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THE UPPER BAJOCIAN (MIDDLE JURASSIC) VEGETATION AND PALEOENVIRONMENT DYNAMICS IN THE EASTERN BINALUD MOUNTAINS (NE IRAN)

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Abstract

The lower part of the Dalichai Formation was analyzed to reconstruct the vegetation, paleoenvironment, and paleoclimate dynamics of these deposits in the Binalud Mountains. The shale and marlstone deposits of the studied section contain abundant and diverse terrestrial and marine palynomorphs. The consistent presence of the dinoflagellate cyst genus *Cribroperidinium crispum* throughout the section and the absence of early Bajocian index taxa support an upper Bajocian age for this interval. Palynofacies indicates a highly proximal to marginal marine depositional setting. The vegetation reconstruction reveals an expanded lowland environment dominated by ferns and Cycadales in the lower part of the section. The overlying interval is characterized by a sea-level rise, which correlates with an increased abundance and diversity of upland SEG conifers and seed ferns. The coastal environment expanded during this phase, leading to the proliferation of coastal SEG such as Cheirolepidiaceae and Araucariaceae, which persisted until the end of the section. The sporomorph assemblages suggest a generally warm and dry climate throughout the studied interval. However, the increase in cool-dependent Araucariaceae toward the uppermost Bajocian is interpreted as evidence of a cooling phase, which aligns with global records of similar climatic shifts during this period.

Keywords: Dalichai Formation; Northeastern Iran; Palynofacies; Palynostratigraphy; Sporomorph ecogroups

تغییرات پوشش گیاهی و محیط دیرینه در نهشته های باژوسین بالایی (ژوراسیک میانی) شرق کوه‌های بینالود (شمال شرق ایران)

بهناز کلنات: استادیار پژوهش، گروه دیرینه‌شناسی گیاهی، مؤسسه تحقیقات جنگلها و مراتع کشور، سازمان تحقیقات، آموزش و ترویج کشاورزی، تهران، ایران

چکیده: بخش پایینی سازند دلیچای در کوه‌های بینالود به‌منظور بازسازی پوشش گیاهی، محیط و اقلیم دیرینه مورد بررسی قرار گرفت. نهشته‌های شیلی و مارنی برش مورد مطالعه حاوی تعداد فراوان و متنوعی از پالینومورف‌های دریایی و خشکی است. حضور دینوفلاژله جنس *Cribroperidinium crispum* در سرتاسر برش مورد مطالعه، همراه با عدم حضور تاکسون‌های شاخص باژوسین پایینی، سن باژوسین بالایی را برای این نهشته‌ها مشخص می‌کند. تحلیل پالینوفاسیس نشان‌دهنده یک محیط رسوبی بسیار نزدیک

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به ساحل تا حاشیه‌ای دریایی است. بررسی گروه‌های اکولوژیکی اسپورومورف‌ها (SEGs) نشان‌دهنده گسترش یک محیط lowland در بخش پایینی برش مورد مطالعه است که سرخس‌ها و سیکادها پوشش گیاهی غالب را در آن تشکیل می‌دهند. در ادامه، با افزایش سطح دریا، گروه اکولوژیک upland شامل مخروطیان و سرخس‌های دانه‌دار افزایش پیدا می‌کنند. افزایش سطح دریا و گسترش محیط ساحلی منجر به افزایش گروه‌های اکولوژیک ساحلی مانند Cheirolepidiaceae و Araucariaceae شده که تا انتهای برش مورد مطالعه ادامه پیدا می‌کنند. اجتماع اسپورومورف‌ها حاکی از غلبه اقلیم گرم و خشک در برش مورد مطالعه است. هرچند افزایش گرده‌های مربوط به Araucariaceae که وابسته به آب‌وهوای سردتر هستند، در بخش انتهایی باژوسین به‌عنوان شاهدی از یک فاز خنک‌شدگی تفسیر می‌شود که با داده‌های جهانی از تغییرات اقلیمی مشابه در این دوره مطابقت دارد.

INTRODUCTION

The Dalichai Formation is a significant geological unit in northern Iran (Alborz and Binalud Mountains), primarily composed of limestone, marl, and shale (e.g. Aghanabati, 2004). It was deposited during the Middle-Upper Jurassic, following the Mid-Cimmerian event, which was a major tectonic phase in the region (Wilmsen & al., 2009). After this event, the region experienced a period of rifting and subsidence, allowing for the deposition of the Dalichai Formation in a relatively shallow marine environment (e.g. Wilmsen & al. 2009; Fürsich & al., 2009). This basin was located at the southern part of the Eurasian margin at around 30° North. The Dalichai Formation typically overlies the Shemshak Group, which is characterized by siliciclastic coal-bearing deposits. The formation is covered by the cliff-forming carbonates of the Lar Formation (Seyed Emami & al., 2020 and the references therein).

The Dalichai Formation has been extensively studied for biostratigraphy and palynological contents in the Alborz Basin (e.g. Ghasemi-Nejad & al., 2012; Dehbozorgi & al., 2013; Skupien & al., 2015; Zarei 2017; Sajjadi & al., 2018; Hashemi-Yazdi & al., 2020; Kalanat & Raoufian, 2023a) and Binalud Mountains (Mafi & al., 2013; Ghasemi-Nejad & al., 2024; Kalanat & al., 2025). The correlation of different Dalichai Formation sections throughout the Alborz and Binalud regions reveals that this formation started to deposit in the late Bajocian, synchronously (Kalanat & al., 2025 and the references therein). Reconstruction of vegetation and sporomorph ecogroups analysis suggest that the Dalichai Formation was deposited in a warm climate in the Alborz Basin (Hashemi-Yazdi & Hashemi, 2017; Sajjadi & al., 2018; Kalanat & Raoufian, 2023a; Sajadi & al., 2023). However, the vegetation and paleoenvironment of the Dalichai Formation remain understudied in the Binalud Mountain.

The present study aims to document the vegetation of the Dalichai Formation in the Binalud Mountains and reconstruct the paleoenvironment and paleoclimate of these deposits using the terrestrial and marine paleoflora (i.e. pollen grains, spores, and dinoflagellate cysts).

MATERIAL AND METHODS

The Dalichai Formation in the studied section (Baqi section) is located in the eastern part of the Binalud Mountains at 36°35′37″N, 58°42′1″E, about 60 km northwest of Neyshabur (Figs. 1A, 1B). These deposits are mapped within the 1:100,000-scale Akhlamad geological map. The area features well-exposed outcrops of the Shemshak Group, Dalichai Formation, and Lar Formation, alongside overlying Cretaceous, Paleogene, Neogene, and Quaternary deposits (Fig. 1C).

Fourteen shale and marlstone samples were collected from the lower 100m of the Dalichai Formation in this section. The samples were processed for palynological studies using standard methods (Traverse 2007) in the Palynology Laboratory of the Research Institute of Forests and Rangelands in Tehran, Iran. Approximately 100g of each sample was treated with hydrochloric acid (35%) to dissolve carbonate minerals, followed by hydrofluoric acid (40%) to remove silicates. Organic matter is then concentrated using heavy liquid (zinc chloride) separation to isolate the palynomorphs from the heavy minerals. The residue is sieved using 15 µm nylon mesh to remove fine particles. Finally, the concentrated palynomorphs are mounted on glass slides for identification and analysis under a transmitted light microscope. All samples contain abundant, well-preserved palynomorph assemblages, except for sample 10, which lacks palynomorphs, likely due to oxidation during or after deposition.

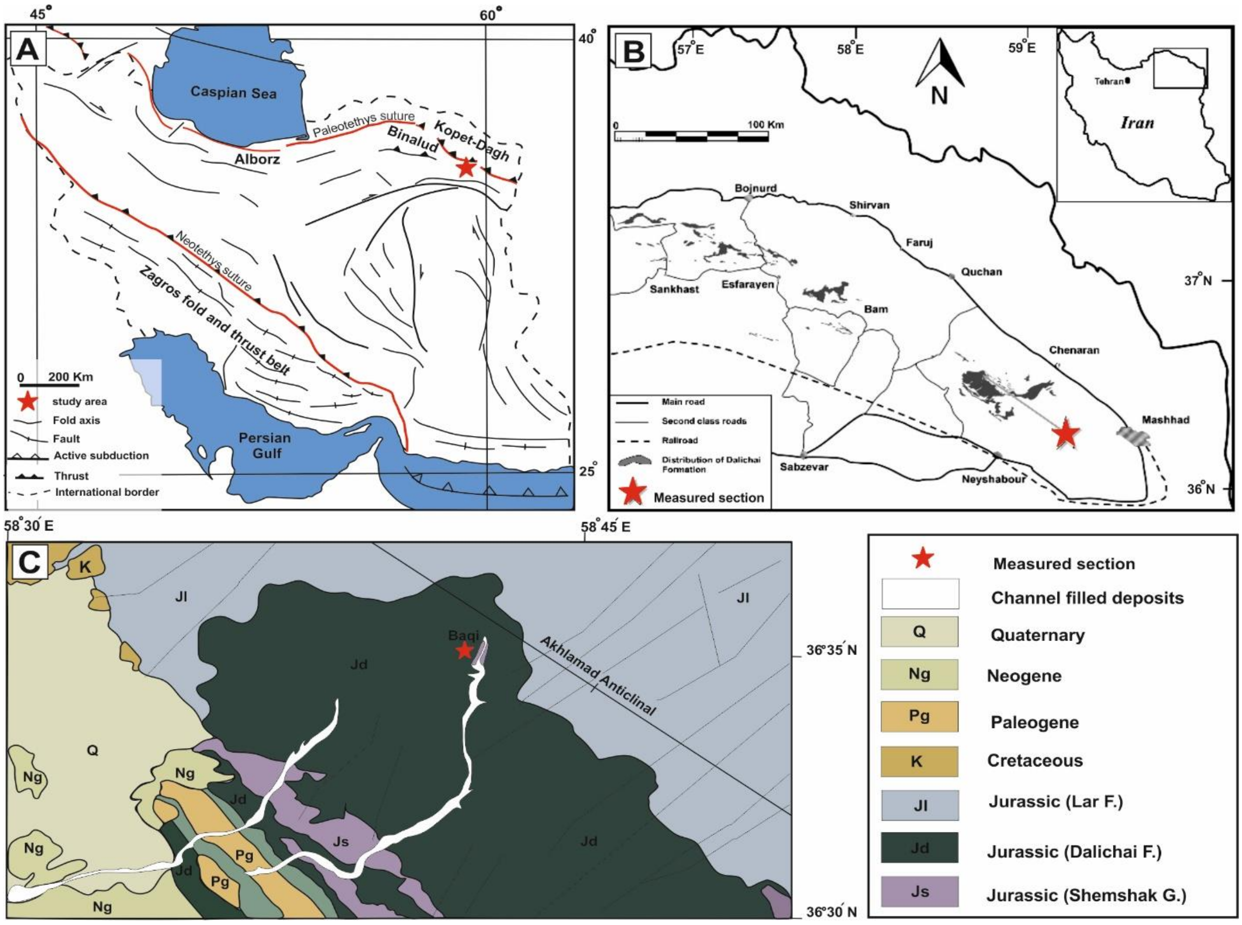

Fig. 1. A, The structural zones of Iran (modified after Angiolini & al. 2007). The studied area is located in the Binalud Mountains (NE Iran); B, The location of the studied area in the northwest of Neyshabur; C, the geological map of the studied section, representing the lithological units in this area.

Palynofacies analysis is based on counting at least 300 marine and terrestrial palynodebry particles in each sample and plotting the proportions of the main groups (phytoclasts, marine palynomorphs, and amorphous organic matter (AOM)) on Tyson's ternary diagram (1993, 1995). The vegetation dynamic and paleoclimate are reconstructed based on calculating the relation of spore and pollen to the total 100 specimens. The sporomorph ecogroups (SEGs) and the referred climate are from Abbink & al. (2001, 2004). The SEGs and affinities of spores and pollen grains are summarized in Table 1.

RESULTS

Lithostratigraphy

The Dalichai Formation in the Baqi section unconformably overlays the shale and sandstone layers of the Shemshak Group. The lower100 meters of the Dalichai Formation in this section can be divided into four lithological units (Fig. 2). The first unit consists of 25 meters of dark gray pencil shale (Fig. 2A). Following this, the second unit comprises 15 meters of light gray shale and marlstone containing calcareous nodules (Fig. 2B). The third unit includes 50 meters of gray shale and marlstone, where ammonites are rarely observed. The fourth unit comprises 10 meters of red shale and marlstone, where small ammonites are abundantly found (Fig. 2C).

Biostratigraphy

In total 23 species belonging to 14 genera of the dinoflagellate cysts were recognized in the study section (Fig. 3). Figures 4 and 5 illustrate the dinoflagellate cysts in the study section. This assemblage is similar to the Jurassic dinoflagellate cysts assemblage of northern and western Europe (Riding & Thomas 1992; Poulsen & Riding 2003).

One dinoflagellate cyst biozone corresponding to the *Cribroperidinium crispum* Total Range Zone (early to late Bajocian) of Riding & Thomas (1992) and DSJ14 biozone of Poulsen & Riding (2003) is recognized in the studied section. This biozone is defined as an interval between the first appearance and the last occurrence of the *Cribroperidinium crispum*. The last occurrences of *Mancodinium semitabulatum* and *Durotrigia daveyi* subdivided this biozone into two subzones a (early Bajocian) and b (late Bajocian).

The consistent presence of the nominate species throughout the section, combined with the absence of early Bajocian index taxa such as *Mancodinium semitabulatum* and *Durotrigia daveyi*, supports an upper Bajocian age for this interval. *Aldorfia aldorfensis*, *Ctenidodinium combazii*, *Nannoceratopsis* spp., *Meiourogonyaulax caytonensis*, *Valensiella ovulum*, *Tubotuberella dangeardii* and *Dissiliodinium giganteum* are other abundant dinoflagellate cysts in this interval.

Table 1. Botanical affinity of the Middle Jurassic sporomorphs in the studied section. The sporomorph ecogroups (SEGs) and climate are from Abbink & al. (2004).

SEG	Spore/pollen	Genera	Affinity	Remark
Upland	pollen	***Alisporites***	Corystospermales, in situ in *Pteruchus* (Townrow 1962), Voltziales (conifers) (Potonié 1962; Grauvogel-Stamm 1978)	
		Platysaccus	Corystospermales (Anderson & Anderson 1983)	
		Indusiisporites	Gymnospermopsida, Podocarpaceae (Boulter & Windle 1993)	
		Quadraeculina	Podocarpaceae (Boulter & Windle 1993)	
		Podocarpidites	Podocarpaceae (Boulter & Windle 1993)	
		alete bisaccate pollen grains	Pinaceae, Podocarpaceae (Van Konijnenburg-Van Cittert 1971; Boulter & Windle 1993)	
lowland	spore	***Cyathidites/ Deltoidospora/ Dictyophyllidites***	Dipteridaceae, Dicksoniaceae, Matoniaaceae, Cyatheaceae (Van Konijnenburg-Van Cittert 1989, 1993; Balme 1995; Abbink & al. 2004)	'drier'; 'warmer '
		Gleicheniidites	Gleicheniaceae (Potonié 1967)	'drier'; 'warmer
		Klukisporites	Schizaeaceae (Couper 1958)	'wetter'; 'warmer’
		Biretisporites	Schizaeaceae (Delcourt & Sprumont 1955)	
		Todisporites	Osmundaceae (Todites-type) (Van Konijnenburg-Van Cittert 1989)	
		Concavissimisporites	Dicksoniaceae/Cyatheaceae (Eboracia; Potonié 1970)	
		Converrucosisporites	Schizaeaceae (Couper 1958)	
		Verrucosisporites	Osmundaceae (Van Konijnenburg-Van Cittert 1978)	
		Ischyosporites	Schizaeaceae (Filatoff 1975)	'wetter'; 'warmer’
		Kyrtomisporis	Filicopsida (Raine & al. 2011)	
	pollen	***Cycadopites***	Bennettitales, Cycadales, Ginkgoales (Abbink & al. 2004)	'drier'; 'warmer'
		Chasmatosporites	Cycadales (Tralau 1968; Abbink & al. 2004)	'drier'; 'cooler'
		Ricciisporites	Bennettitales (Kürschner & al. 2014)	warmer
coastal	pollen	***Araucariacites***	Araucariaceae (Couper 1958; Van Konijnenburg-Van Cittert 1971)	cooler
		Caliallasporites	Araucariaceae (Van Konijnenburg-Van Cittert 1971; Boulter & Windle 1993)	cooler
		Classopollis	Cheirolepidiaceae (Traverse 2007)	warmer
pioneer	pollen	***Cerebropollenites***	Pinaceae (in situ in *Tsuga*) (Couper 1958), (Shang & Zavada 2003)	
Tidally-influenced	spore	***Perotrilites***	Lycopsida: Selaginellaceae? (Raine & al. 2011)	
		Limbosporites	Lycopodiaceae (Lycopsida) (Raine & al. 2011)	
		Retitriletes	Lycopodiaceae (Lycopodium-type) (Potonié 1967)	

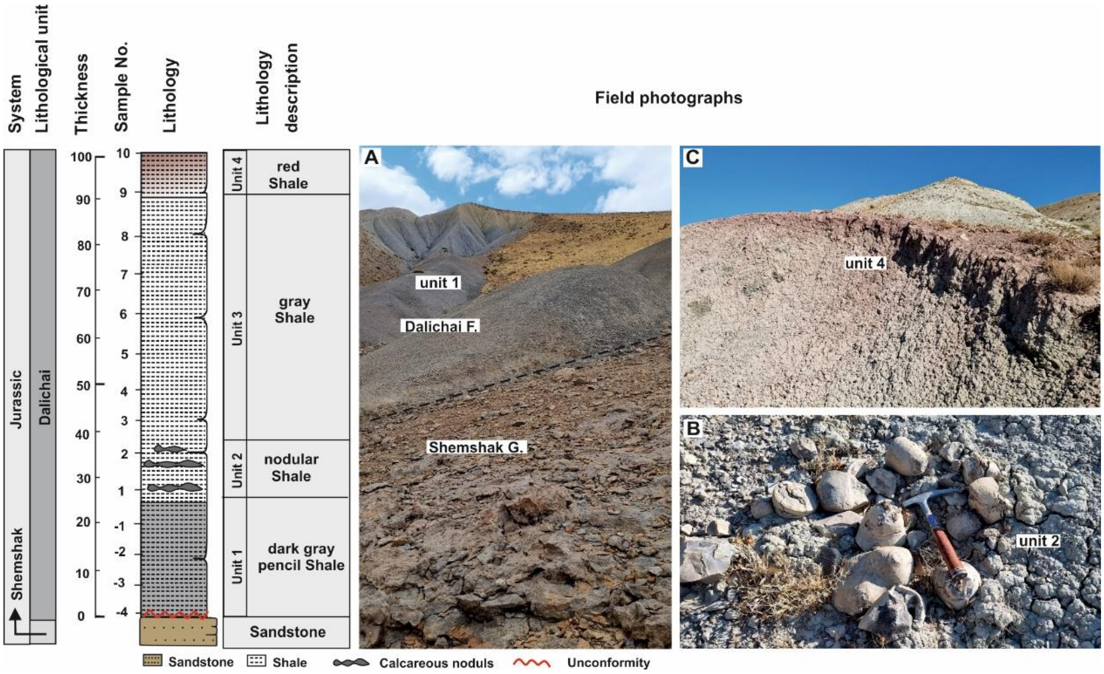

Fig. 2. Lithological units and field photographs of the lower part of the Dalichai Formation in the Baqi section. A, the boundary between sandstones of the Shemshak Group and dark shales (unit 1) at the base of the Dalichai Formation; B, calcareous nodules in unit 2 of the Dalichai Formation; C, Red shales of unit 4 at the upper part of the studied interval.

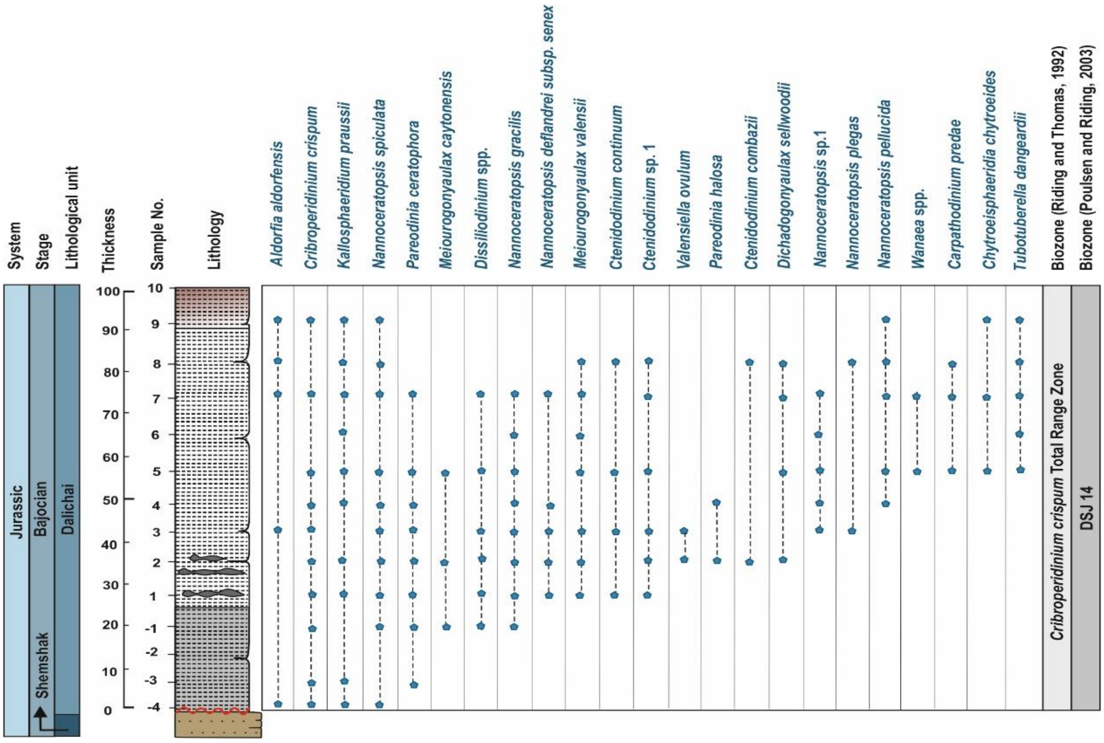

Fig. 3. Distribution of the dinoflagellate cysts in the upper Bajocian strata of the Binalud Mountains.

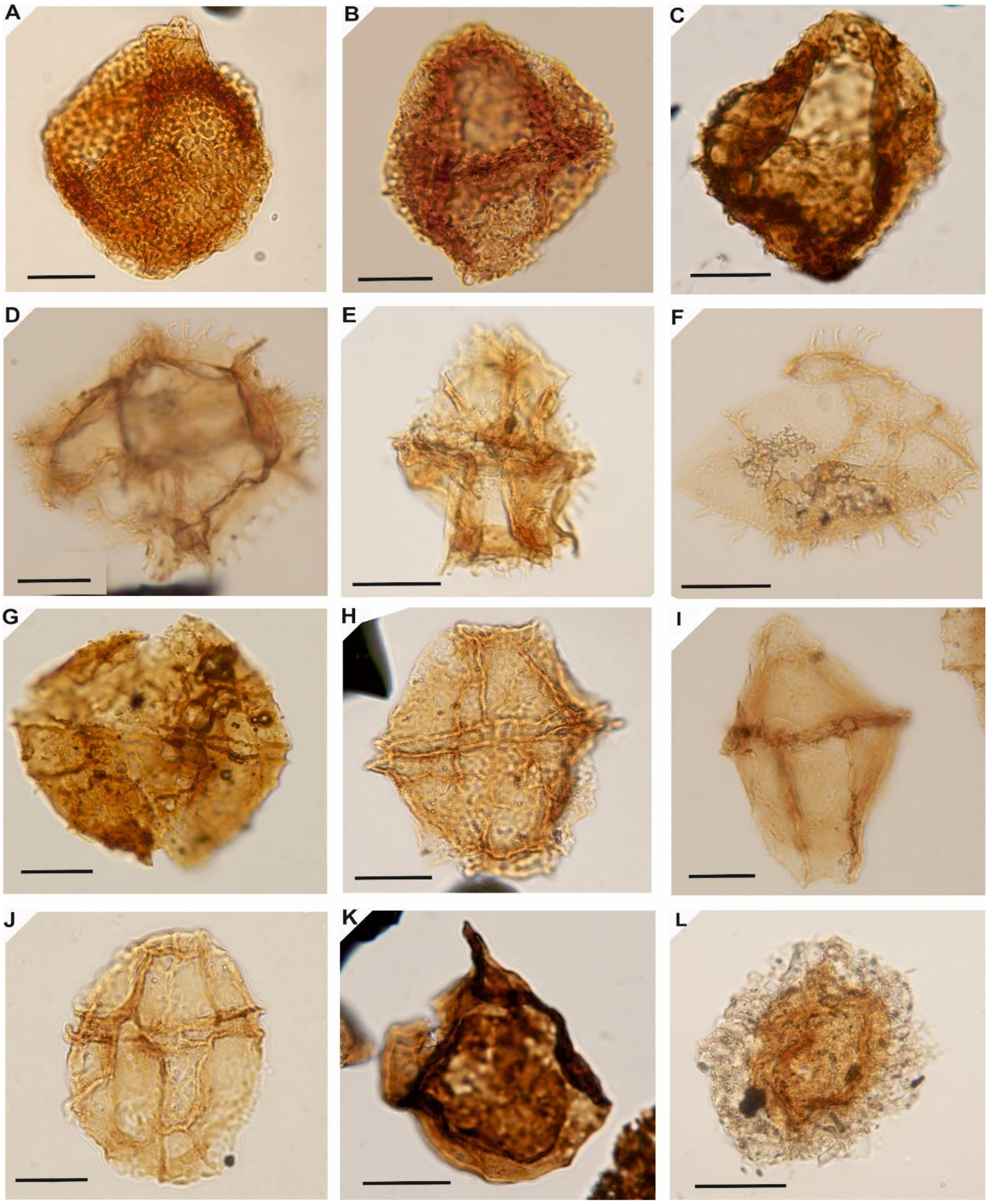

Fig. 4. Dinoflagellate cysts from upper Bajocian of the Binalud Mountains (scale bars=20 µm). A, *Aldorfia aldorfensis* (Gocht 1970) Stover & Evitt 1978 (sample no. 3); B & C, *Cribroperidinium crispum* (Wetzel 1967) Fenton 1981 (sample no. 1 & -1); D, *Dichadogonyaulax combazii* Dupin 1968 (sample no. 7); E, *Ctenidodinium continuum* Gocht 1970 (sample no. 1); F, *Ctenidodinium sellwoodii* (Sarjeant 1975) Stover & Evitt 1978 (sample no. 8); G, *Meiourogonyaulax caytonensis* (Sarjeant 1959) Sarjean 1969 (sample no. -1); H, *Meiourogonyaulax valensii* Sarjeant 1966 (sample no. 5); I, *Tubotuberella dangeardii* (Sarjeant 1968) Stover & Evitt 1978 (sample no. 7); J, *Carpathodinium predae* (Beju 1971) Drugg 1978 (sample no. 7); K, *Pareodinia ceratophora* Deflandre 1947 (sample no. -1); L, *Pareodinia halosa* (Filatoff 1975) Prauss 1989 (sample no. 2).

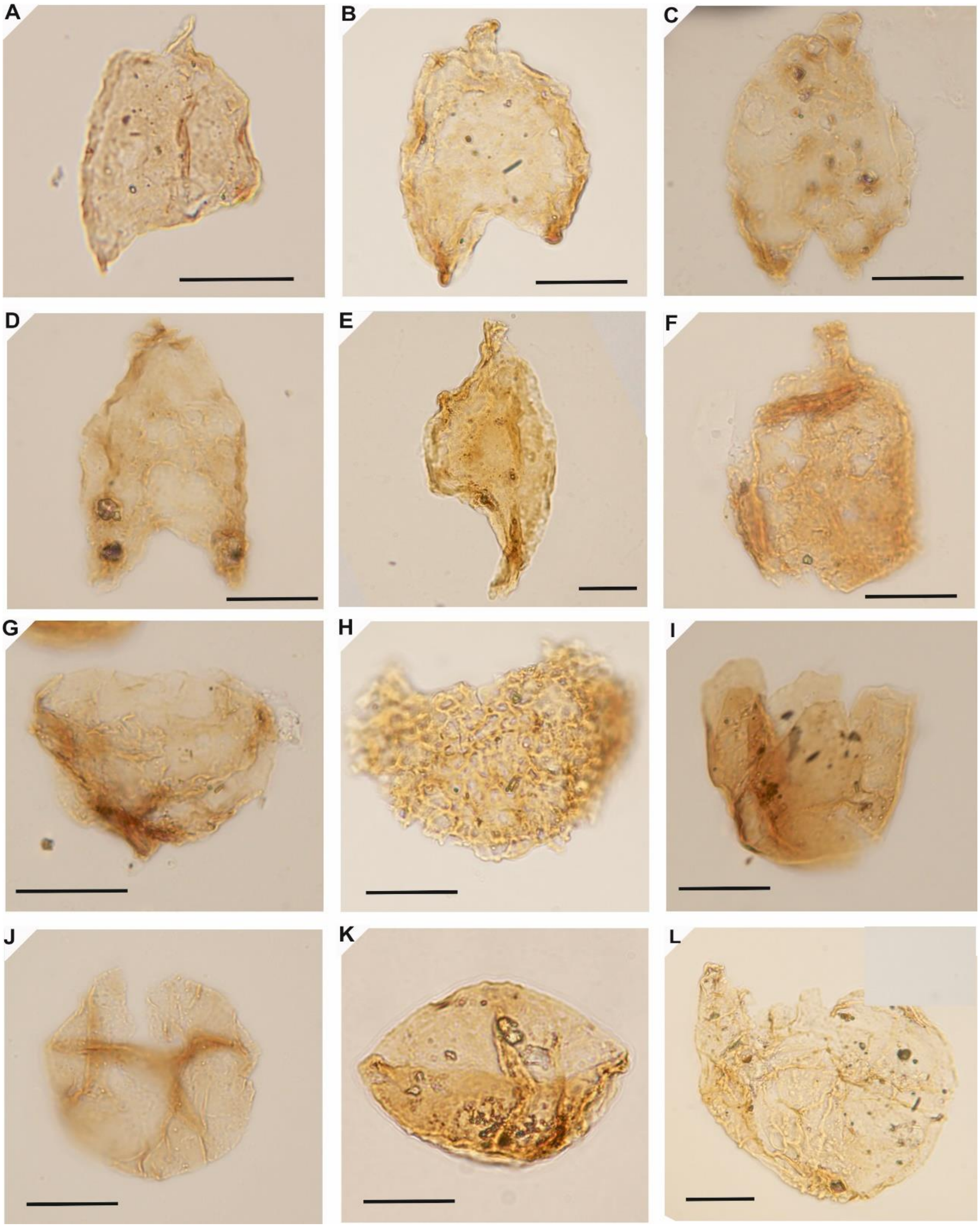

Fig. 5. Dinoflagellate cysts from upper Bajocian of the Binalud Mountains (scale bars=20 µm). A, *Nannoceratopsis deflandrei* subsp. *senex* (van Helden 1977) Ilyina & al. 1994 (sample no. 1); B, *Nannoceratopsis gracilis* Alberti 1961 (sample no. 2); C, *Nannoceratopsis spiculata* Stover 1966 (sample no. 7); D, *Nannoceratopsis pellucida* Deflandre 1939 (sample no. 8); E, *Nannoceratopsis plegas* Drugg 1978 (sample no. 3); F, *Nannoceratopsis* sp. (sample no. 7); G, *Wanaea* sp. (sample no. 7); H, *Valensiella ovulum* (Deflandre 1947) Eisenack 1963 (sample no. 2); I & L, *Kallosphaeridium praussii* Lentin & Williams 1993 (sample no. 7 & 1); J, *Chytroeisphaeridia chytroeides* (Sarjeant 1962) Downie & Sarjeant 1965 (sample no. 8); K, *Dissiliodinium giganteum* Feist-Burkhardt 1990 (sample no. 5).

Palynofacies

Plotting the percentage of organic elements on the ternary diagram AOM-Phytoclast-Palynomorph (Tyson 1995) led to the identification of two palynofacies in the studied section (Fig. 6).

Palynofacies Type I was identified in 3 samples (9, 4, and 3) from the studied interval (Fig. 6). Phytoclasts (opaque and translucent) are the main components (more than 90%) of this palynofacies. Marine palynomorphs and amorphous organic matter are present in low abundance in this palynofacies. This palynofacies is related to a very shallow water sea in a proximal shelf environment (Tyson 1993, 1995).

Palynofacies Type II was identified in 11 samples from the studied sequence (Fig. 6). Phytoclasts (opaque and translucent) and terrestrial palynomorphs (spores and pollen grains) are the main components (75%-95%) of this palynofacies. Amorphous organic matter (up to 25%) and marine palynomorphs (up to 10%) are other components of this palynofacies. This palynofacies is attributed to a marginal oxic to dysoxic basin, slightly deeper than Palynofacies Type I.

The red-colored layers in the upper part of the studied interval lack any palynomorphs, making it impossible to reconstruct their environment using palynofacies. These red deposits are comparable to the ammonitico rosso facies, which has been widely reported from the Jurassic of the Tethys Basin (e.g. Jenkyns 1974; Martire & al. 2006; Reolid & al. 2015). This facies results from the condsation of sediments on the top of the pelagic swells, formed during the opening of the Tethys (Martire & al. 2006). The ammonitico rosso facies has been reported from the Jurassic of the Alborz and Binalud basins in several sections (e.g. Raoufian & al., 2019; Kalanat & Raoufian, 2023b) and is likely related to rifting and the development of a horst-graben system during the formation of the South Caspian Basin (Wilmsen & al. 2009).

Vegetation reconstruction

A total of 16 species belonging to 13 genera of pollen grains and 19 species belonging to the 17 genera of spores were identified from the upper Bajocian interval of the Binalud Mountains (Figs. 7). Figures 8 to 11 illustrate all the sporomorph genera and species in the studied section.

The spore assemblages are dominated by fern spores (e.g. *Cyathidites*, *Deltoidospora*, *Dictyophyllidites*, *Gleicheniidites*, *Klukisporites*, *and Todisporites*) in this interval. The ferns reach their maximum abundance at 15 m (sample number -1) (Fig. 12). Lycopodiaceae are other spore-producer plants that occur sporadically with *Retitriletes*, *Limbosporites*, and *Perotrilites* genera. Their abundance never exceeds 10% of flora in this section (Fig. 12).

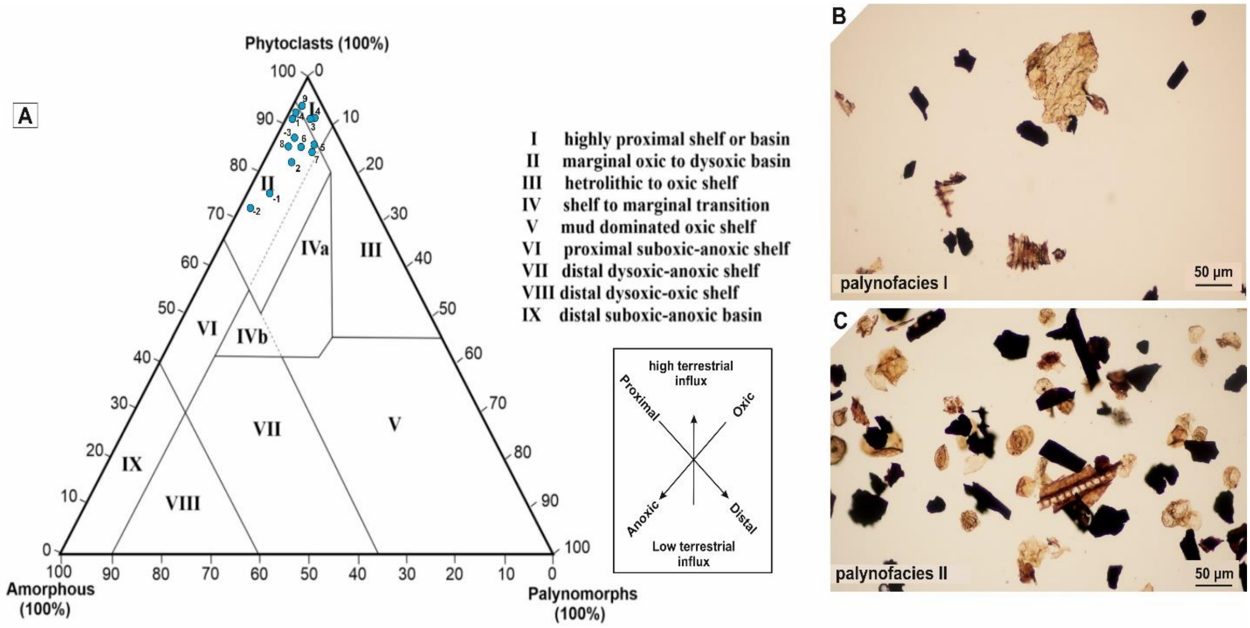

Fig. 6. A, AOM-Phytoclasts-Palynomorphs ternary plot (after Tyson 1993, 1995), with inferred palynofacies and depositional environments for the upper Bajocian strata of the Dalichai Formation in the Baqi section; B, Palynofacies type I (sample no. 4); C, Palynofacies type II (sample no. 7).

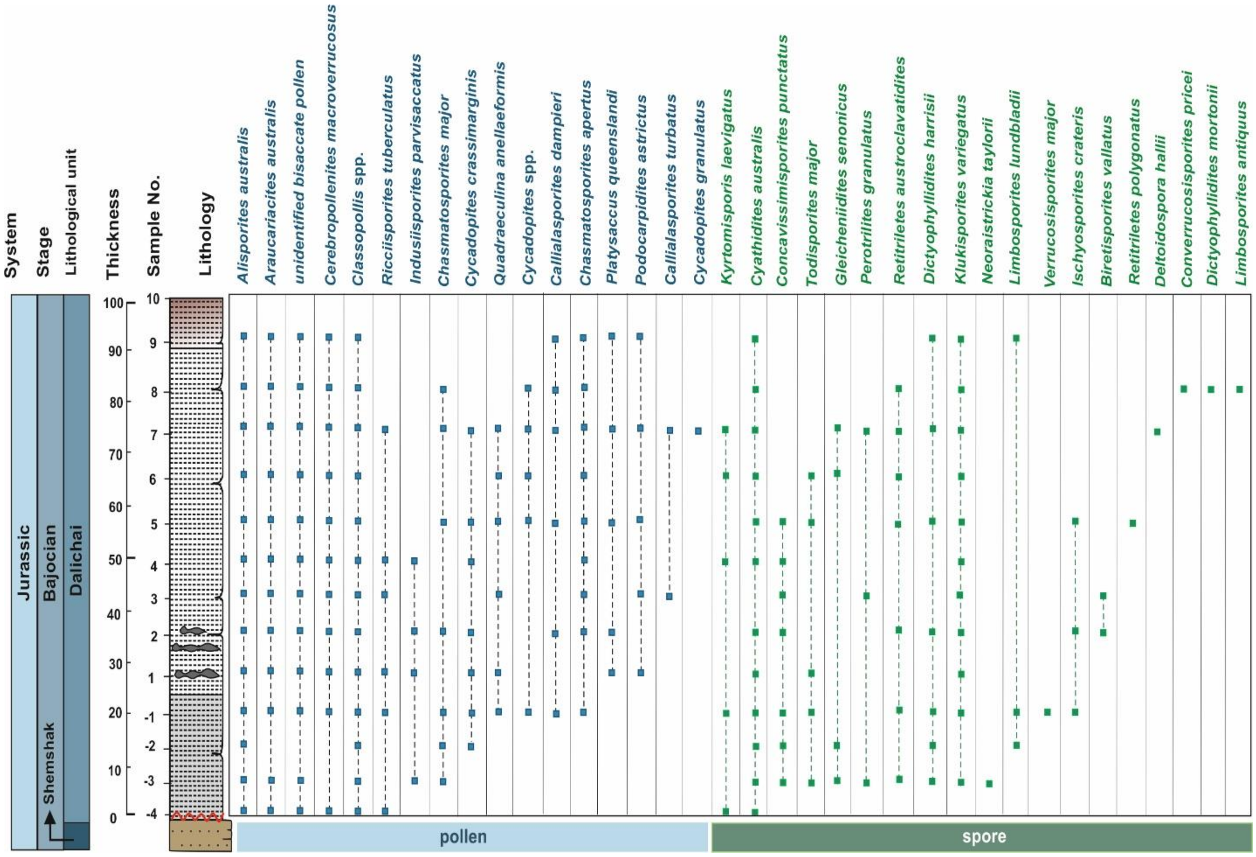

Fig. 7. Distribution of the pollen grains and spores in the upper Bajocian strata of the Dalichai Formation.

Gymnosperm pollen grains are well represented in the studied section. Cheirolepidiaceae (*Classopollis*; up to 40%) and Araucariaceae (*Araucariacites*, *Callialasporites*; up to 30%) are the most abundant pollen grains in this section (Fig. 12). Pinaceae and Podocarpaceae (bisaccate pollen producers) are also present, represented by the genera *Alisporites*, *Indusiisporites*, *Quadraeculina*, and *Podocarpidites*. These groups, along with seed ferns (another bisaccate pollen producer, *Platysaccus*), reach their maximum abundance at 27 m (sample number 2) (Fig. 12). Bennettitales, Cycadales, and Ginkgoales (*Cycadopites*, *Chasmatosporites*, and *Ricciisporites*) occur in low abundance in this interval (Fig. 12).

DISCUSSION

Paleoclimate and sea-level changes

The sporomorph ecogroups (SEGs) refer to classifications of spores and pollen (sporomorphs) based on their ecological preferences and the environments in which the parent plants lived. These SEGs are useful tools for the reconstruction of the ancient seal-level, climate conditions, and vegetation patterns (Abbink & al., 2001, 2004). The main SEGs, which are recognized in the studied interval are including upland (bisaccate pollen producers), lowland (ferns, Bennettitales, and Cycadales), coastal (Cheirolepidiaceae and Araucariaceae), tidally-influenced (Lycopodiaceae), and pioneer (*Cerebropollenites*) (Table 1, Fig. 12). The studied section is divided into four main paleoenvironmental intervals based on variations in these SEGs (Figs. 12, 13).

Interval 1: This interval (the lower 20 meters of the studied section) was deposited after the marine transgression, following the Middle Cimmerian unconformity. Plants belonging to the lowland SEG, which mainly include ferns such as *Cyathidites*, *Dictyophyllidites* are abundant in this interval (Fig. 12). The abundance of these plants indicates the presence of a vast lowland area beside a very shallow sea. The dominance of this flora, which thrive in warm and dry climates (Table 1), along with the high abundance of *Classopollis* pollen, which is recognized as the best indicator of a warm climate in the Jurassic lands (e.g. Volkheimer & al. 2008; Riding & al. 2013), suggests the expansion of a warm and dry climate during this time.

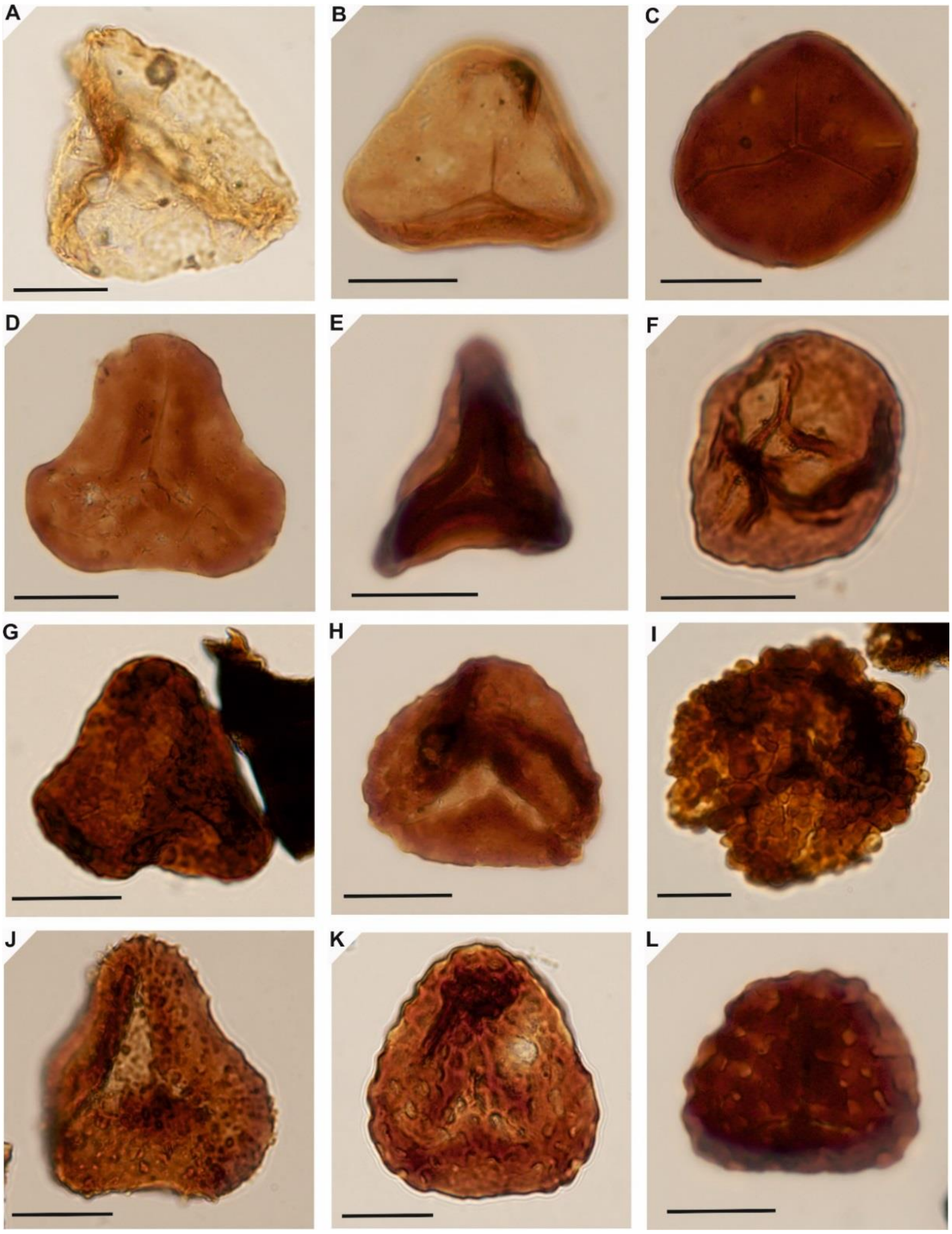

Fig. 8. Spores from upper Bajocian strata of the Binalud Mountains (scale bars=20µm; proximal foci for all samples). A, *Biretisporites vallatus* Sajjadi & Playford 2002 (sample no. 2); B, *Cyathidites australis* Couper 1953 (sample no. 7); C, *Deltoidospora hallii* Miner 1935 (sample no. 7); D, *Dictyophyllidites harrisii* Couper 1958 (sample no. 5); E, *Dictyophyllidites mortonii* (de Jersey 1959) Playford & Dettmann 1965 (sample no. 8); F, *Todisporites major* Couper 1958 (sample no. -3); G, *Concavissimisporites punctatus* (Delcourt & Sprumont 1955) Brenner 1963 (sample no. -3); H, *Converrucosisporites pricei* McKellar 1998 (sample no. 8); I, *Verrucosisporites major* (Couper 1958) Burden & Hills 1989 (sample no. -1); J, *Neoraistrickia taylorii* Playford & Dettmann 1965 (sample no. -1); K & L, *Klukisporites variegatus* Couper 1958 (sample no. 7 & 8).

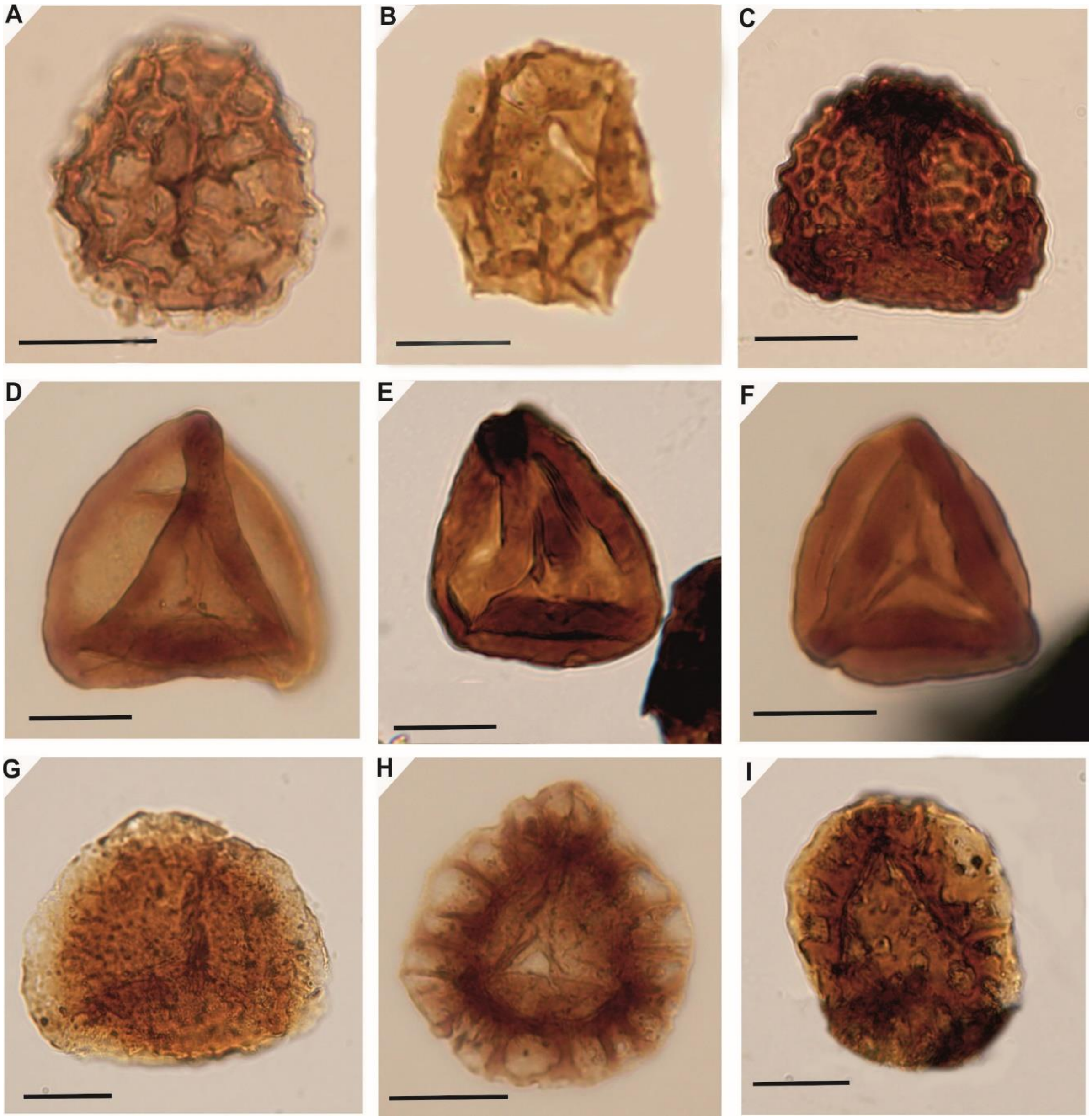

Fig. 9. Spores from upper Bajocian strata of the Binalud Mountains (scale bars=20µm; proximal foci for all samples except for sample B, which show median focus). A, *Retitriletes austroclavatidites* (Cookson 1953) Döring, Krutzsch, Mai & Schulz 1963 (sample no. 8); B, *Retitriletes polygonatus* Hashemi-Yazdi, Sajjadi & Dehbozorgi 2015 (sample no. 5); C, *Ischyosporites crateris* Balme 1957 (sample no. 5); D & E, *Gleicheniidites senonicus* (Ross 1949) emend. Skarby 1964 (sample no. 6 & -1); F, *Kyrtomisporis laevigatus* Mädler 1964 (sample no. 7); G, *Perotrilites granulatus* Couper 1953 (sample no. 3); H, *Limbosporites antiquus* (de Jersy 1964) de Jersy & Raine 1990 (sample no. 8); I, *Limbosporites lundbladii* Nilsson 1958 (sample no. -1).

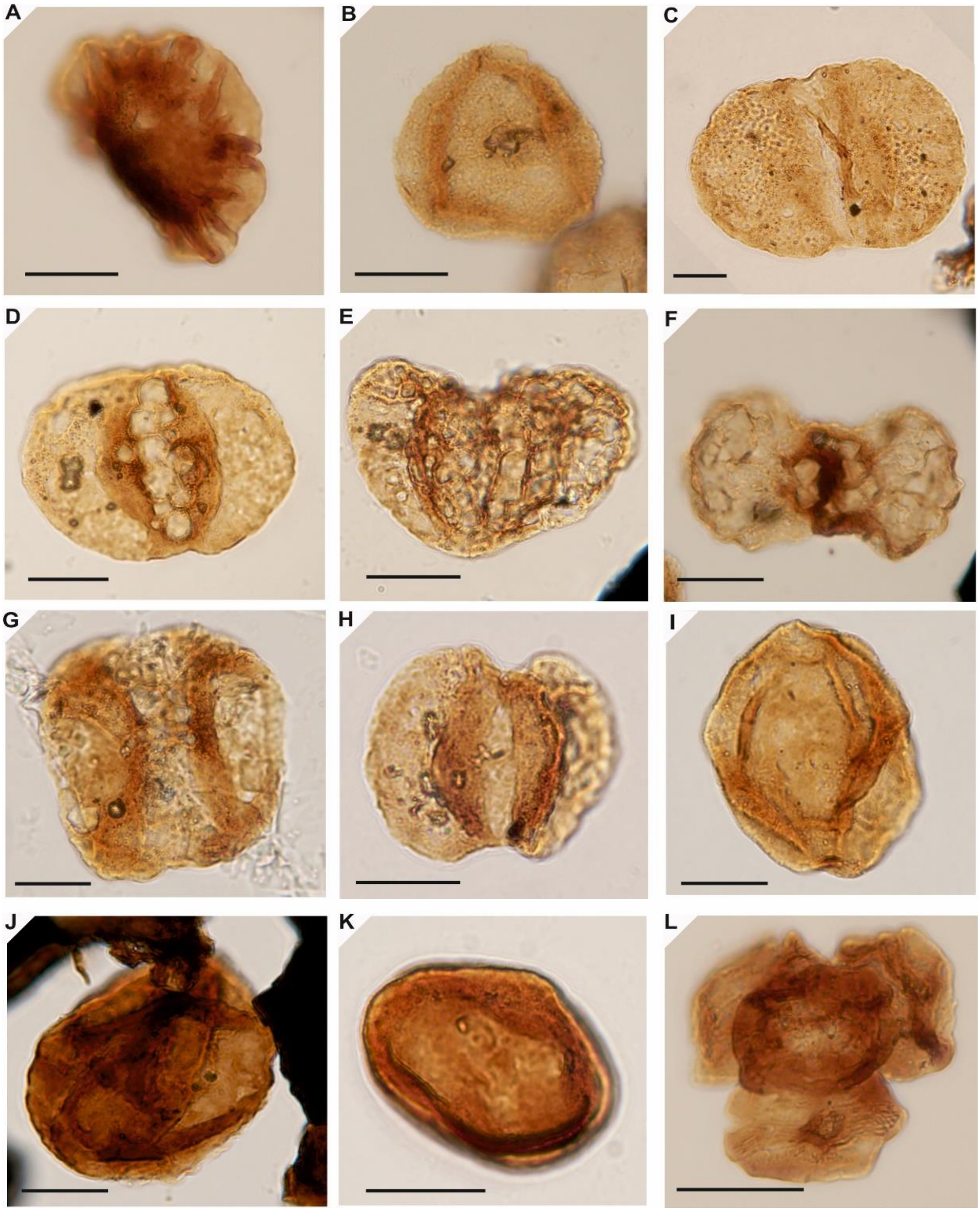

Fig. 10. Pollen grains from upper Bajocian strata of the Binalud Mountains (scale bars=20µm). A, *Callialasporites dampieri* (Balme 1957) Sukh Dev 1961 (sample no. 8; polar view); B, *Callialasporites turbatus* (Balme 1957) Schulz 1967 (sample no. 7, polar view); C, *Alisporites grandis* (Cookson 1953) Dettmann 1963 (sample no. 5; median focus); D, *Alisporites australis* de Jersey 1962 (sample no. 2; median focus); E, *Indusiisporites parvisaccatus* (de Jersey 1959) de Jersey 1963 (sample no. 4; median focus); F, *Platysaccus queenslandi* de Jersey 1962 (sample no. 7; distal focus); G, *Quadraeculina anellaeformis* Maljavkina 1949 (sample no. 3; proximal focus); H, *Podocarpidites astrictus* Haskell 1968 (sample no. 5, median focus); I & J, *Araucariacites australis* Cookson ex Couper 1953 (sample no. 3 & -1; median foci); K & L, *Classopollis* spp. (sample no. 5 & 8; median focus for K, lateral view for L).

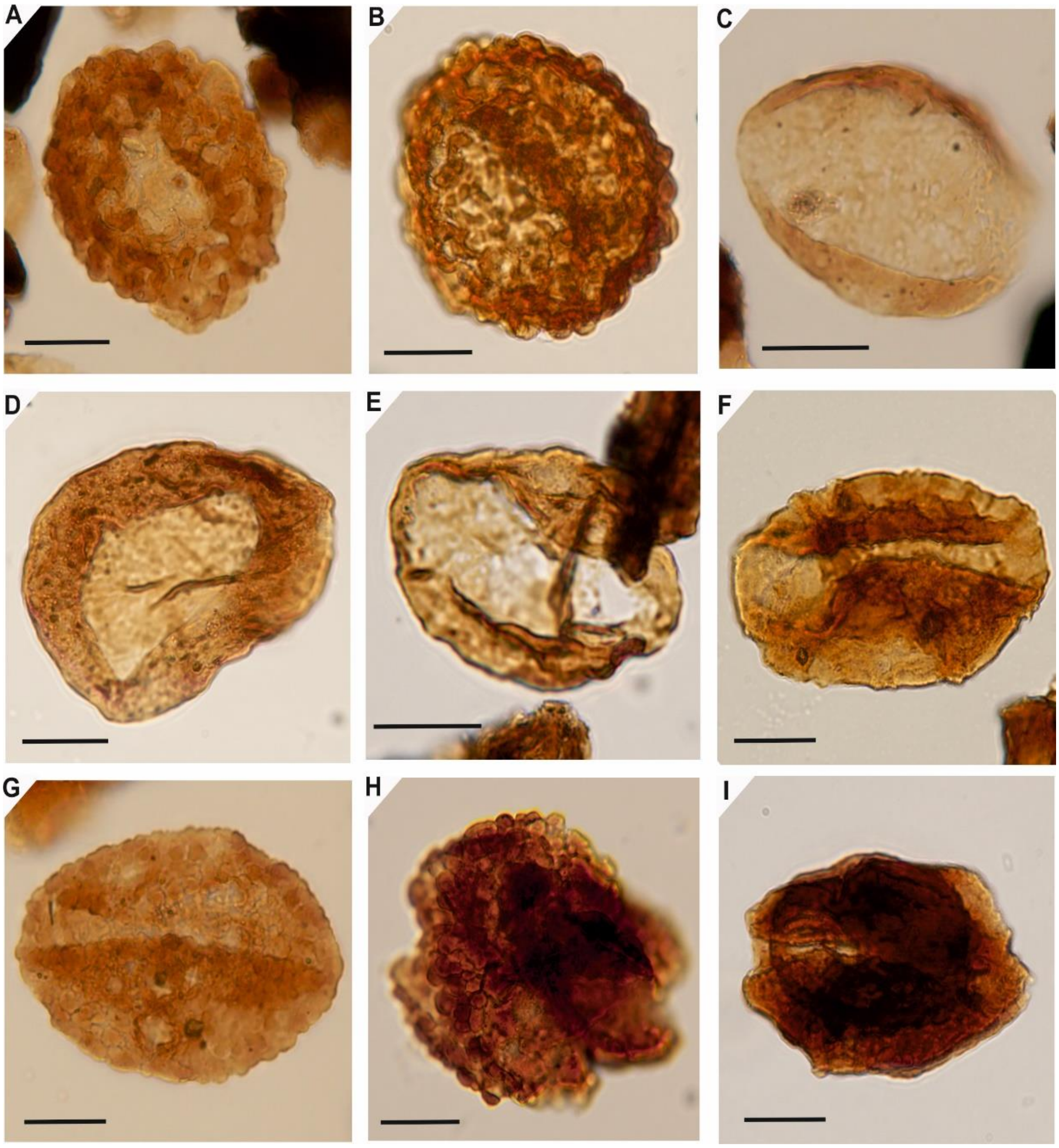

Fig. 11. Pollen grains from upper Bajocian strata of the Binalud Mountains (scale bars=20 µm; median foci for all samples). A & B, *Cerebropollenites macroverrucosus* (Thiergart 1949) Schulz 1967 (sample no. 7 & 3); C & D, *Chasmatosporites apertus* (Rogalska 1954) Nilsson 1958 (sample no. 7 & 2); E, *Chasmatosporites major* Nilsson 1958 (sample no. -1); F, *Cycadopites crassimarginis* (de Jersey 1959) de Jersey 1964 (sample no. -1); G, *Cycadopites granulatus* (de Jersey 1959) de Jersey 1964 (sample no. 7); H & I, *Ricciisporites tuberculatus* Lundblad 1954 (sample no. 1 & 3).

Interval 2: This interval extending from the 25 meters to the 43 meters of the studied section, is characterized by a marked increase in the bisaccate pollen belonging to the upland SEG (Figs. 12 & 13). According to Abbink & al. (2004), in marine environments, the abundance of bisaccate pollen increases with the deepening of the basin, as these pollen grains are transported by wind and have a greater chance of reaching the deeper marine environments. In contrast, the water-transported sporomorphs decrease in offshore environments. The ferns belonging to the warm lowland environments along with *Classopollis* are the second most abundant sporomorphs in this interval (Fig. 12). This plant assemblage indicates a sea-level rise in the marine environment and the dominance of a warm climate during this time. The index fern spores for the wet climate including *Klukisporites* and *Ischyosporites* slightly increase in this interval (Fig. 12). Abbink & al. (2004) suggest that an increase in water-elements of the lowland SEG during a sea-level rise can be attributed to the declining drainage conditions and a higher groundwater table in the lowland.

This interval is also characterized by an increase in pioneer SEG *Cerebropollenites* in the plant community (Fig. 12). This suggests that during the sea level rise, coastal environments such as deltas, estuaries, and low-lying floodplains expanded and *Cerebropollenites*-producing plants, being pioneer species (e.g. Abbink & al. 2004), were among the first to establish themselves in these unstable recently developed environments.

Interval 3: This interval spans 43 to 75 meters of the studied section. It is characterized by dominance of the coastal SEGs, specially *Classopollis and Araucariacites* genera. The fossil records indicate that the parent plant of these genera likely formed coastal forests because they were resistant against the salt spray (Vakhrameev 1991; Batten and Mac Lennan, 1984; Harris 1979; Watson 1988). The high abundance of these genera suggests that the land-ward shift of shoreline in the previous interval have increased the invasion of the coastal area and expanded the coastal SEGs.

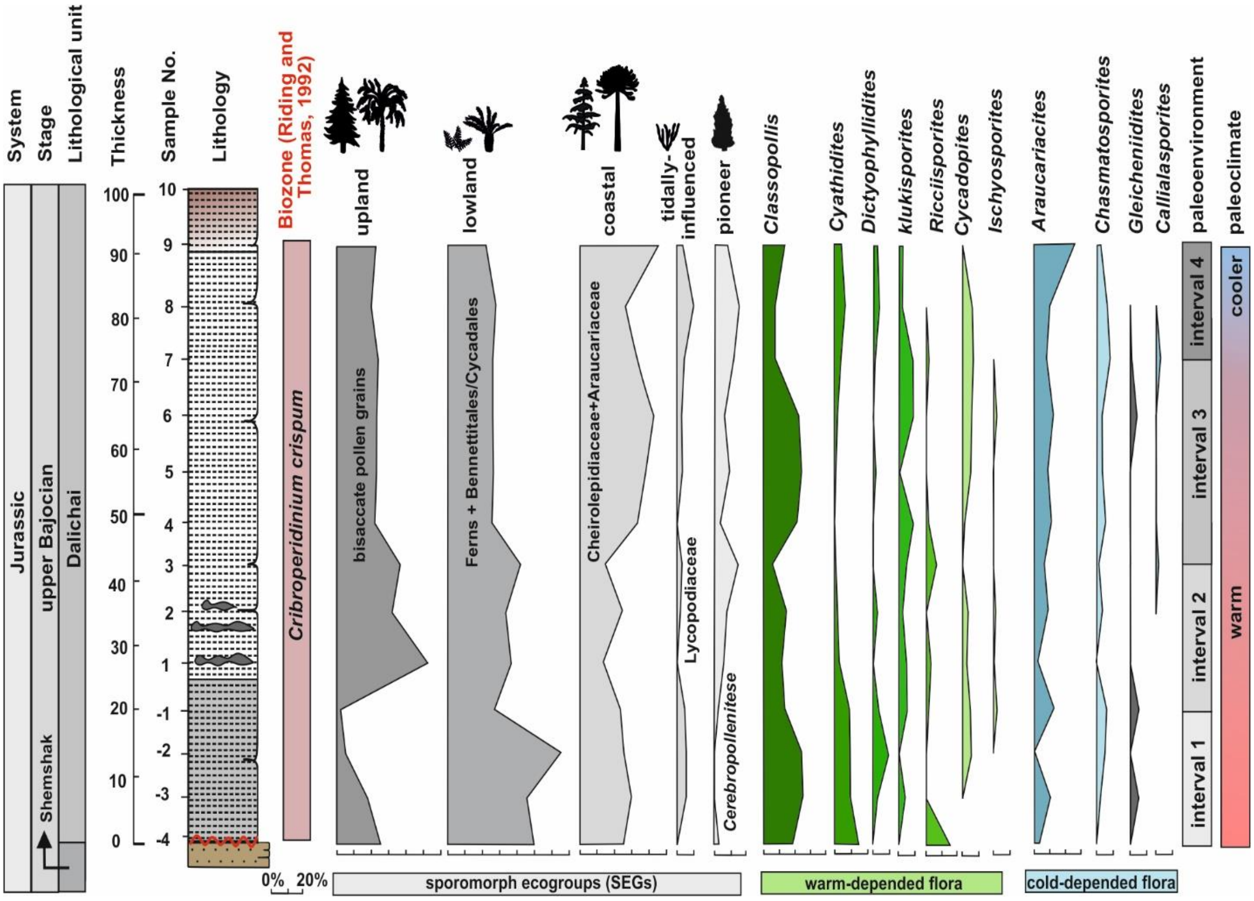

Fig. 12. Variations in the sporomorph ecogroups (SEGs) and main climate-depended plant genera in the upper Bajocian strata of the Binalud Mountains.

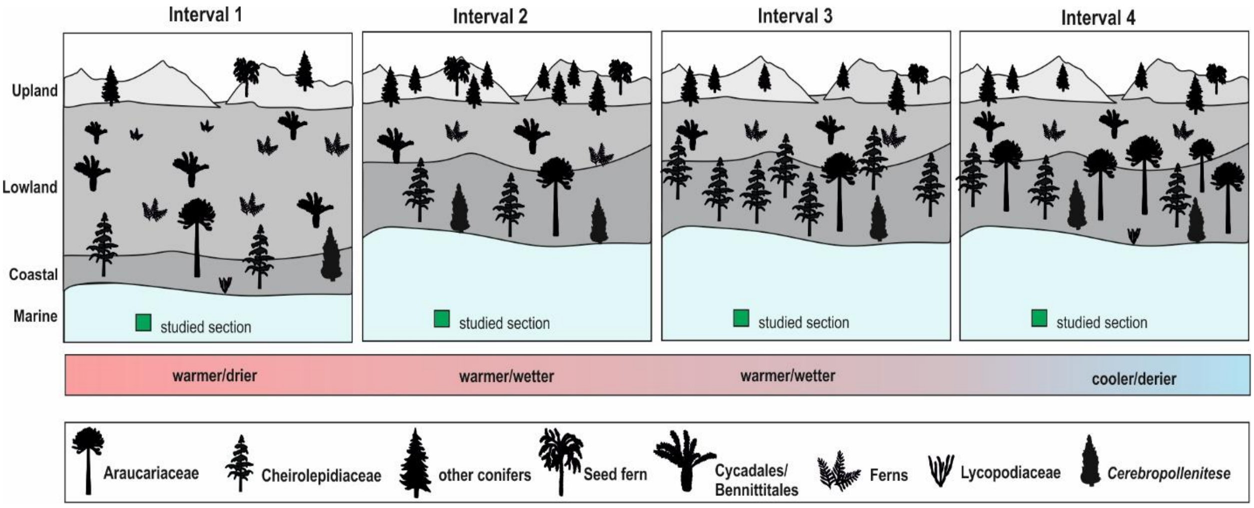

Fig. 13. Schematic reconstruction of the major changes in the vegetation assemblages and paleoenvironment through the upper Bajocian of the Binalud Mountains.

The high abundance of *Classopollis*, along with warm-adapted lowland pollen such as *Cycadopites* and *Klukisporites* in this interval, reflects the dominance of a warm climate during this phase.

Interval 4: This interval spans the upper 15 meters of the studied section. It is characterized by a notable increase in *Araucariacites* and *Callialasporites* pollen grains, taxa associated with relatively cooler conditions (Abbink & al., 2001, 2004), coupled with a decline in *Classopollis* (Fig. 12). This suggests a shift toward a cooling phase during the uppermost Bajocian. Evidence of a cooling phase in this interval has been identified in various parts of the world, supported by geochemical data (Dromart & al., 2003; Wierzbowski & Joachimski, 2007; Dera & al., 2011). The Bajocian-Bathonian boundary is among the few cooling episodes within the generally warm and humid climate that characterized the Jurassic period (e.g. Dera & al. 2011). The decline of water-element flora such as *Klukisporites* and *Ischyosporites* in this interval suggests a drier condition related to the previous interval.

Paleogeographic maps from the Middle Jurassic indicate that the northern regions of Iran, including the Alborz and Binalud zones, were located on the southern margin of Eurasia at a paleolatitude of approximately 30°N during this interval (e.g. Stampfli & Borel, 2002). Reported plant macrofossils from northern and central Iran further confirm that these regions lay within a warm and humid climatic belt (Euro-Sinian climate) (Vajda & Wigforss, 2009). The study of plant communities in the Dalichai Formation using the miospores suggests the dominance of a general warm and humid climate over Middle Jurassic deposits in northern Iran (Dehbozorgi & al., 2013; Hashemi-Yazdi & Hashemi, 2017; Hashemi-Yazdi & al., 2020; Sajadi & al., 2023). However, more detailed studies are needed to identify smaller-scale climatic variations in this region.

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REFERENCES

Abbink, O., Targarona, J., Brinkhuis, H. & Visscher, H. 2001: Late Jurassic to earliest Cretaceous palaeoclimatic evolution of the southern North Sea. -Global and Planetary Change 30: 231-256. https://doi.org/10.1016/S0921-8181(01)00101-1

—, Van Konijnenburg-Van Cittert, J.H.A. & Visscher, H. 2004: A sporomorph ecogroup model for the Northwest European Jurassic Lower Cretaceous: concepts and framework. -Netherlands Journal of Geosciences 83: 17-38. https://doi.org/10.1017/S0016774600020436

Aghanabati, A. 2004: Geology of Iran. Geological survey and mineral exploration of Iran, 586 pp (in Farsi).

Anderson, JM. & Anderson, H.M. 1983: Palaeoflora of southern Africa, Molteno Formation (Triassic) 1. (Part1. Introduction; Part 2. Dicroidium). Balkema, Rotterdam. 567 pp.

Angiolini, L., Gaetani, M., Muttoni, G., Stephenson, M.H. & Zanchi, A. 2007: Tethyan oceanic currents and climate gradients 300 m.y. ago. -Geology 35: 1071-1074. https://doi.org/10.1130/G24031A.1

Balme, B.E. 1995: Fossil in situ spores and pollen grains: An annotated catalogue. -Review of Palaeobotany Palynology 87: 1-323. https://doi.org/10.1016/0034-6667(95)93235-X

Batten, D.J. & MacLennan, A.M. 1984: The paleoenvironmental significance of the conifer family Cheirolepidiaceae in the Cretaceous of Portugal. In: Reif, W.E., Westphal, F. (eds), Third Symposium on Mesozoic Terrestrial Ecosystems, Short Papers. Attempto Verlag, Tübingen, pp. 7-12.

Boulter, M.C. & Windle, T. 1993: A reconstruction of some Middle Jurassic vegetation in Northern Europe. -Papers in Palaeontology 49: 125-154.

Couper, R.A. 1958: British Mesozoic microspores and pollen grains. -Palaeontographica 103: 75-179.

Dehbozorgi, A., Sajjadi, F. & Hashemi, H. 2013: Middle Jurassic palynomorphs of the Dalichai Formation, central Alborz Ranges, northeastern Iran: Paleoecological inferences. Science China: -Earth Sciences 12: 2107-2115. https://doi.org/10.1007/s11430-013-4697-z

Delcourt, A. & Sprumont, G. 1955: Les spores et grains de pollen du Wealdien du Hainaut. Memoires de la Société Belge de Géologie, de Paléontologie et d'Hydrologie 5: 1-73.

Dera, G., Brigaud, B., Monna, F., Laffont, R., Pucéat, E., Deconinck, J.F., Pellenard, P., Joachimski, M.M. & Durlet, C. 2011: Climatic ups and downs in a disturbed Jurassic world. -Geology 39: 215–218. https://doi.org/10.1130/G31579.1

Dromart, G., Garcia, J.-P., Gaumet, F., Picard, S., Rousseau, M., Atrops, F., Lécuyer, C. & Sheppard, S.M.F. 2003: Perturbation of the carbon cycle at the Middle/Late Jurassic transition: Geological and geochemical evidence. -American journal of science 303: 667-707. https://doi.org/10.2475/ajs.303.8.667

Filatoff, J. 1975: Jurassic Palynology of the Perth Basin, Western Australia. -Palaeontographica 154: 1-113.

Fürsich, F.T., Wilmsen, M., Seyed-Emami, K. & Majidifard, M.R. 2009: The Mid-Cimmerian tectonic event (Bajocian) in the Alborz Mountains, northern Iran: Evidence of the break-up unconformity of the South Caspian Basin. In: Brunet, M.F., Wilmsen, M., Granath, J. (eds), South Caspian to Central Iran Basins. Geological Society of London, pp. 189-203.

Ghasemi-Nejad, E., Sabbaghiyan, H. & Mosaddegh, H. 2012: Paleobiogeographic implications of late Bajocian-late Callovian (Middle Jurassic) dinoflagellate cysts from the Central Alborz Mountain, northern Iran. -Journal of Asian Earth Science 43: 1-10. https://doi.org/10.1016/j.jseaes.2011.08.006

—, Esmaili, E., Majidifard, M.R. & Sharifi, M. 2024: Biostratigraphy of Bajocian-Oxfordian strata based on dinoflagellate cysts and ammonites from the Dalichai Formation, northeastern Iran. -Palaeoworld 33: 374-388. https://doi.org/10.1016/j.palwor.2023.04.003

Grauvogel-Stamm, L. 1978: La flore du Grès à Voltzia (Buntsandstein súperieur) des Vosges du Nord (France). Morphologie, anatomie, interprétations phylogénique et paléogéographique. Université Louis-Pasteur de Strasbourg Institut de Géologie 50: 1-225.

Harris, T.M. 1979: The Yorkshire Jurassic flora, V. Coniferales. British Museum (Natural History), London. 166 pp.

Hashemi-Yazdi, F., Bashiri, N. & Sajjadi, F. 2020: Palynofacies and Sporomorph Eco Groups-based paleoecology implications for the Dalichai Formation, Andariyeh, central Alborz. -Journal of Stratigraphy and Sedimentary Research 72: 21-36 (in Farsi). https://doi.org/10.22108/JSSR.2020.118759.1116

— & Hashemi, H. 2020: Paleoenvironmental implications for the Dalichai Formation in two stratigraphic sections, Sharaf and Tapal (central and eastern Alborz Mountains) based on Sporomorph EcoGroups. -Journal of Stratigraphy and Sedimentary Research 68: 1-14 (in Farsi). https://doi.org/10.22108/JSSR.2017.104681.1017

Jenkyns, H.C. 1974: Origin of red nodular limestones (Ammonitico Rosso, Knollenkalke) in the Mediterranean Jurassic: a diagenetic model. In: Hsü, K.J., Jenkyns, H.C. (eds), Pelagic sediments on lands and under the sea. Blackwell, London, pp. 249-271.

Kalanat, B., Davtalab, E. & Raoufian, A. 2025: The biostratigraphy and palaeobiogeography of the Late Jurassic dinoflagellate cysts from the Binalud Mountains, NE Iran. -Marine Micropaleontology 195: 102446. https://doi.org/10.1016/j.marmicro.2025.102446

— & Raoufian, A. 2023a: Palynological evidence for the Middle Jurassic environmental evolution in the eastern part of the Alborz Mountains (northern Iran). -Review of Palaeobotology and Palynology 312: 104874. https://doi.org/10.1016/j.revpalbo.2023.104874

— & Raoufian, A. 2023b: Middle Jurassic syn-sedimentary tectonics and palaeoenvironmental evolution in the eastern part of the Alborz Mountains (N Iran). -Marine and Petroleum Geology 155, 106414. https://doi.org/10.1016/j.marpetgeo.2023.106414

Kürschner, W.M., Mander, L. & McElwain, J.C. 2014: A gymnosperm affinity for Ricciisporites tuberculatus Lundblad: implications for vegetation and environmental reconstructions in the Late Triassic. -Paleobiodiversity and Paleoenvironment 94(2): 295-305. https://doi.org/10.1007/s12549-014-0163-y

Mafi, A., Ghasemi-Nejad, E., Ashouri, A. & Vahidinia, M. 2013: Dinoflagellate cysts from the Upper Bajocian-Lower Oxfordian of the Dalichai Formation in Binalud Mountains (NE Iran): their biostratigraphical and biogeographical significance. -Arabian Journal of Geosciences 6 (127): 1-12. https://doi.org/10.1007/s12517-013-0976-4

Martire, L., Clari, P., Lozar, F. & Pavia, G. 2006: The Rosso Ammonitico Veronese (Middle-Upper Jurassic of the Trento Plateau): A proposal of lithostratigraphic ordering and formalization. -Rivista italiana di paleontologia e stratigrafia 112: 227-250.

Potonié, R. 1962: Synopsis der Sporae in situ. Beihefte zum Geologischen Jahrbuch 52: 1–204.

— 1967: Versuch der Einordnung der fossilen Sporae dispersae in das phylogenetischen System der Pflanzenfamilien. Forschungsber. -Landes Nordrhein-Westfalen 1761: 11-310.

— 1970: Die fossilen Sporen: ihre morphologische (phylogenetische) neben der morphographischen Ordnung. -Westdeutscher Verlag 2108: 193.

Poulsen, N.E. & Riding, J.B. 2003: The Jurassic dinoflagellate cyst zonation of subboreal Northwest Europe. -Geological Survey of Denmark and Greenland Bulletin 1: 115-144. https://doi.org/10.34194/geusb.v1.4650

Raine, J.I., Mildenhall, D.C. & Kennedy, E.M. 2011: New Zealand Fossil Spores and Pollen: An Illustrated Catalogue, 4th edition. GNS Science Miscellaneous Series, no. 4.

Raoufian, A., Zand-Moghadam, H. & Seyed-Emami, K. 2019: Depositional history of Middle-Upper Jurassic succession at the Binalud Mountains, NE Iran: implications of ammonite, trace fossil and stable isotopes in palaeoenvironmental analysis. -Historical Biology 32: 1-18. https://doi.org/10.1080/08912963.2018.1563078

Reolid, M., Rivas, P. & Rodríguez-Tovar, F.J. 2015: Toarcian ammonitico rosso facies from the South Iberian Paleomargin (Betic Cordillera, southern Spain): paleoenvironmental reconstruction. -Facies 61: 22-42. https://doi.org/10.1007/s10347-015-0447-3

Riding, J.B., Leng, M.J., Kender, S., Hesselbo, S.B. & Feist-Burkhardt, S. 2013: Isotopic and palynological evidence for a new Early Jurassic environmental perturbation. -Palaeogeography, Palaeoclimatology, Palaeoecology 374: 16-27. https://doi.org/10.1016/j.palaeo.2012.10.019

— & Thomas, J.E. 1992: Dinoflagellate cysts of the Jurassic system. In: Powell, A.J. (ed), A stratigraphic Index of Dinoflagellate Cysts. Chapman & Hall, London. pp. 1-92.

Sajjadi, F., Dermanaki Farahani, S. & Hashemi-Yazdi, F. 2018: Palynology of the Dalichai Formation in the Guydagh section, southeastern Maragheh, according to dinoflagellate. -Journal of Stratigraphy and Sedimentary Research 34: 91-108 (In Farsi). https://doi.org/10.22108/JSSR.2018.84036.0

Sajjadi, F., Hashemi-Yazdi, F., & Hashemi, H. 2023: Palynostratigraphy and palaeoecology of the Dalichai Formation at the Yonjehzar stratigraphic section, northeastern Tehran, central Alborz. -Geoscience 33: 259-282 (in Farsi). https://doi.org/10.22071/gsj.2023.350092.2013

Seyed-Emami, K., Wilmsen, M., Fürsich, F.T., Majidifard, M.R., Raoufian, A. & Taheri, J. 2020: A summary of the Jurassic System in North and East-Central Iran. -Zitteliana 94: 99-156.

Shang, Y. & Zavada, M. 2003: The ultrastructure of Cerebropollenites from the Jurassic and Cretaceous of Asia. -Grana 42: 102-107. https://doi.org/10.1080/00173130310009020

Skupien, P., Pavlus, J., Falahatgar, M. & Javidan, M. 2015: Middle Jurassic organic-walled dinoflagellate cysts and palynofacies from Telma-Dareh, south of Sari, northern Iran. -Review of Palaeobotany and Palynology 223: 128-137. https://doi.org/10.1016/j.revpalbo.2015.09.009

Stampfli, G.M. & Borel, G.D. 2002: A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrones. -Earth and Planetary Science Letters 196: 17-33. https://doi.org/10.1016/S0012-821X(01)00588-X

Townrow, J.A. 1962: On Pteruchus, a microsporophyll of the Corystosper maceae. -Bulletin of the British Museum 6: 287-320.

Tralau, H. 1968: Some middle Jurassic miospores of southern Sweden. -Geologiska Föreningen i Stockholm Förhandlingar 89: 469-472.

Traverse, A. 2007: Paleopalynology. Second Edition, Springer. 813 pp.

Tyson, R.V. 1993: Palynofacies analysis. In: Jenkins, D.J. (ed), Applied Micropalaeontology. Kluwer Academic Publishers, Dordrecht. pp. 153-191.

Tyson, R.V. 1995: Sedimentary Organic Matter: Organic Facies and Palynofacies. Chapman and Hall, London. 615 pp.

Vakhrameev, V.A. 1991: Jurassic and Cretaceous Floras and Climates of the Earth. Cambridge University Press, Cambridge. 318 pp.

Van Konijnenburg-Van Cittert, J.H.A. 1971: In situ gymnosperm pollen from the Middle Jurassic of Yorkshire. -Acta botanica neerlandica 20: 1-97.

— 1989: Dicksoniaceous spores in situ from the Jurassic of Yorkshire, England. -Review of Palaeobotany and Palynology 61: 273-301. https://doi.org/10.1016/0034-6667(89)90035-3

— 1978: Osmundaceous spores in situ from the Jurassic of Yorkshire, England. -Review of Palaeobotany and Palynology 26: 125-141. https://doi.org/10.1016/0034-6667(78)90009-X

Vajda, V. & Wigforss, J. 2009: Onshore Jurassic of Scandinavia and related areas. -Geologiska Föreningens i Stockholm Förhandlingar 131: 5-23. https://doi.org/10.1080/11035890902975309

Volkheimer, W., Rauhut, O.W.M., Quattrocchio, M.E. & Martinez, M.A. 2008: Jurassic paleoclimates in Argentina, a review. -Revista de la Asociación Geológica Argentina 63: 549-556.

Watson, J. 1988: The Cheirolepidiaceae. In: Beck, C.B. (ed), Origin and evolution of Gymnosperms. Columbia University Press, NewYork, pp. 382-447.

Wierzbowski, H., Joachimski, M. 2007: Reconstruction of late Bajocian-Bathonian marine palaeoenvironments using carbon and oxygen isotope ratios of calcareous fossils from the Polish Jura Chain (central Poland). -Palaeogeography, Palaeoclimatology, Palaeoecology 254: 523-540. https://doi.org/10.1016/j.palaeo.2007.07.010

Wilmsen, M., Fürsich, F.T., Seyed-Emami, K., Majidifard, M.R. & Taheri, J. 2009: The Cimmerian orogeny in northern Iran: tectonostratigraphic evidence from the foreland. -Terra Nova 21: 211-218. https://doi.org/10.1111/j.1365-3121.2009.00876.x

Zarei, E. 2017: Palynofacies analysis and paleoenvironmental interpretation of the Dalichai Formation, northeast of Semnan. -Geopersia 7(1): 27-34. https://doi.org/10.22059/geope.2017.224223.648291

Townrow, J.A. 1962: On Pteruchus, a microsporophyll of the Corystosper maceae. -Bulletin of the British Museum 6: 287-320.