *Lusatia dendroidea*, *Ninadiacrodium dumontii* and *Dorsennidium mutabile* are abundant in this assemblage. *Trunculumarium revinium* has its first occurrence close to the base of Assemblage C in both the Oshtorankuh and Galikuh sections, and in the middle part of the Chalisheh section. *Cymatiogalea aspergillum*, *C. membranispina* and *Dasydiacrodium obsonum* were recorded from the middle–upper part of the assemblage. This interval is also marked by an evident diversification of the acritarch genera *Actinotodissus* (e.g. *Actinotodissus* spp., *A. achrasiii*, *A. ubui*) and *Stelliferidium* (e.g. *Stelliferidium* spp., *S. gautieri*, *S. barbarum*, *S. stelligerum*, *S. magnum*). Other taxa, including *Impluviculus multiangularis*, *Ninadiacrodium caudatum*, *Dasydiacrodium obsonum*, *C. cambriense*, *T. lancariae*, *T. microretis*, *T. phosphoritica* and *V. turbata*, found in the underlying Assemblage B continue to be present.

Distribution: This assemblage is characterised by acritarch taxa that are chronostratigraphically relevant and attributed to the Furongian in different localities worldwide. The assemblage shows marked similarities to Acritarch Assemblage Zone IV of Ghavidel-Syooki and Vecoli (2008) and Acritarch Assemblage Zones IV to IX of Ghavidel-Syooki (2019), being similarly defined by the inception of acritarchs such as *A. achrasii*, *C. randomense*, *C. bellicosa*, *C. membranispina*, *N. caudatum*, *D. obsonum*, *I. multiangularis*, *T. revinium*, *V. africana*, *L. dendroidea* and *N. dumontii*. The last species is considered an excellent biostratigraphical marker for the latest Cambrian (e.g. Servais et al. 2007, Raevskaya and Servais 2009). In several palaeogeographical areas, *N. caudatum*, *D. obsonum*, *C. randomense*, *T. revinium* and *N. dumontii* occur in the *Parabolina spinulosa* to *Acerocare* zones, in late Furongian successions (Raevskaya and Servais 2009, text-figure 2). Such assemblages were recorded in eastern Newfoundland (acritarch zones A3–A5: Martin and Dean 1988; acritarch palynofloras RA5–RA7: Parsons and Anderson 2000), in Morocco (acritarch zone 7: Vanguestaine and Van Looy 1983), and in Belgium and France ('Stoumont assemblage' and acritarch Zone 5: Ribecai and Vanguestaine 1993; Vanguestaine 2002). A similar microflora was found the Furongian *Peltura scarabaeoides* Zone in Sweden (Di Milia et al. 1989). Elements of Assemblage C were also documented in other localities lacking direct trilobite control. More recently, in the Comley area, Shropshire (England), Potter et al. (2012) recorded *C. cambriense*, *C. randomense*, *C.* aff. *aspergillum*, *D. obsonum*, *N. caudatum*, *N. dumontii*, *T. phosphoritica*, *T. revinium*, *V. africana* and *V. turbata* and compared this microflora with a trilobite-controlled succession dated as Furongian (i.e. the *P. spinulosa* Subzone of the *P. spinulosa* Zone; Janshanian age: Parsons and Anderson 2000) in eastern Newfoundland. Other forms, such as *D. obsonum*, were recorded from the Furongian succession of northeastern China (Martin 1993), in assemblages with *N. dumontii* in northern Spain (Albani et al.

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2006), and also in assemblages including *N. caudatum* from Estonia (Paalits 1992) and Arctic Russia (Moczydłowska and Stockfors 2004; Raevskaya and Servais 2009). *N. caudatum* also occurs in the Furongian of the East European Platform (Volkova 1990), of southern Tunisia (Vecoli 1999), together with *V. africana*, and of Sardinia (Ribecai et al. 2005), together with *N. dumontii*. On the basis of correlations with acritarch assemblages from different localities around the world, some of which are independently dated with trilobites, there is sufficient justification for an assignment of the Iranian Assemblage C to the Furongian.

6.2. Palaeobiogeographical considerations

During the Cambrian, most palaeocontinents were assembled in the southern hemisphere (Cocks and Torsvik 2002; Torsvik and Cocks 2009; Berra and Angiolini 2014; Figure 8). Gondwana was the largest continental block, which extended from current-day Australia (positioned near the equator) to North Africa (positioned on the South Pole) and was separated by the Iapetus Ocean from Laurentia. Baltica was an independent continent, located at intermediate latitudes, whereas smaller terranes or terrane assemblages, such as Perunica, Avalonia or Armorica, were parts of Gondwana or were located in its periphery (Servais and Sintubin 2009). Sibumasu, as well as Tarim and North and South China, all bordered Gondwana at mid to high southern palaeolatitudes (Figure 8). Iran was also a part of this Gondwanan margin, at least during part of the early Palaeozoic (e.g. Berberian and King 1981; Lasemi 2001; Muttoni et al. 2009; Torsvik and Cocks 2009). During the Cambrian, the different tectonostratigraphical units of Iran (i.e. Zagros, Alborz and Central Iran basins) were possibly different terranes near the Gondwanan margin, and thus can be considered ‘peri-Gondwanan’ terranes, positioned in intermediate to tropical palaeolatitudes (Figure 8).

The palaeogeographical utility of acritarchs has been recognised for several decades, with the first models of acritarch distribution in the Silurian (e.g. Cramer 1968) and in the Ordovician (e.g. Cramer and Díez 1972; Vavrdová 1974; Li 1987; Vecoli 1999). Although several authors considered that acritarchs are planktonic and consequently not specifically helpful for palaeogeography (e.g. Fortey and Cocks 1992, 2003; Cocks and Verniers 2000), it has been demonstrated that acritarchs and chitinozoans may be as useful as trilobites or brachiopods for palaeobiogeographical considerations (Servais et al. 2005). Recent palaeobiogeographical reconstructions of acritarch provinces (e.g. Servais et al. 2003; Molyneux et al. 2013) clearly indicate that acritarch assemblages are not primarily arranged according to palaeolatitudes, simply following palaeotemperature belts, as assumed by authors working on benthic marine invertebrates (e.g. Fortey and Meilish 1992). Palaeobiogeographical provinces of organic-walled microphytoplankton (acritarchs) basically follow continental margins, similar to modern phytoplankton (Servais et al. 2003). More recently, Molyneux et al. (2013) reviewed the published data and interpretations related to Cambrian to Devonian microphytoplankton palaeobiogeography. These authors pointed out that acritarch distribution patterns can be attributed to palaeolatitude, palaeotemperature, oceanic circulation, continental positions and distal-proximal settings, as well as sedimentary environments and facies. Molyneux et al. (2013) also noted that during the early Palaeozoic, phytoplankton assemblages show varying degrees of cosmopolitanism and endemism through time.

Evidence for acritarch provincialism during the early and middle Cambrian is lacking so far, as the assemblages from most parts of the world are reported to be taxonomically comparable (e.g. Moczydłowska 1991, 1998). Moczydłowska (1998) considered that the most uniform global distribution of Cambrian acritarch assemblages occurred during the later part of the Miolingian, during a maximum flooding event. For the upper part of the Cambrian, the most detailed revision of acritarch palaeobiogeography was provided by Ghavidel-Syooki and Vecoli (2008).

During the Miaolingian and Furongian, some of the most common genera, such as *Timofeevia* and *Vulcanisphaera*, are recorded mostly from high-latitude regions, but they are known from almost all regions, clearly showing a global distribution and a general cosmopolitanism (see e.g. Kroeck et al. 2020). Figure 8 indicates the position of the study area in a palaeogeographical reconstruction, together with the position of other Iranian terranes, and localities from other parts of the margin of Gondwana from which late Cambrian acritarch assemblages have been reported, including Tunisia, Algeria, Spain, Poland, Belgium and northern France, England and Wales, Ireland, eastern Newfoundland, New Brunswick, and Argentina. The assemblages from all these localities are very similar in composition, although the taxonomic nomenclature, in particular at the the species level, very often differs, which is mainly due to taxonomic splitting. Ghavidel-Syooki and Vecoli (2008) pointed out that the assemblages from Laurentia and Kolguev Island (southeastern Barents Sea, plotted on the Baltica continent by Molyneux et al. 2013, figure 23.3) are least similar to most other regions. The present study seems to confirm the high ubiquitous value of the middle–upper Cambrian acritarch microflora: genera such as *Timofeevia*, *Vulcanisphaera*, *Ninadiacrodium* and *Lusatia* abundantly recorded in the A, B and C assemblages were also documented not only in Gondwana but also in Baltica and in the countries belonging to the Avalonia microcontinent in the Ordovician. Accordingly, future, more detailed studies, including detailed taxonomic revisions (including synonomies of species names) of the acritarch taxa present, are needed to better understand the palaeobiogeographical distribution of the different genera and species and of the different assemblages.

8. Conclusions

Palynological analysis of the middle–late Cambrian sequence of Chalisheh, Galikuh and Oshtorankuh sections allows the establishment of three acritarch biozones which integrate those proposed by Ghavidel-Syooki and Vecoli (2008), providing a well-calibrated zonation, useful for large-scale correlation and subsurface investigations addressed to hydrocarbon exploration.

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- Assemblage A, ranging from the Mila C Member to the Ilbeyk Formation *p.p.* in the Chalisheh and Galikuh sections: This assemblage, attributed to the Miaolingian (late Wuliuan–Guzhangian), has many similarities to Acritarch Assemblage Zones I and II of Ghavidel-Syooki and Vecoli (2008), documented in the Mila C Member in the Tang-e-Ilbeyk section of the Zagros Basin.
- Assemblage B, belonging to the Ilbeyk Formation *p.p.*: This assemblage, marked by the FAD of *Leiofusa stoumonensis*, can possibly be correlated to Acritarch Assemblage Zone III of Ghavidel-Syooki and Vecoli (2008), documented from the base of the Ilbeyk Formation in the Tang-e-Ilbeyk section and assigned to the early Furongian. Nevertheless, the FAD of *L. stoumonensis* at the base of Zone III documented in the same section by Ghavidel-Syooki (2019), which was already investigated by Ghavidel-Syooki and Vecoli (2008), suggests that the topmost part of the Mila C Member and the lowermost part of the Ilbeyk Formation can also be attributed to the early Furongian. If these data can be confirmed, this diachronous occurrence of *L. stoumonensis* could indicate that the lithostratigraphical boundary between the Mila and Ilbeyk formations is not isochronous throughout the Zagros Basin, and/or the presence of a hiatus in the upper part of the Mila Formation in both Chalisheh and Galikuh sections. Notably, in the Oshtorankuh section, the absence of Assemblage B from the Ilbeyk Formation indicates that the hiatus belonging to the Mila B and C members includes also the basal part of this formation.
- Assemblage C, ranging from the Ilbeyk Formation *p.p.* to its uppermost part: This assemblage shows many similarities to Acritarch Assemblage Zone IV of Ghavidel-Syooki and Vecoli (2008) and is indicative of a Furongian age.

The present study adds new data, although preliminary, to document that during the Miaolingian and Furongian, cosmopolitanism of acritarch assemblages was high, with most taxa being recorded from all areas worldwide, although so far most descriptions are from localities that were situated in high latitudes during the Cambrian.

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Disclosure statement

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Appendix 1. List of taxa

Actinotodissus achrasii (Martin 1972) Yin 1986
Actinotodissus ubui (Martin 1969) Fensome et al. 1990
Actinotodissus spp.
Comasphaeridium silesiense Moczydłowska 1998
Comasphaeridium strigosum (Jankauskas & Posti 1976) Downie 1982
Comasphaeridium spp.
Cristallinium cambriense (Slavíková 1968) Vanguestaine 1978
Cristallinium dubium Volkova 1990
Cristallinium randomense Martin in Martin & Dean 1981 emend. Martin in Martin & Dean 1988
Cristallinium sp.
Cymatiogalea aspergillum Martin in Martin & Dean 1988
Cymatiogalea membranispina Deunff 1961
Cymatiogalea sp.
Dasydiacrodium obsonum Martin in Martin & Dean 1988
Dasydiacrodium spp.
Dorsennidium mutabile (Di Milia et al. 1989) Sarjeant & Stancliffe 1994
Eliasum sp.
Granomarginata squamacea Volkova 1968
Impluviculus multiangularis (Umnova in Umnova & Fanderflit 1971) Volkova 1990
Leiofusa stoumonensis Vanguestaine 1973
Leiosphaeridia sp.
Lusatia dendroidea Burmann 1970 emend, Albani et al. 2007
Multiplicisphaeridium sp. cf. *eopiriferum* Fombella 1978
Ninadiacrodium caudatum (Vanguestaine 1973) Raevskaya & Servais 2009
Ninadiacrodium dumontii (Vanguestaine 1973) Raevskaya & Servais 2009
Polygonium sp.
Pterospermella sp.
Retisphaeridium dichamerum Staplin et al. 1965
Retisphaeridium lechistanium Jachowicz-Zdanowska 2013
Retisphaeridium ovillense (Cramer & Díez 1972) Vanguestaine 2002
Retisphaeridium sp.
Solisphaeridium flexipilosum Slaviková 1968 emend. Moczydłowska 1998
Solisphaeridium multiflexipilosum Slaviková 1968 emend. Moczydłowska 1998
Stelliferidium gautieri (Martin 1972) Pittau 1985
Stelliferidium sp. cf. *gautieri* (Martin 1972) Pittau 1985
Stelliferidium magnum Palacios et al. 2009
Stelliferidium spp.
Symplassosphaeridium cambriense Slaviková 1968
Timofeevia lancariae (Cramer & Díez 1972) Vanguestaine 1978
Timofeevia microretis Martin in Martin & Dean 1981
Timofeevia pentagonalis (Vanguestaine 1974) Vanguestaine 1978
Timofeevia phosphoritica Vanguestaine 1978
Timofeevia spp.
Trunculumarium revinium (Vanguestaine 1973) Loeblich & Tappan 1976
Vulcanisphaera africana Deunff 1961
Vulcanisphaera spinulifera (Volkova 1990) Parsons & Anderson 2000
Vulcanisphaera turbata Martin in Martin & Dean 1981
Vulcanisphaera spp.

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