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RESEARCH PAPER

Palynostratigrapgy of Hojdek Formation in the Mazino, Southwest Tabas; palaeoenvironment analysis

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Abstract
Diverse and moderately preserved palynofloras occur in the lower Middle Jurassic sediments of the Hojedk Formation in the Mazino, southwestern of Tabas, east central Iran. This palynofloras comprise thirty-six species including spores (fourteen species allocated to eleven genera), and various types of pollen (twenty-two species designated to ten genera). Vertical distribution of miospores allows erection within the Hojedk Formation of one biozone–*Klukisporites variegatus* Taxon Range zone– based on the first observed occurrence (FOO) and the last observed occurrence (LOO) of selected taxa. Moreover, this biozone compared with palynozones from ±coeval strata in Iran and elsewhere. Abundance of ferns and cycadophytes in parent floras implies that the host strata accumulated under a moist warm climate during the early Middle Jurassic in this locality. Based on various data of sporomorph ecogroups (SEGs) in Mazino, it should consider that there were several environments of upland, lowland, river, and tidally influenced delta. Besides, hygrophytes and megathermic eco-plants distributed in the Mazino area during this time interval.

Keywords: Middle Jurassic, Palynostratigraphy, Palaeoenvironment, Mazino, Tabas Block

Introduction

Iranian Jurassic palynological assemblages have been investigated by Arjang (1975), Ashraf (1977), Kimyai (1968, 1974, 1975, 1977), Achilles et al. (1984), Bharadwaj and Kumar (1986), Wheeler and Sarjeant (1990), Vaez-Javadi et al. (2003), Vaez-Javadi and Ghavidel-Syooki (2005), Sajjadi et al. (2007), Ghasemi-Nejad et al. (2012), Dehbozorgi et al. (2013), Navidi-Izad et al. (2015), Hashemi-Yazdi et al. (2014), Sajjadi & Dermaneki Farahani (2007), Vaez-Javadi (2017a, b, 2018), Vaez-Javadi and Abbasi (2018), Vaez-Javadi and Mirzaie-Ataabadi (2019), Badihagh et al. (2019), Vaez-Javadi (2020), and Vaez-Javadi and Ghanbarian (2021). Despite these studies, palynological contents of the Jurassic deposits remain unexplored, especially in Central-East Iran. Therefore, Palynological analysis of the Hojedk Formation, Mazino Kouchekali, southwest Tabas is undertaken to document and to appraise the stratigraphic significance of miospores. This locality has been known for a long time for its deposits of coal, because the roof shales of the coal seams yield a rich macroflora and the coal geology has been the object of scientific studies for many years (Khoddam-Alhoseini et al., 1989; Aghanabati, 2014). Middle Jurassic terrestrial macroflora remains are well-known in various localities in central east Iran microcontinent such as Calshaneh, Jafar Abad, Chahrekhneh, Mazino, Calshur, North and South Kouchekali in the Tabas Block (e.g. Vaez-

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Javadi, 2014, 2015, 2018; Vaez-Javadi and Namjoo, 2016; Badihagh et al., 2019; Mehdizadeh et al., 2017, 2018; Vaez-Javadi and Abbaszadeh, 2021;) and Bahabad in Yazd Block (Mehdizadeh, 2017). Moreover, the Hojedk Formation yield well-preserved plant fossils assemblages in the Kerman Basin (e.g. Vassiliev, 1984; Poole and Mirzaei-Ataabadi, 2005; Ameri et al., 2014; Vaez-Javadi and Mirzaie-Ataabadi, 2006) important for floral comparison analysis (e.g. Barbacka et al., 2014).

The aim of this paper is fourfold:

To introduce the Middle Jurassic palynomorphs from the Mazino coal exploration borehole in the Mazino mine, southwest of Tabas, and correlate successions from north, east and central east Iran during this interval.

To establish biostratigraphy of the miospore assemblage in this succession.

To determine 'relative abundance of palynomorphs' and 'sporomorph ecogroups', reconstructing palaeoclimate and paleoenvironment interpretations based on original data.

To integrate palynomorph data with macroplant fossils of this core and their assignment to 'eco-plant model' indicating humidity (EPH) as well as temperature (EPT) demands with considering related miospore taxa proxies

Geological setting and stratigraphy

The Iranian microplate was a continental block that collided with Eurasia in the Late Triassic (Alavi et al., 1997; Zanchi et al., 2009, 2015; Berra et al., 2017), as a part of the Cimmerian continent collage (Sengör, 1979, 1990). During the 135◦ post-Triassic, counter clockwise rotation of the Central Iran zone (Davoudzadeh et al., 1981; Soffel and Forster, 1984; Phillip and Floquet, 2000), small oceanic basins started to open around Central Iran as back-arc basins, above the Neotethyan subduction zone (Berberian and Berberian, 1981; Agard et al., 2011; Fotoohi Rad et al., 2009; Rossetti et al., 2010). Such rotation also caused fragmentation of the Central Iran zone into individual Lut (eastern), Tabas (central), and Yazd (western) blocks (Berberian and King, 1981; Tirrul et al., 1983; Walker and Jackson, 2004) which named Central East Iranian Microcontinent (CEIM; Takin, 1972). These blocks are separated by a series of intersecting regional-scale faults. Kalmard Fault which is a strike-slip fault (Khorrami et al., 2019) and Nayband Fault located at the western and eastern margins of Tabas Block, respectively. After the Cimmerian orogenic activities, faulting to the north and south of this area created a new basin between the faults (Shahabpour, 1998; Berberian & King, 1981) in which thick Jurassic successions were deposited. These units are well exposed especially in the Tabas Block. The deposition of a thick sequence of terrigenous sediments lasted until the Bajocian-Bathonian (Berberian & King, 1981), the age of the Middle Cimmerian event. Tipper (1921) called this succession, typically consisting of sandstone and shale deposits with coal seams, the "Jurassic Plant bearing Series" in the Kerman Basin. Beckett (1956) named these deposits the "Coal bearing Series". The National Stratigraphic Committee of Iran (1964, in Aghanabati, 1998) introduced the name "Hojedk Formation" for this succession. The microfossils of the Hojedk Formation studied herein were collected from a measured stratigraphic core-section of the well number 1 in the Mazino, about 82 km western of the Tabas city (coordinates: 33° 17′ 56″ North latitude and 56° 24′ 1″ East longitude; Fig. 1). In this locality, the Hojedk Formation is ca. 240 m thick and consists of dark gray siltstone, sandstone, shale/black shale, and several coal seams (Fig. 2).

Materials and methods

In a survey to the Mazino area for geology purposes resulted in the collecting of Middle Jurassic samples. These strata in Mazino core section yielded the specimens studied in this paper.

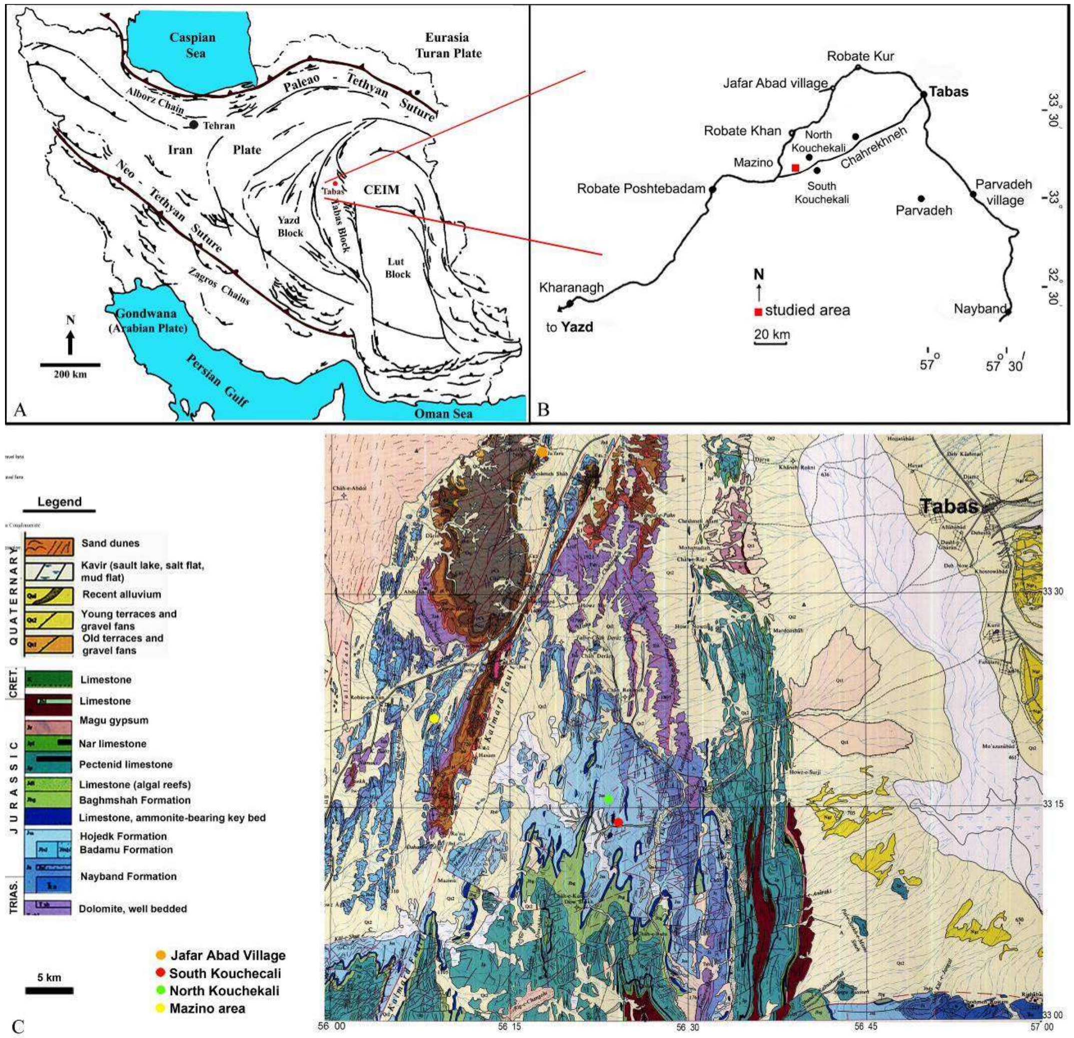

Figure 1. Structural and lithostratigraphic framework plus locality details. **A.** Main structural units and sutures/ main faults of Iran (simplified and modified tectonic map of Iran showing the main structures; CEIM= Central East Iranian Microcontinent after Alavi et al., 1997). B. Close-up of the study area showing the roads and position of the studied core in Mazino, southwest Tabas. C. Geological map of Tabas Block (Aghanabati & Haghipour, 1978)

Thirty-two samples gathered and numbered as FJHM (the acronym of Fatemeh, Javadi, Hojedk, and Mazino). Standard palynological procedures (e.g., Phipps and Playford, 1984) were used for retrieval and for the concentration of palynomorphs. After a mild surface washing the samples were crushed and ca. 60g were separated. This fraction of the material was chemically treated as follows: ca. 24 h. of cold 10% HCl, 30 h. 40% HF and 20 min. of 90°C 10% HCl. The samples were then washed in water and sieved on a 20μm filter. The organic residues were evaluated attention being paid on the palynomorph content for systematics. In this context, the optimal conditions for microscopically observations are clean preparations with transparent light brown palynomorphs. All slides were studied and photographed with Olympus microscope and Canon camera. All rock samples, residues, and mounted slides used herein are permanently housed in the Paleontology Collection at the Department of Soft rock geology, College of Science, University of Tehran, Tehran, Iran (I.R.). The biozonation of the studied Middle Jurassic core-stratigraphic section was undertaken on the basis of the "First Observed Occurrence" (FOO) and the "Last Observed Occurrence" (LOO) of stratigraphically significant miospore and dinoflagellate cyst species. The established biozones compared with biozones from northern, central, and central eastern Iran and a comparative biostratigraphic chart produced. Furthermore, the "sporomorph ecogroups" and “eco-plant” considered and the environment of the parent plants identified.

Results

The studied sediments in Mazino contain various species of miospores referable to the early Middle Jurassic. The Hojedk Formation samples contain 14 species of spores (11 genera), 22 species of pollen (10 genera). Selected better preserved taxa with known stratigraphic distribution and/or persistence are illustrated in Plates 1-2. One assemblage of miospores recognized herein (Fig. 2).

Miospore Assemblage

The miospore assemblage contains following species: *Acanthotriletes varius* Nilsson 1958 emend. Schuurman 1977, *Aratrisporites fischeri* (Klaus 1960) Playford & Dettmann 1965, *Calamospora tener* (Leschik 1955) de Jersey 1962, *Concavisporites* sp. cf. *C. jurienensis* Balme 1975, *Concavisporites kaiseri* Arjang 1975, *Concavisporites kermanense* Arjang 1975, *Cyathidites* sp. cf. *C. australis* Couper 1953, *Cyclogranisporites orbiculus* Potonié & Kremp 1954, *Dictyophyllidites mortonii* (de Jersey 1959) Playford & Dettmann 1965, *Granulatisporites granulatus* Ibrahim 1933, *Klukisporites variegatus* Couper 1958, *Klukisporites* sp., *Limbosporites lundbladii* Nilsson 1958, *Lycopodiumsporites* sp. (SPORE); *Alisporites* sp. cf. *A. robostus* Nilsson 1958, *Alisporites similis* (Blame) Dettmann, 1963, *Alisporites thomasii* (Couper 1958) Pocock 1962, *Araucariacites australis* Cookson 1947, *Callialasporites dampieri* (Blame 1975) Sokh Dev 1961, *Callialasporites* sp. cf. *C. microvelatus* Schulz 1966, *Callialasporites trilobatus* (Balme 1957) Sukh Dev 1961, *Callialasporites turbatus* (Blame) Schulz 1967, *Chasmatosporites apertus* (Rogalska 1954) Nilsson 1958, *Chasmatosporites* sp. cf. *C. elegans* Nilsson 1958, *Chasmatosporites hians* Nilsson 1958, *Chasmatosporites major* Nilsson 1958, *Classopollis meyeriana* (Klaus 1960) de Jersey 1973, *Classopollis torosus* (Reissinger 1950) Couper 1958, *Classopollis* sp., *Cycadopites follicularis* Wodehouse 1933 ex Wilson & Webster 1946, *Cycadopites crassimarginis* (de Jersey 1959) de Jersey 1964, *Cycadopites granulatus* (de Jersey 1962) de Jersey 1964, *Monosulcites minimus* Cookson 1947, *Perinopollenites elatoides* Couper 1958, *Parcisporites cacheutensis* Jain 1968, and *Vitreisporites jurassicus* Pocock 1970 (POLLEN).

Palynostratigraphy

One assemblage recognized from this succession based on the vertical ranges of certain miospore species with known stratigraphic significance and/or persistence throughout the section. It is an assemblage biozone with its lower and upper boundaries identified by the first observed occurrence (FOO) and the last observed occurrence (LOO) of *Klukisporites variegatus* (Fig. 2).

Relative abundance of taxa

In this investigation relative abundance of palynomorphs studied. Six of the most common and often quantitatively abundant miospore taxa, in descending order, are *Klukisporites* (Filicales), *Classopollis*, *Callialasporites* (Coniferales), *Chasmatosporites* (Cycadales), *Alisporites* (Corystospermales), and *Araucariacites* (Coniferales) with 22.96, 12.04, 9.07, 9.07, 6.85, and 6.85 percent, respectively (Figs. 3, 4).

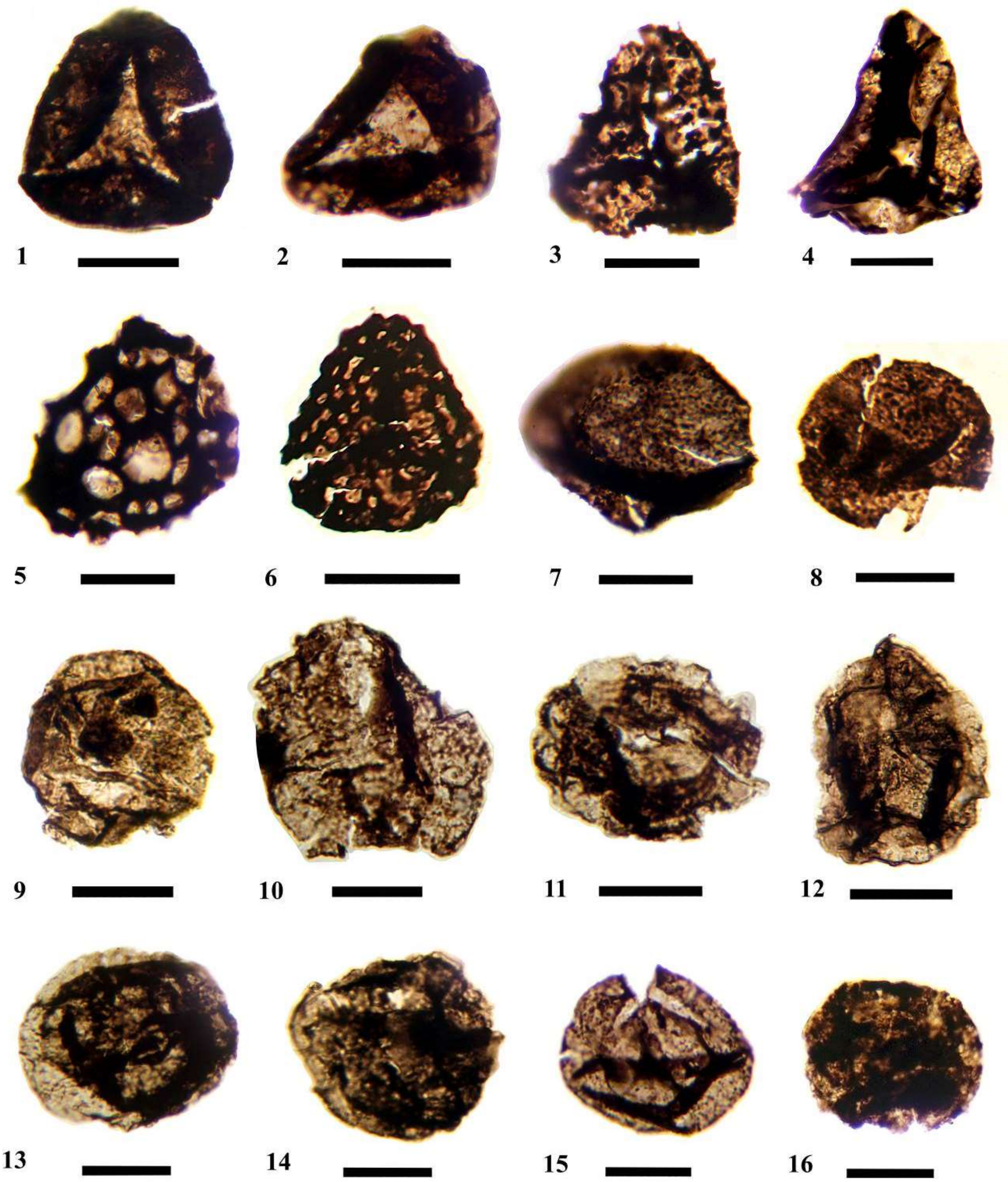

Plate 1. Fig. 1- *Concavisporites* sp. cf. *C. jurienensis*, FJHMz-48; Fig. 2- *Concavisporites kaiseri*, FJHMz-11; Fig. 3- *Acanthosporites varius*, FJHMz-52; Fig.4- *Dictyophyllidites mortonii*, FJHMz-11; Fig. 5- *Lycopodiumsporites* sp., FJHMz-35; Fig. 6- *Klukisporites variegatus*, FJHMz-2; Figs. 7, 8- *Cyclogranisporites orbiculus*, FJHMz-51, FJHMz-2; Fig. 9- *Calamospora tener*, FJHMz-3; Fig. 10- *Alisporites thomasii*, FJHMz-8; Fig. 11- *Callialasporites dampieri*, FJHMz-8; Fig. 12- *Callialasporites trilobatus*, FJHMz-8; Fig. 13- *Callialasporites* sp. cf. *C. turbatus*, FJHMz-52; Figs. 14, 15- *Aratrisporites fischeri*, FJHMz-2, FJHMz-52; Fig. 16- *Araucariacites australis*, FJHMz-35. Scale bars are 20 μm

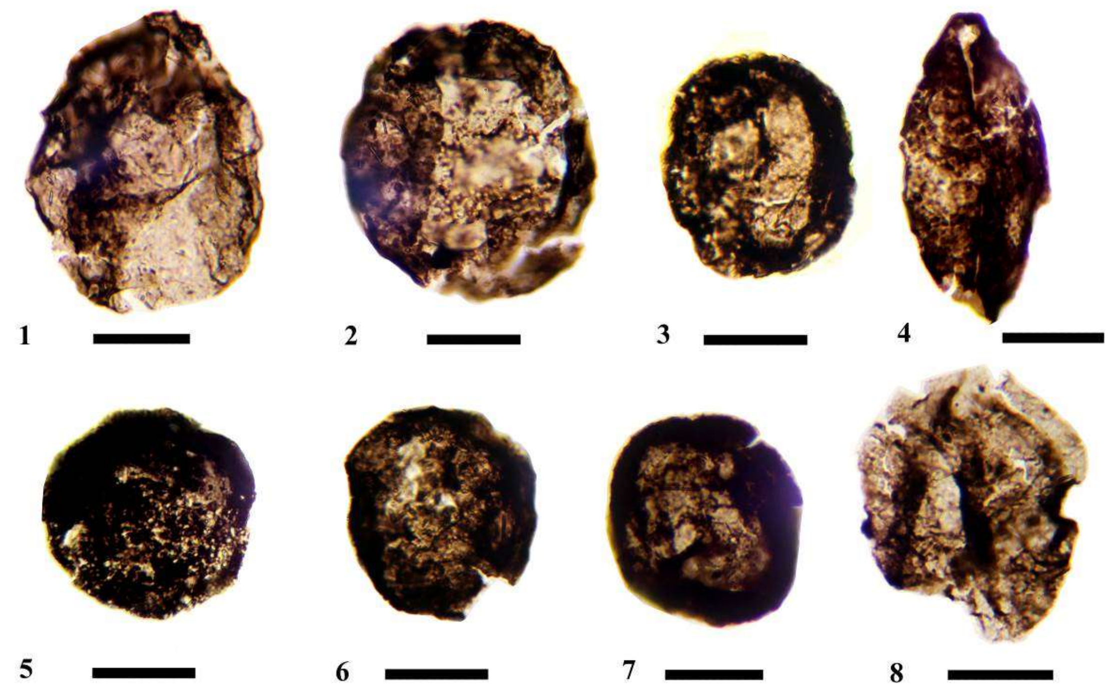

Plate 2. Fig. 1- *Chasmatosporites major*, FJHMz-14; Fig. 2- *Chasmatosporites hians*, FJHMz-14; Fig. 3- *Chasmatosporites apertus*, FJHMz-8; Fig. 4- *Cycadopites follicularis*, FJHMz-35; Fig. 5- *Classopollis torosus*, FJHMz-8; Figs. 6, 7- *Classopollis meyeriana*, FJHMz-2, FJHMz-52; Fig. 8- *Perinopollenites elatoides*, FJHMz-14. Scale bars are 20 µm

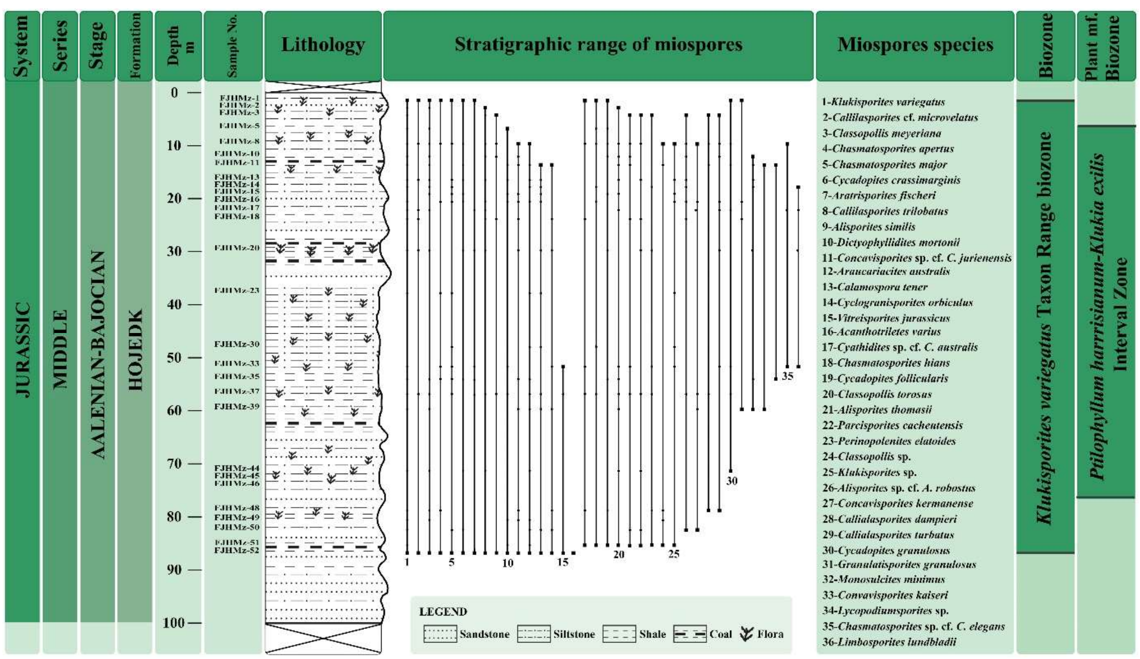

Figure 2. Palynostratigraphy of the Mazino core section, southwest Tabas

Based on botanical affinity of miospores, relative abundance of parent plants (Abbink et al., 2004), in descending order, are ferns, coniferophytes, cycadophytes, pteridosperms, Equisetopsida, and lycophytes with 36.11, 32.59, 15.19, 7.41, 4.26, and 2.78 percent, respectively (Figs. 5, 6). Therefore, a warm humid condition was prominent during the early

Middle Jurassic in this area. Vaez-Javadi and Abbaszadeh (2022) studied plant macrofossil remains herein. They found that relative abundance of Filicales, Cycadales, Coniferales, and Equisetales with 43.18, 31.82, 13.63, and 4.64 percent, respectively were the most plentiful orders in this succession. Moreover, *Klukia exilis* as the parent plant of *Klukisporites variegatus*, *Elatides thomasii* as the parent plant of *Classopollis*, and *Nilssonia bozorga* as the parent pant of *Cycadopites* was the most abundance species in this area with 14.77%, 11.36%, and 6.8%, respectively.

Comparative biostratigraphy of the Middle Jurassic

The erected miospore biozone is comparable with relevant contributions on the northern hemisphere included regions from Iran, Iraq, and Afghanistan, the Indian subcontinent, Europe and Australia.

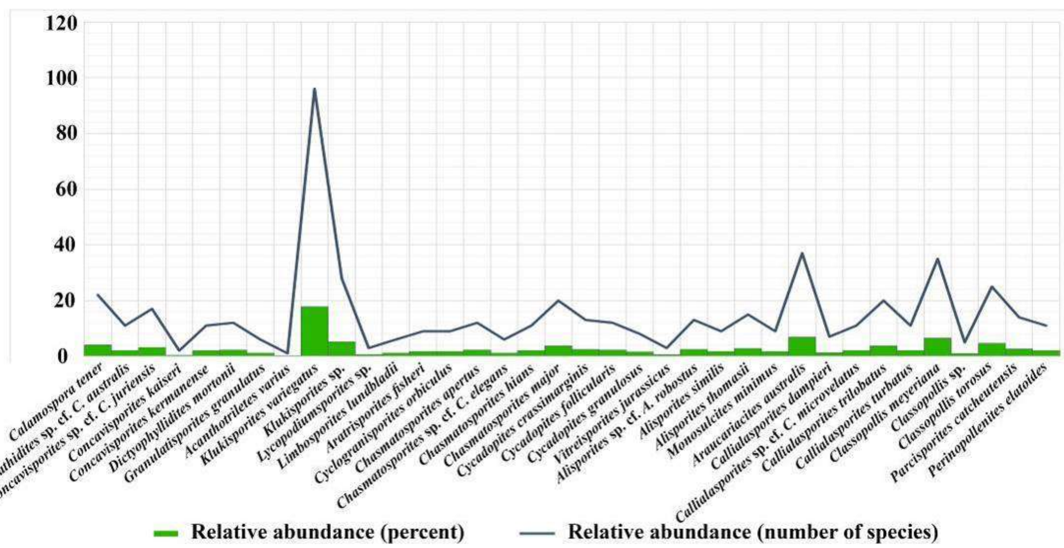

Figure 3. Comparable chart of relative abundance (percent) and number of miospore species during the early Middle Jurassic in Mazino

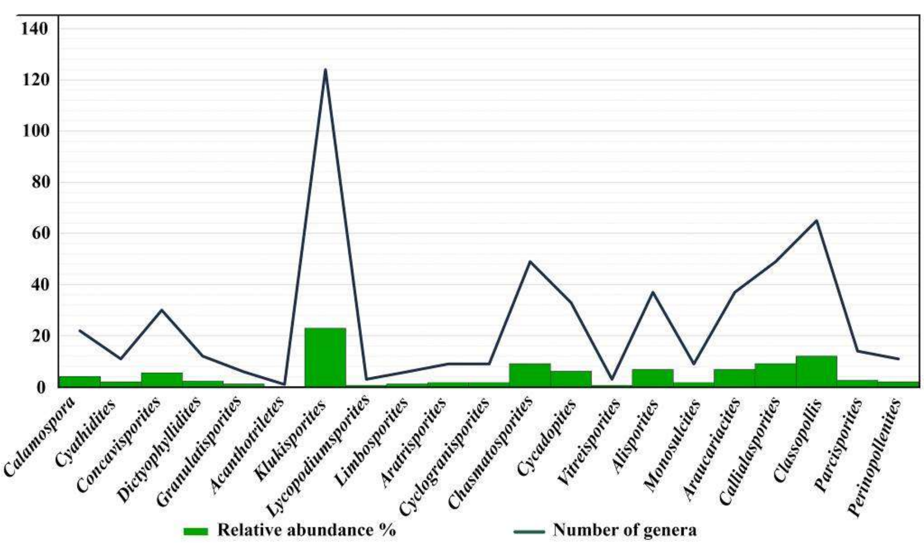

Figure 4. Comparable chart of relative abundance (percent) and number of various miospore genera during the early Middle Jurassic in Mazino

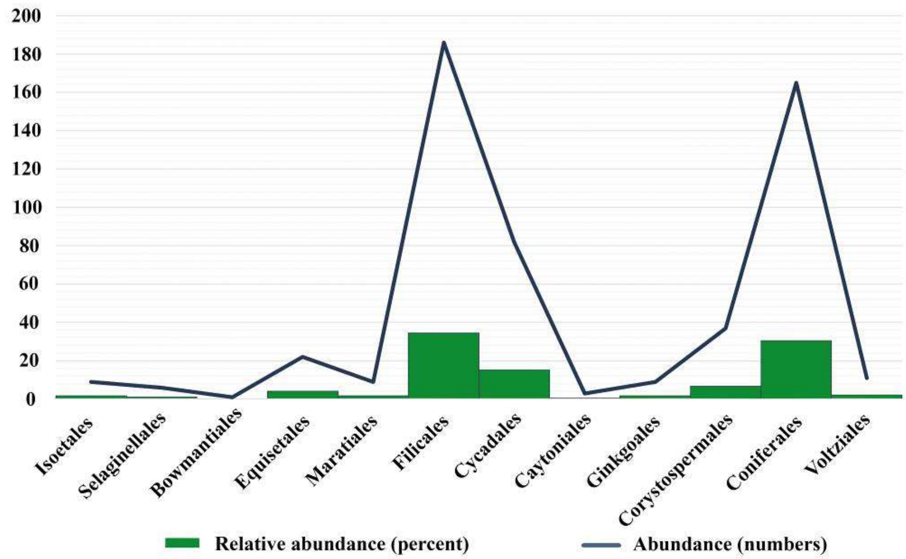

Figure 5. Comparable chart of relative abundance (percent) and number of parent plant macrofossil orders during the early Middle Jurassic in Mazino

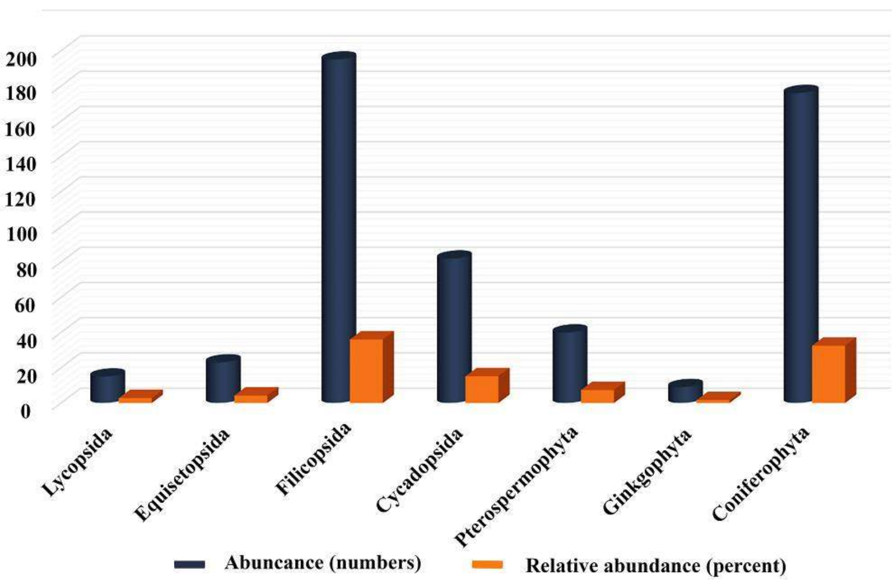

Figure 6. Comparable chart of relative abundance (percent) and number of parent plant macrofossil classes/divisions during the early Middle Jurassic in Mazino

This biozone is comparable with the *Klukisporites variegatus-Monosulcites minimus* Assemblage Zone in the Hojedk, Kerman Basin of Kimyai (1968), *Klukisporites variegatus* Assemblage Subzone of Arjang (1975), *Klukisporites* (*Ischyosporites*) *variegatus-Striatella seebergensis* (*Duplexisporites problematicus*) Zone of Ashraf (1977), Assemblage C-*Klukisporites variegatus* of Bharadwaj and Kumar (1986) and Sajjadi et al. (2007). Moreover, it compared with the *Vitreisporites pallidus-Cycadopites follicularis* Assemblage Zone in the Jajarm area, East Alborz (Vaez-Javadi and Ghavidel-Syooki, 2005), *Klukisporites* Zone in the Eshkelli, Kerman Basin (Hashemi–Yazdi et al., 2014), *Vitreisporites pallidus-Klukisporites variegatus* Assemblage Zone in the South Kouchekali, Tabas (Vaez-Javadi, 2017a), *Klukisporites variegatus- Callialasporites dampieri* Assemblage zone in Calshaneh and Calshour (Vaez-Javadi, 2017b), *Klukisporites variegatus-Callialasporites trilobatus* Assemblage Zone in Chahrekhneh (Vaez-Javadi, 2020), and *Klukisporites variegatus*-

Chasmatosporites apertus Interval zone in Karimabad section, Bahabad, northwest Yazd (Vaez-Javadi and Ghanbarian, 2021) (Table 1).

Furthermore, this miospore biozone is comparable with the *Contignisporites cooksonii* Assemblage Zone in the West Bengal, India (Vijaya and Sen, 2005), *Klukisporites variegatus-Concavisporites subgranulosus* Zone in the Yorkshire, England (de Jersey, 1970), *Ischyosporites variegatus-Duplexisporites problematicus-Tsugapollenites dampieri* Zone in the southwest of Germany (Weiss, 1989), *Callialasporites-Perinopollenites* Zone in the Bornholm, Denmark (Koppelhus & Nielsen 1994), and *Tsugapollenites* (*Callialasporites*) *segmentus–Callialasporites dampieri* Assemblage zone in the Eastern Queensland, Australia (Reiser & Williams, 1969).

Table 1. Comparative Middle Jurassic biostratigraphy chart of several regions in Iran based on Kimyai (1968), Arjang (1975), Vaez-Javadi & Ghavidel-Syooki (2005), Hashemi-Yazdi et al. (2014), Vaez-Javadi, 2017a, b, 2020), Vaez-Javadi & Ghanbarian (2021), and this study

PERIOD	EPOCH	AGE	IRAN							
			ALBORZ Jajarm Vaez-Javadi & Gavidel Syooki	KERMAN Eshkelli... Hashemi-yazdi et al. 2014; Arjang, 1975	KERMAN Hojedk Kimyai, 1968	TABAS S Kouchekali Vaez-Javadi, 2017a	TABAS Calshaneh Vaez-Javadi, 2017b	TABAS Bahabad Vaez-Javadi & Ghanbarian	TABAS Chah-Rekhneh Vaez-Javadi, 2020	TABAS Mazino This study
JURASSIC	MIDDLE	BATHONIAN								
		BAJOCIAN	*Vitreisporites pallidus-Cycadopites follicularis* Assemblage zone	*Klukisporites* Zone; *Klukisporites variegatus* Subzone	*Klukisporites variegatus- Monosulcites minimus* Assemblage zone	*Vitreisporites pallidus-Klukisporites variegatus* Assemblage zone; *Contignisporites problematicus* Taxon Range zone	*Klukisporites variegatus-Callialasporites dampieri* Assemblage Zone	*Klukisporites variegatus-Chasmatosporites apertus* Interval zone	*Klukisporites variegatus-Callialasporites trilobatus* Assemblage zone	*Klukisporites variegatus* Taxon Range biozone
		AALENIAN				*Callilasporites trilobatus-Parcisporites cacheutensis* Assemblage subzone				

Palaeogeography and palaeoclimate interpretation

Palynological data used to reconstruct changes in palaeoecosystems applying the 'Sporomorph Ecogroup Model' (Abbink et al., 2001, 2004). This conceptual model enables the distinguishing of palaeocommunities integrating palynological and palaeobotanical information. Distinct Sporomorph Ecogroups (SEGs) reflect palynological data obtained from the Mazino core-section listed together with the related taxa of plant macroscopic remains in Table 2. Abbink et al. (2001, 2004) compiled published data for their conceptual model, based on interpretation of adaptive features of plant remains. The environmental preferences of sphenophytes and pteridophytes are generally supposed as being wet and warm, lowland marsh or river. *Equisetites* related to wet and warm, even swamp environments (Barbacka, 2009; Costamagna et al., 2018). Ferns with large leaves such as *Dictyophyllum* correspond well with wet habitats such as marshes or river banks (van Konijnenburg-van Cittert, 2002), while *Cladophlebis/Todites* prefer wet or slightly drier conditions (Scanu et al., 2015; Bruun Christensen, 1995). However, ferns prefer generally shady, humid and temperate to warm environments although not all taxa were restricted to such conditions (Abbink et al., 2004; van Konijnenburg-van Cittert, 2002).

Bisaccate pollen grains assigned to Pteridospermales and certain Coniferales and are according to Abbink's model, characteristic of highland vegetation. *Corollina* (*Classopollis*) spp. grew in upland or drier lowlands (Götz et al., 2011). In general, Jurassic deposits are rich in *Classopollis* pollen, which reflect an abundance of Cheirolepidiaceans according to Francis (1984) and Watson (1988). These xerophytic or drought resistant-plants generally preferred upland arid habitats, nonetheless occasionally occurred in coastal areas (e.g. Van Konijnenburg van Cittert and van der Burgh, 1996; Abbink, 1998). Cycadales (Nilssoniaceae) grew during the Mesozoic as lowland plants in subtropical areas with warm climate or co-occurred with ginkgophytes and conifers in open forests (Batten, 1974; van Konijnenburg-van Cittert and van der Burgh, 1989; Kustatscher et al., 2010). Thus, miospores such as *Classopollis/Corollina torosus* show an upland environment. Equisetales and ferns indicate lowland and riverside environments (Vakhrameev, 1991; Naugolnykh, 2009). Since there are various data of plant miospores, this demonstrates several types of ecogroups in Mazino during early Middle Jurassic. Thus, there were several environments of upland, warmer/wetter lowland, river, tidally influenced delta.

However, the SEG model represents a simplified Eco-Plant model. According to hydrologic and temperature conditions, the Eco-Plant model classifies plants into different EPH (the effect of humidity) and EPT (the effect of temperature) groups due to their climatic preferences (Zhang et al., 2020).

Table 2. Sporomorph Ecogroups of the Mazino core section

Sporomorph Ecogroups	R. A. %	Genus	R. A. %	Remarks
Upland	26.6	***Alisporites thomasii Vitreisporites pallidus* (bisaccate pollen)**	7.41	Pteridospermales grew in upland (sometimes lowland sources, such as flood plains)
		***Araucariacites*, *Classopollis* (alete pollen)**	18.89	Coniferales grew in upland/warm and drier lowland
Lowland	51.67	***Chasmatosporites* spp.**	9.07	Relatively cool and drier areas
		Monosulcites minimus	1.67	
		***Cycadopites* spp.**	6.11	Lowland subtropical areas
		***Concavisporites* spp.**	5.56	Relatively warm and drier areas
		***Cyathidites* spp.**	2.04	Humid warm areas
		***Dictyophyllidites* spp.**	2.22	
		***Klukisporites* spp.**	22.96	
		***Perinopollenites* spp.**	2.04	Relatively cool and humid areas
River	5.18	***Calamospora tener***	4.07	Wet, warm areas even swamps
		Limbosporites lundbladii	1.11	
Tidally influenced delta	9.07	***Callialasporites* spp.**	9.07	Relatively cool

In contrast, in the SEG model, plants classified as belonging to a wetter, drier, warmer, or cooler group. Additionally, in the SEG model (Abbink et al., 2004) due to uncertain botanical affinities of some palynomorphs, several plants indicating a different climate and environment categorized in the same group. For example, in the Eco-Plant model, Ginkgoales classified as mesophytes and mesothermic plants, but Bennetittales as hygrophytes and megathermic plants (Zhang et al., 2020). In contrast, in the SEG model, Ginkgoales, Cycadales, and Bennetittales are all included in the same group of the "Lowland SEG" and indicate a "drier" and "warmer" climate (Abbink et al., 2004). Therefore, the Eco-Plant model allows for more detailed and precise statements on paleoclimate than the SEG model. Zhang et al. (2020, 2021) use the Eco-Plant model for the analysis of paleoenvironmental and paleoclimate variations. They use the term EPH (the effect of humidity) to separates the palynomorphs and their parent plants into five groups: Hydrophytes, Hygrophytes, Mesophytes, Xerophytes, and Euryphytes; and the term EPT (the effect of temperature) categorizes the palynomorphs and their parent plants into four groups: Megathermic, Mesothermic, Microthermic, and Eurythermic. Hygrophytes are plants that are living in excessively wet habitats with high air and soil moisture but usually no water stagnation on the surface, such as the lower tiers of wet forests, or open habitats with constantly wet soils and wet air. Mesophytes are plants that have some ability to resist periods of drought or to regulate their water metabolism in moist areas such as dry meadows or pine forests. Xerophytes are plants that can resist long periods of drought and are living in stony steppes and dry rock outcrops. Euryphytes are plants that adapt to great variations in humidity. In addition, Megathermic plants inhabiting regions such as tropics and subtropics with a mean annual air temperature (MAT) above 20°C. Mesothermic plants inhabiting regions such as warm temperate zones with a MAT between 14 to 20°C. Microthermic plants inhabiting regions such as the cool temperate zone, the subarctic zone, or elevated areas with a MAT below 14°C. Eurythermic plants that can tolerate a wide range of temperatures.

Therefore, based on Zhang et al. (2021), Equisetales and Lycopodiales are hygrophytes and eurythermic plants; Araucariaceae and Caytoniaceae are hygrophytes and megathermic plants; Family Schizeaceae (of Filicales) and Cycadales are mesophytes and megathermic plants Table 3).

Table 3. Mesozoic plants and their assignment to Eco-Plant model indicating humidity (EPH) as well as temperature (EPT) demands and related miospore taxa proxies (modified after Zhang et al., 2021)

Division	Family/Order	EPH	EPT	Genus
Lycophyte	Lycopodiales	Hygrophytes	Eurythermic	*Lycopodiumsporites*
	Isoetales	Hydrophytes	Eurythermic	*Aratrisporites*
Sphenophyte	Equisetales	Hygrophytes	Eurythermic	*Calamospora*
Filicophyte	Cyatheales	Hygrophytes	Megathermic	*Cyathidites*
	Schizeales/Schizeaceae	Mesophytes	Megathermic	*Klukisporites*
	Marattiales	Hygrophytes	Megathermic	*Cyclogranisporites*
	Gleicheniales	Mesophytes	Megathermic	*Dictyophyllidites*
Pteridospermophyte	Corystospermales	Mesophytes	Megathermic	*Alisporites*
	Caytoniaceae	Hygrophytes	Megathermic	*Vitriesporites*
Coniferophyte	Araucariaceae	Hygrophytes	Megathermic	*Araucariacites*, *Callialasporites*
	Chirolepidaceae	Xerophytes	Megathermic	*Classopollis*
	Cupressaceae	Euryphytes	Eurythermic	*Perinopollenites*
Cycadophyte	Cycadales	Mesophytes	Megathermic	*Cycadopites*, *Chasmatosporites*
Ginkgophyte	Ginkgoales	Mesophytes	Mesothermic	*Monosulcites*

Division Pteridospermophyta with two orders (Caytoniales and Corystospermales) has proxies in this area. The order Caytoniales consists of one family Caytoniaceae (Thomas and Seward, 1925). The species were cosmopolitan and rather common small trees in the Mesozoic plant communities though they never attaining a dominant status (Krassilov, 1977; Taylor and Taylor, 2009). The *in situ* fossils indicate a deltaic or floodplain environment in which water supply is abundant and where arborescent plants provide shade (Harris, 1964; Rees, 1993; van Konijnenburg-van Cittert, 1971). They mainly distributed in the subtropical region of both hemispheres (Vakhrameev, 1991). *Vitreisporites* is comparable to the *in situ* pollen of *Caytonanthus* (van Konijnenburg-van Cittert et al., 2017). It considered as in situ pollen of *Sagenopteris nilssoniana* (Potonié, 1958; Zhang et al., 2021), which reported from the Mazino core section (Vaez-Javadi & Abbaszadeh, 2022).

The Corystospermales were probably small to large woody shrubs and trees (Decombeix et al., 2014) that originated in the late Paleozoic and spread worldwide in the Mesozoic during the climate warming of the Late Permian/Early Triassic (Taylor et al., 2006; Taylor et al., 2009). Although the leaf fossil of *Pachypteris papillosa* from Yorkshire thought to be a large mangrove shrub forming a thicket beside the river, it should also be noted that the leaf of *Pachypteris lanceolata* from Yorkshire shows no link to marine horizons (Harris, 1983). Bisaccate pollen *Alisporites* is comparable to the *in situ* pollen of *Pteruchus* (Balme, 1995; Kremp et al., 1960a; Osborn and Taylor, 1993; Taylor et al., 1984).

Division Coniferophytes of gymnosperms consists three orders (Araucariales, Chirolepidiales, and Cupressales) herein. Order Araucariales includes Family Araucriaceae. Most species of extant Araucariaceae are restricted to subtropical rainforests in the Pacific and the Southeast Asian region and tend to be most common at the margins of complex forest types (Christenhusz et al., 2011). Normally they exposed to the atmosphere above the forest canopy and they are not able to regenerate under a dense canopy in the absence of disturbances such as tectonic and volcanic activity (Kershaw & Wagstaff, 2001). *Callialasporites* and *Araucariacites* assigned to this order.

The Order Chirolepidiales consists of one family of Mesozoic conifers, the Chirolepidaceae (Krassilov, 2009). The species were large trees, woody shrubs, and possibly herbs (Steart et al., 2014). Evidence from sediments and cuticle morphology indicate that the plants were adapted to xeric habitats and grew in brackish coastal mires as well as on the margin of freshwater rivers and lakes (Alvin, 1982; Steart et al., 2014). Generally, they are drought resistant, thermophilous shrubs and trees with a preference for subtropical to tropical climates, and were never dominant in cool regions (Francis, 1983; Vakhrameev, 1991). They were also adapted to semi-arid and arid low-lying water-margin environments that produce mud flats (Taylor et al., 2009; Vakhrameev, 1991). *Classopollis/Corollina* is pollen of this fossil family (Zhang et al., 2021). Order Cupressales Link includes Family Cupressaceae (Christenhusz et al., 2011). The species are small- to large-sized trees that distributed worldwide during the Mesozoic (Taylor et al., 2009). Ecologically, many extant species are strictly mesic; occurring mostly in regions of high rainfall and generally high humidity, largely on mountain flanks but also sometimes spread to riverside and boggier valley bottom sites. *Perinopollenites* is comparable to the *in situ* pollen of *Elatides* Heer (Kremp & Ames, 1962a; Srivastava, 1987).

The extant order Cycadales consists of two families, the Cycadaceae and the Zamiaceae, with species distributing mainly in tropical and subtropical regions (Christenhusz et al., 2011). Fossils with in situ pollen of *Androstrobus* can be found in Mesozoic records (Hill, 1990; van Konijnenburg-van Cittert, 1971; Zavialova & van Konijnenburg-van Cittert, 2016). Extant cycads can occur in habitats ranging from dense tropical rainforest to open woodland (Kramer & Green, 1990). *Cycadopites* is a pure morphological genus with a broad definition (Kremp & Ames, 1961b). It found *in situ* in cycadalean, bennettitalean, and ginkgoalean plants (Balme, 1995). Therefore, the affinity for *Cycadopites* is obscure. Another dispersed pollen genus related to *Androstrobus* pollen type is *Chasmatosporites* (Table 2). Genus *Nilssonia* with various species reported from the Mazino core (Vaez-Javadi & Abbaszadeh, 2022). Therefore, hygrophytes and megathermic eco-plants dominated in the Mazino area during early Middle Jurassic.

Conclusions

The palynofloras of the lower Middle Jurassic sediment of the Hojedk Formation studied in the Mazino core section, southwestern of Tabas, east central Iran. Palynofloras comprise thirty-six species including spores (14 species allocated to 11 genera), various types of pollen (22 species designated to 10 genera). Vertical distribution of index miospores allows erection within the Hojedk Formation of one biozone–*Klukisporites variegatus* Taxon Range zone. This biozone compared with palynozones from ±coeval strata in Iran and elsewhere. In this investigation relative abundance of palynomorphs studied. Six of the most common and quantitatively abundant miospore taxa, in descending order, are *Klukisporites* (Filicales), *Classopollis*, *Callialasporites* (Coniferales), *Chasmatosporites* (Cycadales), *Alisporites* (Corystospermales), and *Araucariacites* (Coniferales) with 22.96, 12.04, 9.07, 9.07, 6.85, and 6.85 percent, respectively. Based on botanical affinity of miospores, relative abundance of parent plants, in descending order, are ferns, coniferophytes, cycadophytes, pteridosperms, Equisetopsida, and lycophytes with 36.11, 32.59, 15.19, 7.41, 4.26, and 2.78 percent, respectively. Abundance of ferns and cycadophytes in parent floras implies that the host strata accumulated under a moist warm climate during the early Middle Jurassic in this locality. Based on various data of sporomorph ecogroups (SEGs) in Mazino, there were upland, lowland, river, and tidally influenced delta environments. Moreover, based on parent plants of miospores, hygrophytes and megathermic eco-plants of Zhang et al. (2021) dominated in the Mazino area during the early Middle Jurassic interval.

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