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Palynology of the Middle Jurassic strata from the Alborz Ranges, northwestern Iran

Palinología de estratos del Jurásico Medio de las Montañas Alborz, Noroeste de Irán

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ABSTRACT

Palynomorphs are used for palynostratigraphy, and to derive paleoecological and paleobiogeographical inferences from the Middle Jurassic Shemshak Formation, Alborz Ranges, northwestern Iran. The rock unit contains diverse, reasonably preserved palynofloras dominated by miospores and dinoflagellate cysts. Vertical distribution of miospores allows for the introduction of *Klukisporites variegatus* -*Striatella* spp.- *Contignisporites burgeri* assemblage zone in the host strata. The presence of such key miospore species as *Striatella jurassica*, *S. patenii*, *S. seebergensis*, and *Contignisporites burgeri* indicates a Middle Jurassic (late Bajocian–Bathonian) age. Based on the stratigraphic distribution of dinoflagellate cysts, encountered *Cribroperidinium crispum* Total Range Biozone (late Bajocian); *Dichadogonyaulax sellwoodii* Interval Biozone (Bathonian–early Callovian), and Subzone "a" of the *D. sellwoodii* Zone (early–middle Bathonian) are identified. Miospores dominating the examined assemblages are assigned, in ascending order of abundance, to Pterophyta, Coniferophyta, Pteridospermophyta, Lycophyta, Ginkgophyta, Cycadophyta, and Sphenophyta. Such parental vegetation apparently flourished under a wet, warm-to-warm-temperate climate. The co-occurrence of such index warm-moderate water dinoflagellate cysts as *Pareodinia halosa*, *Ctenidodinium continuum*, and *Pareodinia ceratophora* supports this overview. The assemblages though contain both Eurasian and Gondwanan elements but bear closer similarity to those from the former, thus suggesting paleoproximity to the northeastern margin of the Neotethys Ocean during the Middle Jurassic.

Keywords: Miospores, Dinoflagellate cysts, Paleobiogeography, Paleoecology, Shemshak Formation, Iran.

RESUMEN

Palinomorfos son utilizados en la palinoestratigrafía y para apoyar interpretaciones paleoecológicas y paleobiogeográficas de la Formación Shemshak del Jurásico Medio de las Montañas Alborz, Noroeste de Irán. Esta unidad de roca contiene una diversa palinoflora, razonablemente bien preservada, dominada por miosporas y quistes de dinoflagelados. La distribución vertical de las miosporas incluye la zona de asociación Klukisporites variegatus -Striatella spp.- Contignisporites burgeri en los estratos estudiados. La presencia de especies clave de miosporas como Striatella jurassica, S. patenii, S. seebergensis, y Contignisporites burgeri indica una edad Jurásico Medio (Bajociano tardío–Bathoniano). Con base en la distribución estratigráfica de los quistes de dinoflagelados, se identificó la Biozona de Alcance Total de Cribroperidinium crispum (Bajocian tardío); el Intervalo de Biozona de Dichadogonyaulax sellwoodii (Bathoniano–Calloviano temprano), y la Subzona "a" de la Zona de D. sellwoodii Zone (Bathoniano temprano-medio). Las miosporas dominantes en las asociaciones de las muestras examinadas son asignadas, en orden ascendente de abundancia a: Pterophyta, Coniferophyta, Pteridospermophyta, Lycophyta, Ginkgophyta, Cycadophyta, y Sphenophyta. Esta vegetación parental floreció aparentemente, bajo un clima húmedo, cálido a cálido templado. La co-presencia de estos quistes de agua cálida-moderada, como Pareodinia halosa, Ctenidodinium continuum, y Pareodinia ceratophora apoya esta interpretación. Aunque las asociaciones contienen tanto elementos de Eurasia y Gondwana, tienen mayor afinidad con Eurasia, sugiriendo una paleoproximidad al margen noreste del Océano Neotethys durante el Jurásico Medio.

Palabras clave: Miosporas, quistes de Dinoflagelados, Paleobiogeografía, Paleoecología, Formación Shemshak, Irán.

1. Introduction

As a result of the Early Cimmerian tectonic event, Iran is separated into two geologically independent zones; one in the northeast (comprising central Iran, northern and northeastern Iran) and the other in the southwest (Zagros area). These two distinct sedimentary-structural zones comprise the Jurassic strata of remarkably variable litho- and biofacies.

The late Triassic–Middle Jurassic deposits in the former zone are characterized by the Shemshak Formation bounded by two unconformities. The Shemshak Formation (Assereto, 1966) comprises a thick siliciclastic succession, widely distributed across central and northern Iran, the so-called Iran Plate (Seyed-Emami, 2003; Aghanabati, 2004; Seyed-Emami *et al.*, 2008; Fürsich *et al.*, 2009a). Generally, the Shemshak Formation rests unconformably on the Lower–Middle Triassic platform carbonates of the Elika Formation and in turn is followed by basinal carbonates of the Middle Jurassic Dalichai Formation. Much of the Shemshak Formation sedimentation in the Alborz Ranges took place on coastal plains in fluvial, lacustrine, or deltaic settings, paralic swamps, lakes, meandering as well as braided rivers, and shallow–deep shelfal environments (*e.g.*, Seyed-Emami, 2003; Seyed-Emami *et al.*, 2001, 2005, 2006, 2008; Fürsich *et al.*, 2005, 2009a; Sajjadi and Hakimi Tehrani, 2009; Sajjadi *et al.*, 2010). Due to an apparently humid climate, swamps were widespread, which is reflected by abundant and economically important coal deposits (Repin, 1987).

The age of the Shemshak Formation spans the Late Triassic–Middle Jurassic, deduced mostly from fossil plants (*e.g.*, Barnard, 1968; Fakhr, 1977, Barnard and Miller, 1976; Schweitzer, 1977, 1978; Achilles *et al.*, 1984; Schweitzer and Kirchner, 1995, 1996, 1998, 2003; Schweitzer *et al.*, 1997, 2000, 2009; Badihagh and Uhl, 2019; Sadeghi and Hashemi, 2021), ammonites (*e.g.*, Seyed-Emami *et al.*, 2001, 2005, 2006), belemnites (*e.g.*, Parent *et al.*, 2013) and bivalves (Aghanabati, 2014).

Despite a wide areal extension of the Shemshak Formation on the Iran Plate, palynological investigations previously attempted are not widespread (Kimyai, 1975; Achilles *et al.*, 1984; Bharadwaj and Kumar, 1988; Sajjadi and Hakimi Tehrani, 2009; Sajjadi *et al.*, 2010; Ghasemi-Nejad *et al.*, 2004, 2008). This scarcity is mostly due to the detrimental effect of heat/temperature, leading to the formation of coal seams within the rock unit.

The objective of this research is to record the palynological characteristics of the Shemshak Formation located near Namin in Ardabil Province (western Alborz). This study aims to evaluate its stratigraphic, paleobotanical, paleoecological, and paleobiogeographical importance, while also comparing it with other Middle Jurassic data from Eurasia and Gondwana.

Palynostratigraphy is a well-recognized and effective biostratigraphic method (Traverse, 2007) that also serves to reconstruct plant communities, aiding in the interpretation of paleoenvironmental and paleoclimatic conditions (*e.g.*, Abbink *et al.*, 2004; Volkheimer *et al.*, 2009). Investigating in situ palynomorphs within plant macrofossils creates a crucial connection between dispersed miospores and their corresponding botanical relationships (Filatoff, 1975; Balme, 1995).

2. Geological Setting and Stratigraphy

The Upper Triassic–Middle Jurassic Shemshak Formation or Group is one of the most widespread lithostratigraphic units of the Iran Plate. This Plate is part of the Cimmerian terranes, sandwiched between the Turan Plate in the north (part of Eurasia) and the Zagros fold belt in the south (part of Gondwana). The Iran Plate became detached from the northeastern margin of Gondwana during the Early Permian (Stampfli and Borel, 2002) and moved northwards during the Triassic, thus closing off the Paleotethys Ocean regionally. (*e.g.*, Stampfli and Borel, 2002).

This orogenic movement has been termed the Early Cimmerian Orogeny. This event brought

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about a drastic change in the sedimentary regime as the orogeny built the Cimmerian mountains along the Paleotethys suture zone. Denudation of this mountain chain produced large amounts of sediment that collected in an extensive foreland basin situated to the south. The resulting rock unit is the Shemshak Formation or Group. Due to its vast thickness in eastern Alborz (up to 4000m), some have elevated the unit to Group rank (*e.g.*, Aghanabati, 1998; Seyed-Emami, 2003; Fürsich *et al.*, 2009a).

Consequently, the unit has been subdivided into various members/formations, and different lithostratigraphic schemes have been proposed (Nabavi and Seyed-Emami, 1977; Nabavi, 1980; Repin, 1987; Aghanabati, 1998). In the western part of the Alborz Ranges, the Shemshak Formation can be adopted. In this study, we utilize the formation usage.

In most areas, the Shemshak Formation lies unconformably on the Elika Formation, but locally it may overlie older beds (*e.g.*, Permian or even older rocks). In turn, it is overlain by the Dalichai-Lar formations from which it is separated by the Mid-Cimmerian tectonic event (Fürsich *et al.*, 2009b). The Shemshak Formation is considered to be diachronous at both lower and upper boundaries (Assereto, 1966); the rock unit is collectively attributed to the Rhaetian–Middle Jurassic (Aghanabati, 1998). The upper limit of the Shemshak Formation apparently possibly extends to the Callovian in western Alborz Ranges as the succeeding Dalichai Formation commences from the Callovian (Aghanabati, 1998).

The section investigated is situated northeast of Ardabil, 5 km northwest of Namin, Ardabil Province; western Alborz Ranges (Figure 1), the coordinates of the base of the section are N38°35′26″ and E48°20′33″. There, the rock unit here mainly consists of 282m of alternation of sandstones, siltstones, shales, limestones and calcareous shales. The lower boundary is covered whereas the upper limit is unconformable with the Middle Jurassic Dalichai Formation. There is a rhyolite vein in the lower part of the section studied (Figure 1).

3. Material and methods

Forty-six samples are collected from the shale and siltstone successions of the Namin stratigraphic section (Figure 1). Standard palynological procedures (*e.g.*, Phipps and Playford, 1984, Wood, 1996) were applied for extraction and concentration of the palynomorphs. Samples were firstly disaggregated into pea-sized pieces (1-2 mm in diameter) and treated with 30% HCl to eliminate carbonates. The residue was then washed to neutrality and the remaining inorganic matter dissolved in HF (*ca.* 40%); fluoride precipitants formed during this step were removed using hot 30% HCl followed by washing the residue to neutrality. The organic residue was sieved via a 20μm mesh.

Heavy minerals and other remaining inorganic particles are removed by the use of a heavy-liquid solution ($ZnCl_2$) at appropriate specific gravity. The remaining residue was then sieved through a 20μm nylon sieve before mounting on slides. At least three permanent strew slides per sample were prepared using Entellan as the mounting medium. An Olympus BH-2 microscope of the School of Geology, College of Science, University of Tehran, equipped with a mechanical stage and automatic Leitz camera facility, was employed for light microscopy and 35mm photography. Representative taxa are illustrated in Plates I-III. All rock samples, residues, and strew slides used in this investigation are permanently housed in the University of Tehran Palynology Collection (UTSH 1-46) at the School of Geology, College of Science, University of Tehran, Tehran, Iran.

4. Characteristics and stratigraphic significance of the Shemshak palynofloras

Summarized below is a qualitative complexion of the palynofloras assemblages retrieved from the Shemshak Formation followed by taxonomical comparisons that may be drawn with approximately coeval palynological assemblages from Iran

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and elsewhere. An appraisal of the age of the rock unit based on palynological data is also attempted.

4.1. GENERAL FEATURES

Apart from virtually no dinoflagellates cysts intervals at the uppermost part of the section studied, the majority of the subject samples are palyniferous containing reasonably diverse and reasonably preserved palynofloras of terrestrial and marine derivation. Most of the samples are dominated by miospores and marine palynomorphs (dinoflagellate cysts), rare acritarchs, foraminiferal test linings, and fungal spores in good states of preservation. The assemblages comprise 44 spore species (30 genera; 41.06%), 19 pollen species (eight genera; 12.56%), and 20 dinoflagellate cysts (11 genera; 46.25%).

A general summary of the qualitative and quantitative features of the palynofloral assemblages retrieved from the upper part of the Shemshak Formation follows. The palynological contents are productive and reasonably preserved thus allowing documenting and appraising the stratigraphic significance of the recovered miospores and dinoflagellate cysts and, in turn, providing clues on the

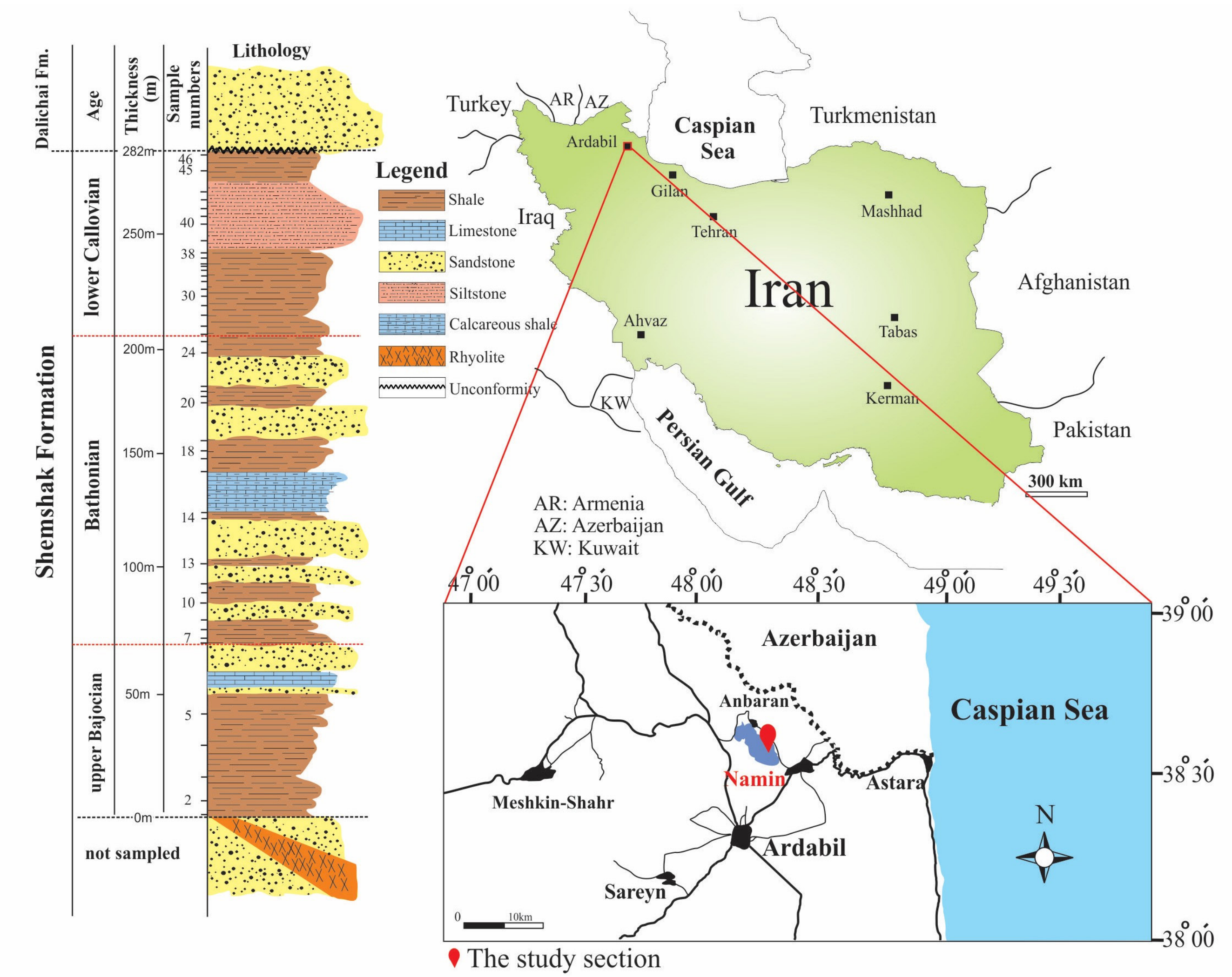

Figure 1 Stratigraphic column with sample positions, and geographic location, Shemshak Formation, Namin stratigraphic section, northwestern Iran.

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Middle Jurassic paleogeography and paleoecology of northwestern Iran.

The stratigraphic distribution of certain species enables the introduction of one informal spore-pollen assemblage, and two formal dinoflagellate cyst zones and a subzone (Figure 2). These are based mainly on the first and last appearance datum (FOOs and LOOs) of certain species, respectively. These biozones have potential value for both inter-basinal correlation and relative age determination by reference to known Iranian, Eurasian, and Gondwanan Jurassic palynostratigraphic schemes. Of the taxa encountered in the biozones, only those with known stratigraphic value and/or persistence through all or a certain part of the section are illustrated in Plates I-III.

4.2. PALYNOSTRATIGRAPHY

The Namin palynofloras comprise 44 spore species (30 genera), and 19 pollen species (eight genera). The vertical ranges of certain miospore species with known stratigraphic significance and/or persistence throughout the section investigated authorize the introduction of one informal miospore-based biozone as *Klukisporites variegatus* -*Striatella* spp.- *Contignisporites burgeri* assemblage zone (Figure 2). The lower and upper stratigraphic boundaries of this biozone extend from the base to the top of the studied section (282 m). Only miospores taxa with known stratigraphic importance and/or persistence are illustrated in Plates I and II. The associated miospores include:

Spores: *Anapiculatisporites* sp., *Biretisporites vallatus*, *Calamospora tener*, *Cerebropollenites macroverrucosus*, *Chasmatosporites apertus*, *C. major*, *Cibotiumspora jurienensis, Concavissimisporites verrucosus, Converrucosisporites pricei, Converrucosisporites* sp. A, *Converrucosisporites* sp. B, *Cyathidites australis*, *C. minor, Deltoidospora hallii, Densoisporites velatus, Dictyophyllidites harrisii, D. mortonii, Foveosporites pseudoalveolatus, Gleicheniidites senonicus, Granulatisporites granulatus, Ischyosporites* spp., *Klukisporites variegatus*, *K. scaberis, Kyrtomisporis laevigatus, Limbosporites antiquus, L. denmeadii, L. lunblandii, Limbosporites spp., Lycopodiumsporites rugulatus, Matonisporites crassiangulatus, Murospora florida, Neoraistrickia parvibacula, Neorestrickia sp., Osmundacidites senectus, O. wellmanii, Punctatisporites microtumulus, Retitriletes spp., Striatella jurassica, S. patenii, S. seebergensis, Striatella sp., Toripustulatisporites sp., Todisporites major, T. minor, Verrucosisporites varians, Zebrasporites interscriptus*.

Pollen: *Alisporites australis, A. grandis, A. lowoodensis, A. similis, Araucariacites australis, Callialasporites dampieri, C. microvelatus, C. segmentatus, C. trilobatus, Cycadopites crassimarginis, C. follicularis, C. grandis, Cycadopites* spp., *Podocarpidites* sp. cf. *P. ellipticus, Sulcosaccispora* sp. cf. *S. lata*.

The Namin biozonation scheme is compared (Figure 3) with ±coeval palynozones introduced from Gondwana (*e.g.*, Balme, 1957, 1964; Filatoff, 1975; McKellar, 1998; Mantle and Riding, 2012; Ibrahim *et al.*, 2001; Tripathi, 2004; Quattrocchio *et al.*, 2001; Stukins *et al.*, 2013) and Eurasia (*e.g.*, Stefanowicz, 2008; Rostovtseva, 2011; Ashraf, 1977; Ashraf *et al.*, 1999, 2010; Arjang, 1975; Achilles *et al.*, 1984; Bharadwaj and Kumar, 1986; Sajjadi *et al.*, 2007; Dehbozorgi, 2014; Hashemi Yazdi *et al.*, 2014; Sajjadi and Dermanaki Farahani, 2017; Hashemi Yazdi *et al.* 2018; Badihagh *et al.*, 2019).

Dinoflagellate cysts are excellent index fossils for the Middle-Late Jurassic because many have a wide geographical distribution and relatively short duration (Riding and Thomas, 1992; Poulsen and Riding, 2003; Riding, 2020; Figure 4). Diverse and profuse dinoflagellate cyst assemblages, in good state of preservation, occur in the Namin stratigraphic section. The assemblages comprise 20 dinoflagellate cysts species (11 genera). Two dinoflagellate cyst zones and a subzone are distinguished in the studied strata (Figure 2) based on the first (FOO) and last (LOO) appearances of the dinoflagellate cysts index species:

1. *Cribroperidinium crispum* Total Range Biozone of Woollam and Riding (1983; Bajocian).

Cribroperidinium crispum Total Range Biozone spans 71m of the studied interval and is defined by the first observed (FOO) and last observed (LOO)

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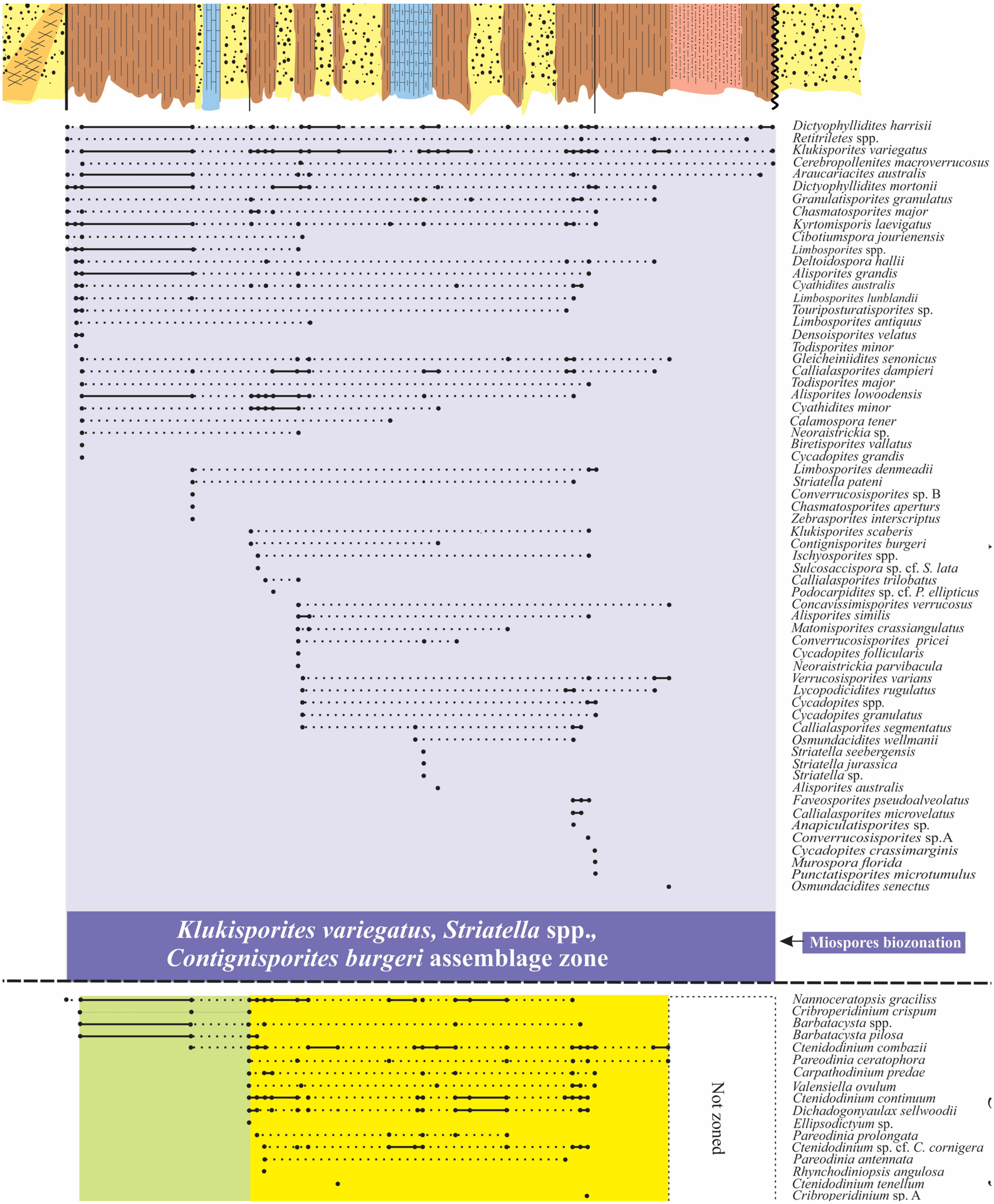

Figure 2 Stratigraphic distribution of miospore taxa and dinoflagellates cysts through the sampled strata, and proposed palynostratigraphic zonations of the Shemshak Formation in the Namin area, northwestern Alborz Ranges.

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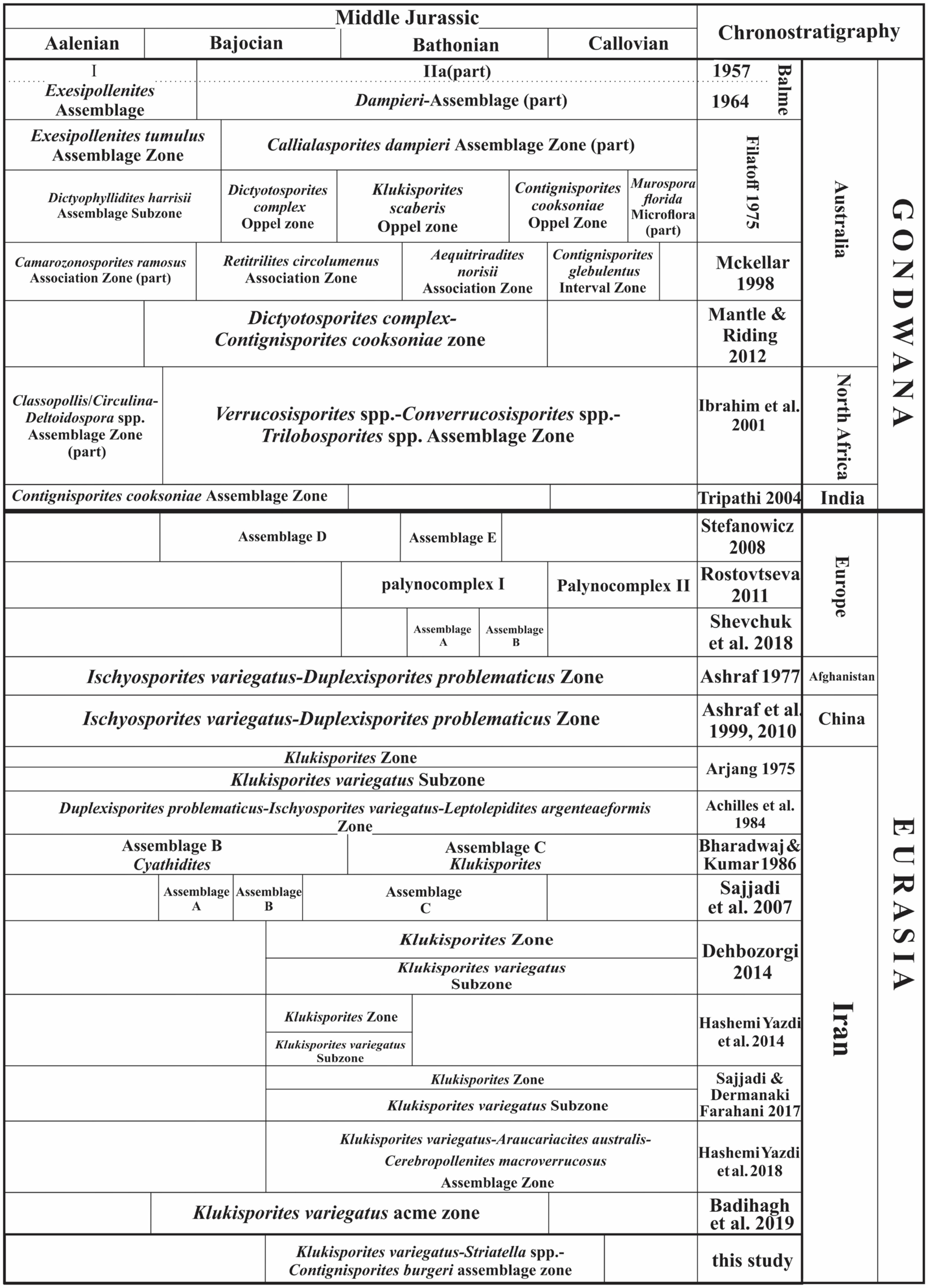

Figure 3 Miospore-based correlation of the Middle Jurassic Shemshak Formation with those established in the Gondwanan and Eurasian coeval strata.

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of *Cribroperidinium crispum* (al. *Acanthaulax crispa*). The lower and upper stratigraphic limits of the biozone occur 4m and 75m respectively, above the base of the section. Suggested literature ages for this biozone are late Bajocian (Woollam and Riding, 1983) and early–late Bajocian (Riding and Thomas, 1992; Figure 2). Described originally from England (Woollam and Riding, 1983; p.11) the biozone has subsequently been reported from continental northwest Europe (Poulsen and Riding, 2003) as well as parts of Iran (Ghasemi-Nejad *et al.*, 2012; Mafi *et al.*, 2014; Dehbozorgi, 2014; Hashemi Yazdi, 2015; Sajjadi *et al.*, 2018; Dehbozorgi *et al.*, 2018; Dehbozorgi and Senemari, 2020; Mohammad-khani and Zarei, 2018; Figure 4). Other species recorded from this biozone include: *Barbatacycsta* spp., *B. pilosa*, *Ctenididinium combazii*, and *Nannoceratopsis gracilis*.

2. *Dichadogonyaulax sellwoodii* Interval Biozone of Woollam and Riding (1983; Bathonian–early Callovian).

Succeeding the *C. crispum* Total Range Biozone, the *Dichadogonyaulax* (al. *Ctenidodinium*) *sellwoodii* Interval Biozone ranges from the LOO of *C. crispum* (at 75m above the base) to the LOO of *Ctenidodinium combazii* (241m above the base); thus spanning 166m of the section (Figure 2). The suggested literature age for this biozone is Bathonian–early Callovian, *e.g.*, Riding and Thomas (1992), and Poulsen and Riding (2003).

Described originally from England (Woollam and Riding, 1983; p.11) the biozone has been reported subsequently from sub-boreal northwest Europe (*e.g.*, Poulsen and Riding, 2003), as well as, Egypt (Ibrahim *et al.*, 2001) and parts of Iran (Ghasemi-Nejad *et al.*, 2012; Mafi *et al.*, 2014; Dehbozorgi, 2014; Hashemi Yazdi, 2015; Sajjadi *et al.*, 2018; Dehbozorgi *et al.*, 2018; Dehbozorgi and Senemari, 2020; Mohammad-khani and Zarei, 2018; Figure 4). Dinoflagellate cysts in the *D. sellwoodii* Biozone are more common and diverse than in the preceding *C. crispum* Biozone. Except for *C. crispum*, other species of the older biozone range into the younger biozone. In addition to *D. sellwoodii* other species first appearing in the younger biozone include: *Carpathodinium predae*, *Cribroperidinium* sp. A, *Cribroperidinium* sp. B, *Ctenidodinium* sp. cf. *C. cornigera*, *C. continuum*, *C. tenellum*, *Ellipsodictyum sp.*, *Pareodinia halosa*, *P. prolongata*, *P. ceratophora*, *P. antennata*, *Rhynchodiniopsis angulosa* and

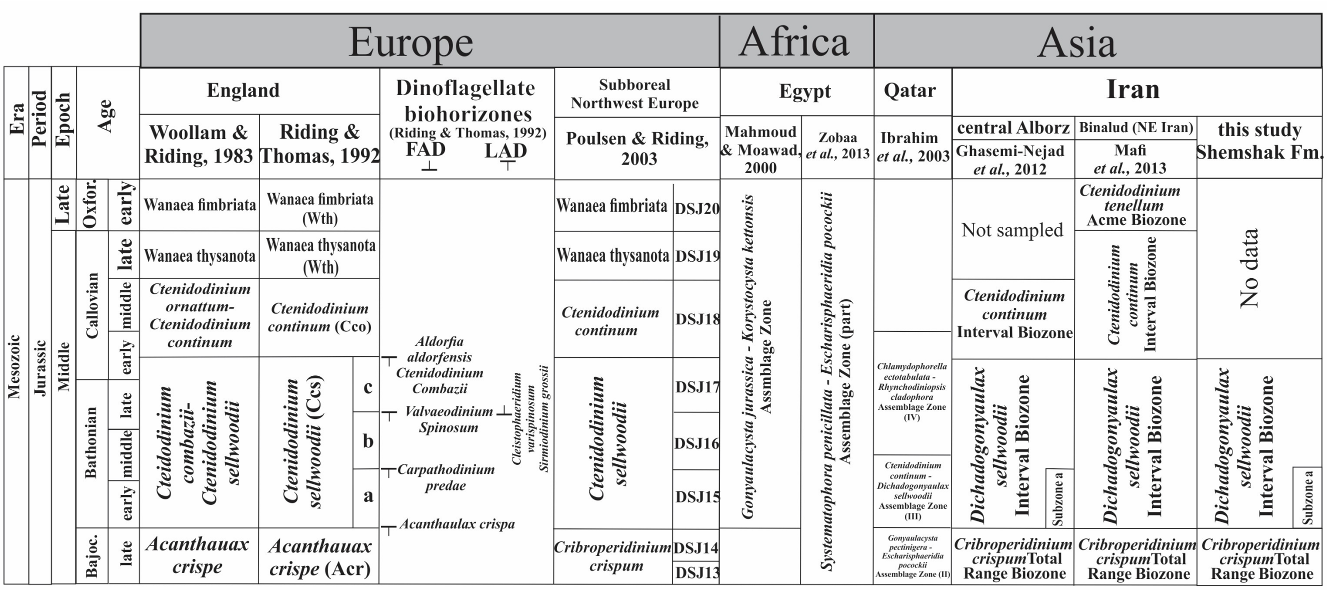

Figure 4 Dinoflagellate-based palynostratigraphic correlation scheme proposed herein for the Middle Jurassic Shemshak Formation with those established in coeval strata.

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Valensiella ovulum (Figure 2).

2.1. Subzone "a" of Riding and Thomas (1992; early–middle Bathonian).

A subzone recognized within the lower part of the *D. sellwoodii* Interval Biozone is here designated as Subzone"a" (Figure 2). The respective LOOs of *Cribroperidinium crispum* and *Carpathodinium predae* define this subzone. This is compatible with the DSJ15 subzone as part of the northwestern European *Ctenidodinium sellwoodii* Zone (Poulsen and Riding, 2003), and are both considered of the early–middle Bathonian age (Riding and Thomas, 1992; Figure 4).

5. Age of the palynofloras

Spores and pollen grains provide the sole direct means of determining the age of the Shemshak Formation in the studied section. Dating can be achieved by taking into account the known vertical restriction of certain species in the Middle Jurassic.

Two forms are the most abundant palynomorphs in all the samples studied including *K. variegatus* and *Callialasporites dampieri* (Figure 5). In Iran, the former commence from the Middle Jurassic (*e.g.*, Arjang, 1975; Achilles *et al.*, 1984). The relative abundance of *K. variegatus* and araucarian pollen, notably *Callialasporites dampieri*, yet the absence of *Corollina* spp. and *Callialasporites turbatus* in the Namin section suggests an age no older than the Middle Jurassic (*e.g.*, Helby *et al.*, 1987). An upper age limit is afforded by the absence of *Retitriletes watherooensis*, *Trilobosporites*, *Pilosisporites*, *Cicatricosisporites* spp. and *Ruffordiaspora* spp. suggesting that the section is no younger than Late Jurassic (Kimmeridgian; *e.g.*, Helby *et al.*, 1987; McKellar, 1998; Batten and Koppelhus, 1996). Accordingly, the age of Namin section has been confined to the Middle Jurassic.

The first appearance of *Contignisporites burgeri* in the lower mid part of the section suggests that the strata at that level are no older than Bathonian (Filatoff and Price, 1988, fig. 1). The last appearance datum (LADE) of *Striatella patenii* (middle Bathonian; Filatoff and Price, 1988), *S. scanica* (Callovian; Filatoff and Price, 1988; Batten and Koppelhus, 1996), *S. seebergensis* (early Bathonian; Filatoff and Price, 1988; Batten and Koppelhus, 1996), and *S. jurassica* (Callovian–? Portlandian; Filatoff and Price, 1988; Batten and Koppelhus, 1996) suggest late Bajocian–Bathonian age for the most part of the Namin section. Furthermore, the co-occurrence of multiple *Striatella* species, along with *Contignisporites burgeri* (Filatoff and Price, 1988, fig. 1) supports the age determination.

Importantly the occurrence of several key dinoflagellate cyst index taxa has also greatly helped to restrict the age of the Shemshak Formation palynological assemblages to the late Bajocian–early Callovian. Two identified biozones, namely the *Cribroperidinium crispum* Total Range Zone (late Bajocian), *Dichadogonyaulax sellwoodii* Interval Biozone (Bathonian–early Callovian), and Subzone "a" (early–middle Bathonian) contribute to this enhancement. Notably, the presence of the eponymous dinoflagellate cyst further aids in constraining the age of the Shemshak Formation palynological assemblages to the late Bajocian–early Callovian.

6. Paleobiogeographic and paleoecological implications

Pangea's rifting and fragmentation, which began in the Early Triassic, culminated in the supercontinent's breakup into the northern Laurasia and southern Gondwana landmasses during the Middle Triassic. In the Permian, the Iranian microcontinent was separated from Gondwana and migrated northward, finally colliding with Eurasia during the Triassic period (Berberian and King, 1981; Alavi *et al.*, 1997; Stampfli and Borel, 2002; Wilmsen *et al.*, 2009a). The Late Triassic collision of the Cimmeride with Eurasia (Corsin and Stampfli, 1977; Stampfli *et al.*, 1991; Muttoni *et al.*, 2001; Moix *et al.*, 2008) caused the beginning of the Cimmerian orogeny and development of peripheral foreland basins that accommodated units such as the Shemshak and Dalichai formations at the southern margin of Eurasia (Fürsich *et al.*, 2009b).

The Iran plate was part of the Eurasian continent during the Jurassic (Wilmsen *et al.*, 2009b; Robert *et al.*, 2014). Studies of Jurassic fossil plant composition and distribution throughout Eurasia reveal two paleoclimatic plant provinces: Siberian in the north and Euro-Sinian in southern Eurasia (Vakhrameev, 1987). The existing paleogeographic maps (Thierry, 2000; Robert *et al.*, 2014) show that in the Middle Jurassic, the north and center of the Iranian plate was located in the northeastern margin of the Neotethys Ocean (Figure 6), in latitudes

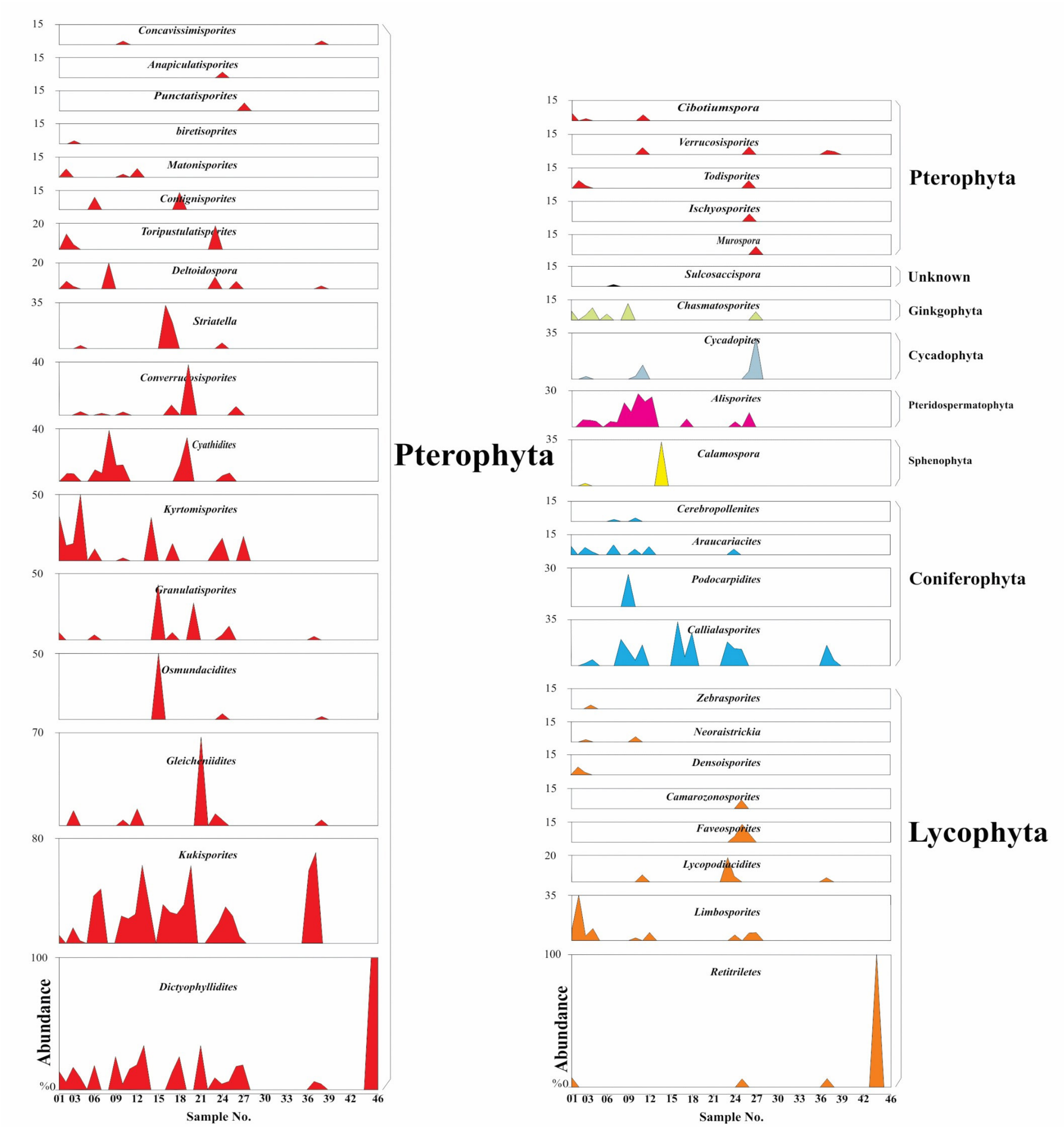

Figure 5 Abundance (percentage) of miospores of the Shemshak Formation at the Namin stratigraphic section.

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20° to 30°N (Seyed-Emami *et al.*, 2008; Wilmsen *et al.*, 2009b).

The worldwide distribution of the Middle Jurassic Araucariaceae-fern-dominated palynofloras confirms the extensive connections within Laurasia and Gondwana, which were clustered around the Tethys Ocean (Mantle and Ridding, 2012). Despite the overall similarities of the Middle Jurassic terrestrial palynoflora of Gondwana and Eurasia, there were some forms largely endemic to the southern hemisphere (Gondwana) that was not found in the Namin section, these include: *Aequitriradites norrisii, Anapiculatisporites dawsonensis, A. pristidentatus, Annulispora densata, Antulsporites saevus, Apiculatisporis taroomensis, Camarozonosporites ramosus, Coronatispora perforata, Convolutispora Prisca, Contignisporites cooksoniae, Dejerseysporites biannuliverrucatus, Dictyotosporites complex, Microcachryidites antarcticus, Neoraistrickia densata, N. elongate, N. equalis, N. rugobacula, Nevesisporites undatus, Perotrilites whitfordensis, Retitriletes circolumenus, R. facetus, R. huttonensis, R. neofacetus, R. nodosus, R. proxiradiatus, Sculptisporis moretonensis, Staplinisporites manifestus, Trilites volkheimeri, Trilobosporites antiquus, Trisaccites microsaccatus, Tuberculatosporites westbournensis, Uvaesporites verrucosus*. Consequently, comparing the studied palynofloras with those reported from Gondwana and Eurasia reveals that it is more similar to those from Eurasia.

The tripartite dinoflagellate cyst biozonation (*Cribroperidinium crispum*, *Dichadogonyaulax sellwoodii* and Subzone "a" of the *D. sellwoodii* Zone) identified in the Namin section is very similar to coeval northern Iran (Ghasemi-Nejad *et al.*, 2012; Mafi *et al.*, 2014; Dehbozorgi, 2014; Hashemi Yazdi, 2015; Mohammad-khani and Zarei, 2018; Sajjadi *et al.*, 2018), Northwest European (Woollam and Riding, 1983; Riding and Thomas, 1992; Poulsen and Riding, 2003) and the Russian Platform (Riding *et al.*, 1999). The close similarities of the dinoflagellate cyst assemblages of northern Iran with those of Northwest Europe and the northwestern Tethys during the Middle Jurassic indicate a direct marine connection and faunal exchange between the two areas (Ghasemi-Nejad *et al.*, 2012). The ammonite fauna of the Middle Jurassic in Central Alborz Ranges shows very close relations and similarities to the fauna from other parts of Alborz

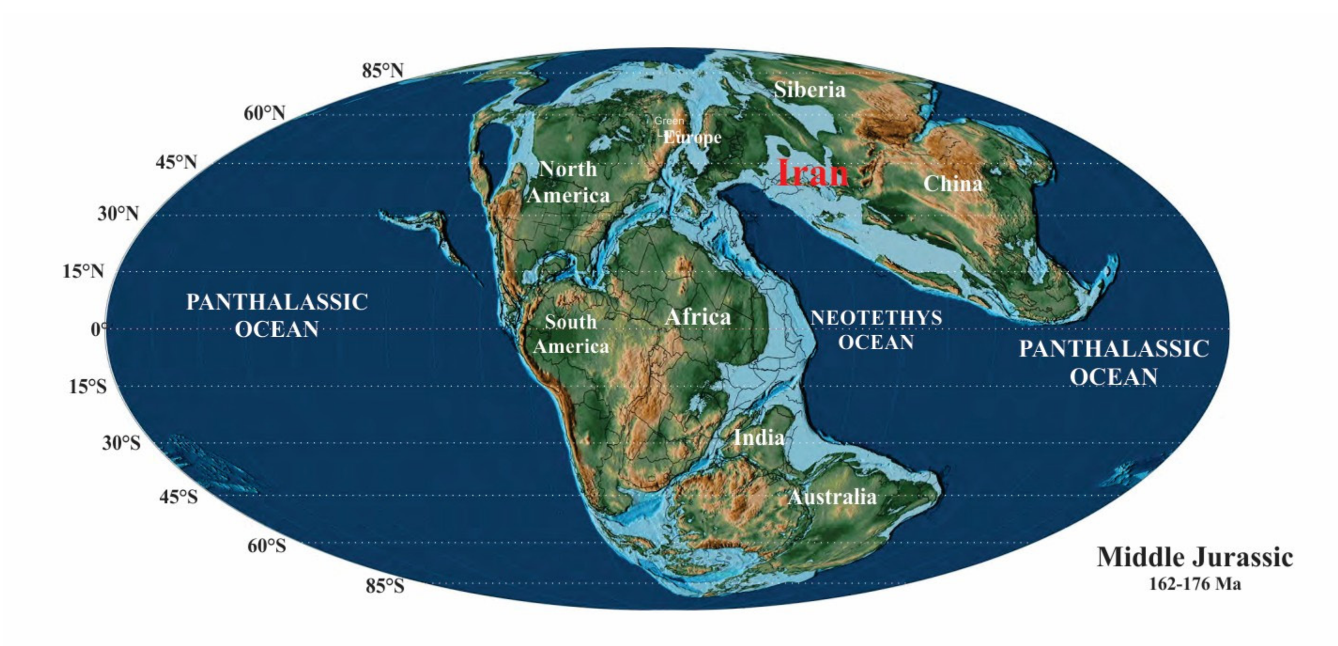

Figure 6 Paleogeographic Maps of the Middle Jurassic (modified after Robert *et al.*, 2014).

Table 1. Inferred botanical affinities of miospore taxa identified in this study. Principal sources of information concerning botanical relationships of sporae dispersae: Potonié, 1962, 1967; Couper, 1960; Dettmann, 1963, 1986, 1994; Mädler, 1964; Pocock, 1970; Filatoff, 1975; Filatoff and Price, 1988; de Jersey and Raine, 1990; Vakhrameev, 1991; Dettmann and Clifford, 1992; Boulter and Windle, 1993; Balme, 1995; Batten and Dutta 1997; Hubbard and Boulter 1997; Abbink, 1998; McKellar, 1998; Sajjadi and Playford, 2002; Roghi, 2004; Barrón *et al.*, 2006.

Ranges, Kopeh-Dagh, East-Central Iran as well as European and Submediterranean regions (Seyed–Emami, *et al.*, 2008).

Plant macrofossils are useful in paleobotanical and paleoecological studies. By determining the parental plants of miospores, it is possible to provide paleoecological interpretations reflecting a history of the kind of parent vegetation (Traverse, 2007). Inferred botanical affinities of the miospores presented herein (Table 1) have been obtained from various sources (*e.g.*, Potonié, 1962, 1967; Couper, 1960; Dettmann, 1963, 1986, 1994; Mädler, 1964; Pocock, 1970; Filatoff, 1975; Filatoff and Price, 1988; de Jersey and Raine, 1990; Vakhrameev, 1991; Dettmann and Clifford, 1992; Boulter and Windle, 1993; Balme, 1995; Batten and Dutta, 1997; Hubbard and Boulter, 1997; Abbink, 1998; McKellar, 1998; Sajjadi and Playford, 2002; Roghi, 2004; Barrón *et al.*, 2006).

All palynomorphs occurring in three slides from palyniferous samples are counted. The relative abundance of the encountered miospores per sample and their parent plants are shown in Figures 5 and 7. As a result, miospores (53.51%) are the dominant palynomorph component in the Namin section. Their inferred botanical affinities are: Pterophyta (72%), Coniferophyta (8%), Pteridospermophyta (7%), Lycophyta (9%), Ginkgophyta (2%), Cycadophyta (1%) and Sphenophyta (1%); (Figure 7). 0.11% of miospores are unassigned as their affinities are unknown. This inferred botanical composition implies ferns dominated the source vegetation (Figures 5 and 7).

From Figure 7 and Table 1, it is apparent that ferns comprise the following plant families: Osmundaceae, Schizaeaceae, Dipteriaceae, Matoniaceae, and Dicksoniaceae. Such a composition implies that the parental vegetation flourished in a warm to warm-temperate, high-humidity climate (Van Konijnenburg-Van Cittert, 2002). Spores

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of Lycophytic affiliation (both Lycopodium and Selaginellid types) quantitatively constitute the second largest miospores group, although much lower in number than the fern spores. Lycopodium and Selaginella both flourish in moist tropical environments (Sajjadi and Playford, 2002; Tryon and Tryon, 2012). The least common pteridophyte representative in the material examined is Calamospora, an equisetalean-like spore, indicating derivation from arthrophytes. Assuming analogy with modern equivalents, horsetails, the parent plant of these palynomorphs would indicate wet habitats of temperate to subtropical climatic zones (Sajjadi and Playford, 2002; Sajjadi *et al.*, 2015).

Dispersed conifer pollen in the Namin sediments is thought to have derived from Podocarpaceae, and Araucariaceae. The Araucariaceae-type pollen in particular consistently dominates the Shemshak Formation palynofloras. Conifers, dominated by Araucariaceae and Podocarpaceae (Table 1) are known to indicate a warm, non-seasonal, possibly coastal environment (Mohr, 1989; Abbink, 1998). The co-occurrence of some index warm to moderate water dinoflagellate cysts (Riding and Hubbard, 1999) such as *Pareodinia halosa*, *Ctenidodinium continuum*, and *Pareodinia ceratophora* confirms this overview.

7. Conclusions

The Shemshak palynofloras at the Namin section include in total 83 species of palynomorphs, including 44 spore species (30 genera), 19 pollen species (eight genera), and 20 dinoflagellate cysts

Figure 7 **Diagram of abundance percentage of different groups of parent plants of miospores, Shemshak Formation, Namin stratigraphic section.**

species (11 genera). Relative abundances of miospore species vary significantly among samples; however, representatives of *K. variegatus* and *Callialasporites dampieri* are particularly abundant. Vertical distribution of certain miospores species enables the introduction of one palynozone, here informally termed the *Klukisporites variegatus*-*Striatella* spp.-*Contignisporites burgeri* assemblage zone.

The presence of multiple *Striatella* species, as well as, *Contignisporites burgeri* and *Murospora florida* collectively indicates a Middle Jurassic (late Bajocian–early Callovian) age. Dinoflagellate cyst species distribution led to the identification of two biozones, which in ascending order are: *Cribroperidinium crispum* Total Range Zone (late Bajocian), *Dichadogonyaulax sellwoodii* Interval Zone (Bathonian–early Callovian), and Subzone "a" (early–middle Bathonian). The overall age range of the studied unit, late Bajocian–early Callovian, concurs well with that assessed on the basis of miospores and dinoflagellate cysts.

From a paleofloristic viewpoint, inferred natural relationships of the dispersed spores and pollen imply derivation from a diverse flora, comprising in descending quantitative order, Pterophyta, Coniferophyta, Pteridospermophyta, Lycophyta, Ginkgophyta, Cycadophyta and Sphenophyta. Most miospores are related to ferns indicating that this group was a dominant component of the source vegetation. Comparison with modern plant ecology indicates a moist warm to warm-temperate climate during deposition of the host strata. The presence of some index intermediate to warm water dinoflagellate cysts such as *Pareodinia halosa*, *Ctenidodinium continuum*, and *Pareodinia ceratophora* confirms this overview.

In paleobigeographical terms, most of the miospores and dinoflagellate cysts are shared between the Eurasian and Gondwanan provinces, with a slight preference for Eurasian taxa. This characterization suggests that the Middle Jurassic Shemshak Formation in the western part of the Alborz Ranges was deposited in the southern margin of Eurasia.

Contributions of authors

FSH: data interpretation, supervision, original draft, and final edit financial support; FHY: data interpretation, graphic design; AK: processing palynological samples and basic stratigraphic data; NNI: fieldwork and sampling; MTB: fieldwork, sampling, original draft, graphic design.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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Supplementary data

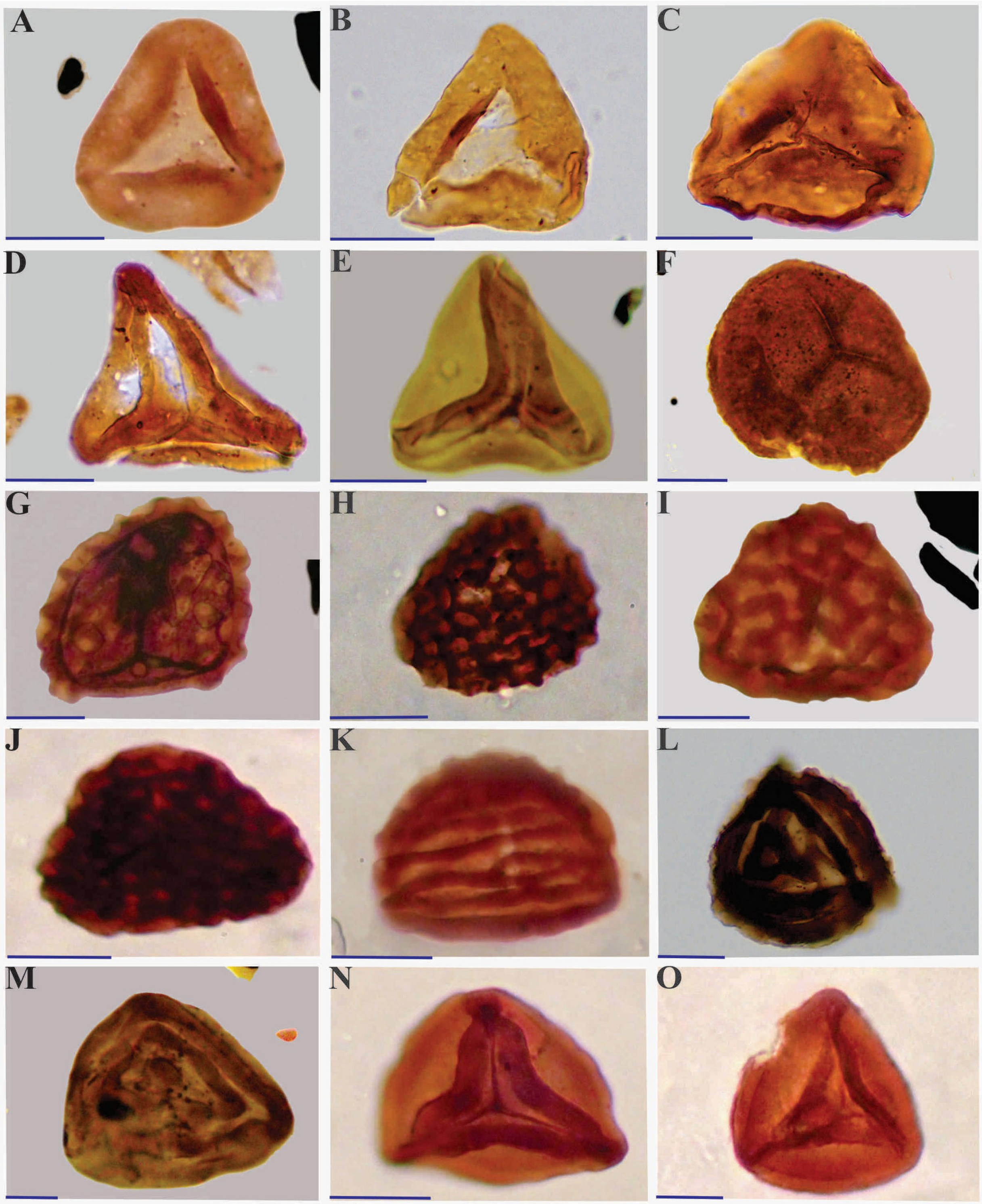

Plate I (A, B) *Cyathidites australis* Couper, 1953; proximal foci. (C) *Dictyophyllidites harrisii* Couper, 1958; proximal focus. (D, E) *Gleicheniidites senonicus* Ross emend. Skarby 1964; proximal foci. (F) *Foveosporites pseudoalveolatus* (Couper) McKellar, 1998; proximal focus. (G) *Klukisporites scaberis* (Cookson and Dettmann) Dettmann, 1963; proximal focus. (H, I, J) *Klukisporites variegatus* Couper, 1958; distal foci. (K) *Contignisporites burgeri* Filatoff, McKellar and Price, 1988; distal focus. (L, M) *Striatella seebergensis* Mädler, 1964; distal foci. (N, O) *Kyrtomisporis laevigatus* Mädler, 1964; proximal foci. Scale bar equals 20 µm.

http://dx.doi.org/10.18268/BSGM2025v77n1a141124

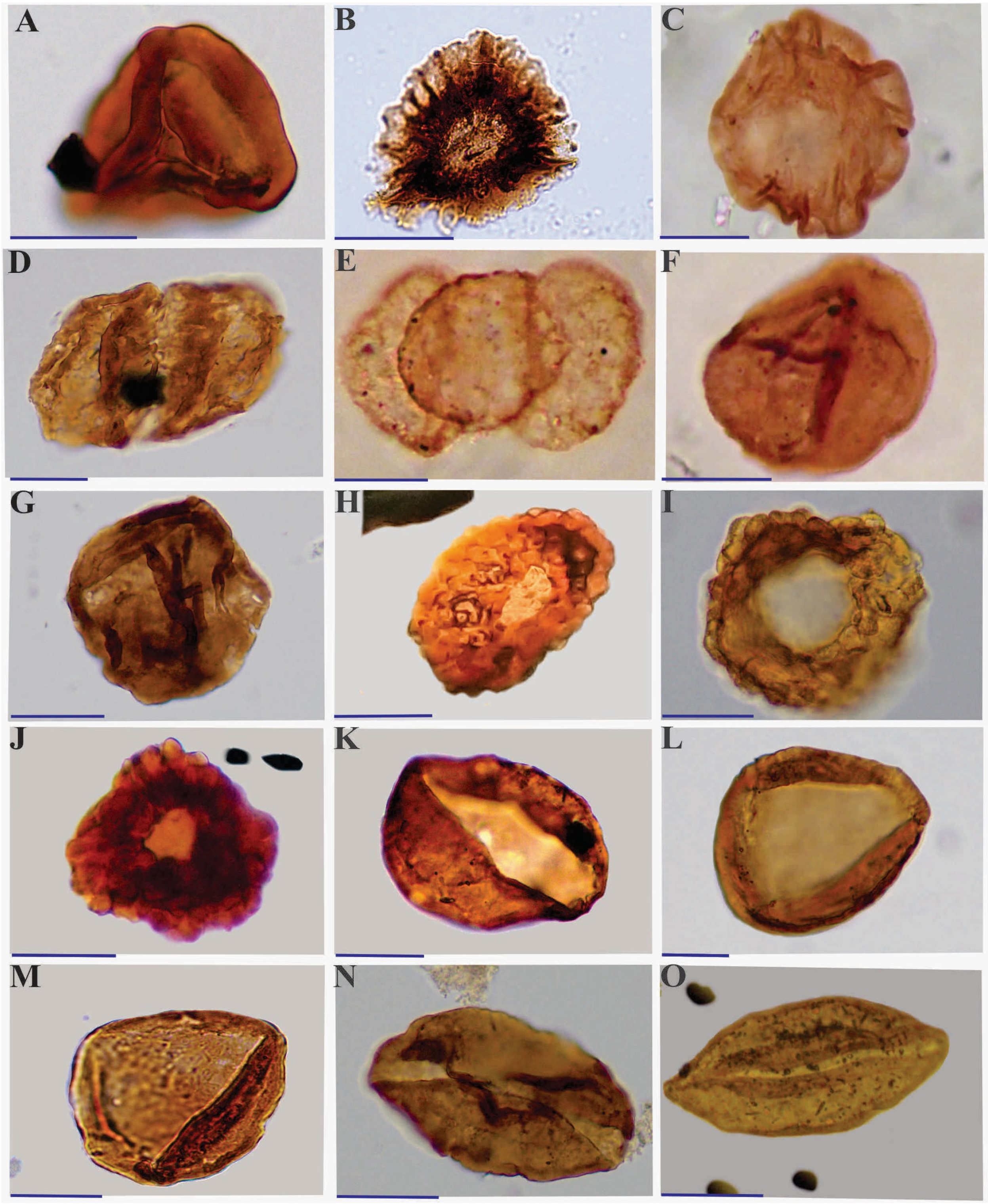

Plate II (A) *Kyrtomisporis laevigatus* Mädler, 1964; proximal focus. (B) *Limbosporites antiquus* (de Jersy) de Jersy and Raine, 1990; median focus. (C) *Callialasporites dampieri* (Balme) Sukh Dev, 1961; polar view. (D) *Alisporites australis* Jersey, 1962; distal focus. (E) *Alisporites lowoodensis* Jersey, 1963; median focus. (F, G) *Araucariacites australis* Cookson ex Couper, 195; median foci. (H, I, J) *Cerebropollenites macroverrucosus* (Thiergart) Schulz, 1967; distal foci. (K) *Chasmatosporites major* Nilsson, 1958; distal focus. (L, M) *Chasmatosporites apertus* (Rogalska) Nilsson, 1958; distal foci. (N, O) *Cycadopites follicularis* Wilson and Webster, 1946; distal foci. Scale bar equals 20 μm.

http://dx.doi.org/10.18268/BSGM2025v77n1a141124

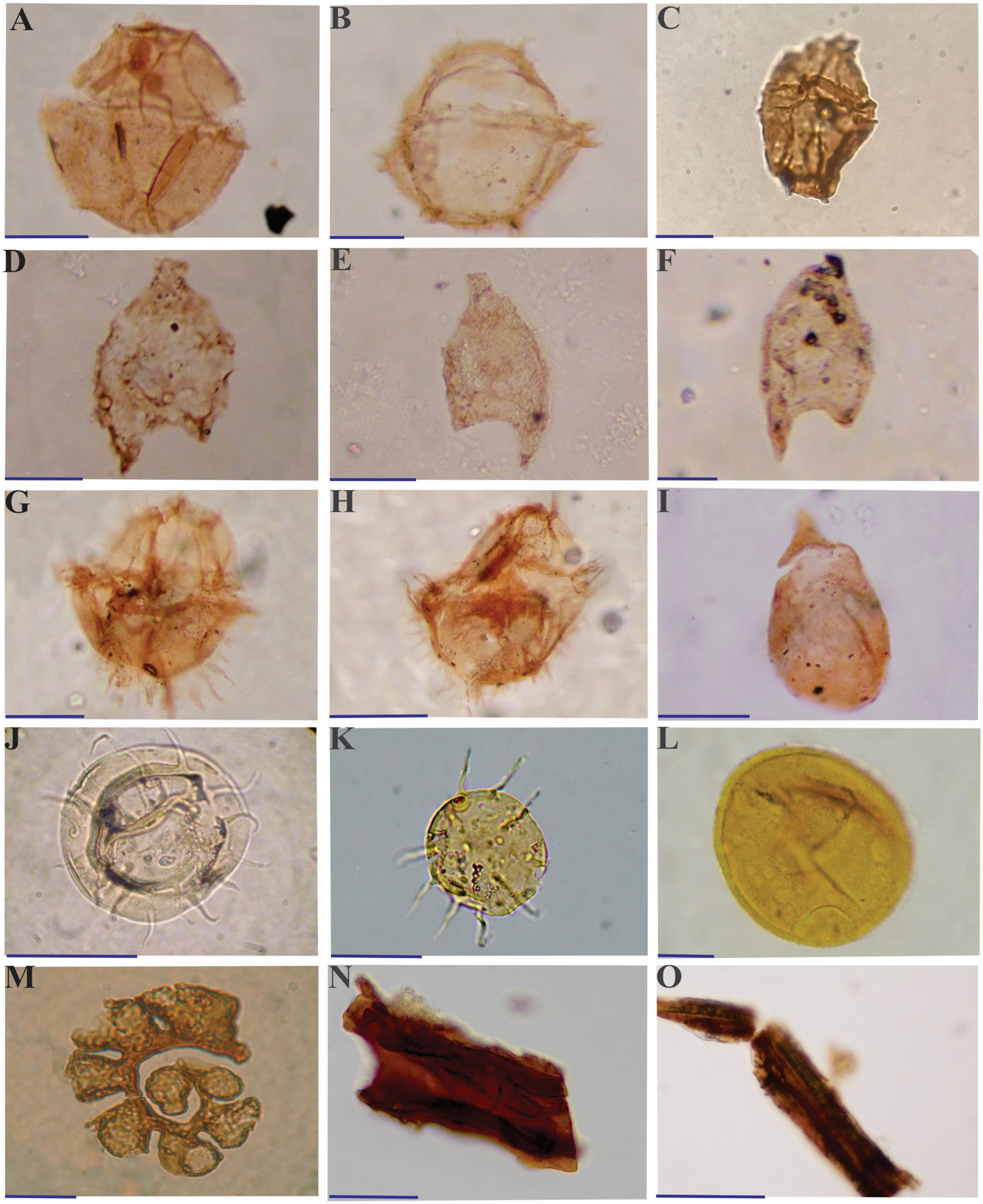

Plate III (A, B) *Dichadogonyaulax sellwoodii* (Sarjeant) Stover and Evitt, 1978. (C) *Carpathodinium predae* (Beju) Drugg, 1978. (D, E, F) *Nannoceratopsis gracillis* Alberti emend Evitt, 1962. (G, H) *Ctenidodinium combazii* Dupin, 1968. (I) *Pareodinia ceratophora* Deflandre, 1947. (J, K) *Michystridium* spp. (L) *Tasmanites* sp. (M) Coiled foraminiferal test lining. (N-O) Plant tissue fragments. Scale bar equals 20 μm.