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RESEARCH PAPER

Miocene miospores in the Upper Red Formation, Zanjan, northwestern Iran

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Abstract

The Upper Red Formation has extensive outcrops in the southern and western parts of the Zanjan province, northwestern Iran. Here, we studied a sequence of lowermost part of this formation near Mehr-Abad village, northwestern Zanjan. Lithostratigraphy, sedimentology and ichnology of the URF have been studied in recent decades but palynology of this formation has not been investigated. This article is a preliminary report of miospores. The palynofloras comprise thirty species including three algae spores (in three genera), seven fern species (in seven genera), various type of gymnosperm (thirteen species designated to nine genera), and angiosperm pollen species (seven species designated to six genera); for example, *Botryococcus* sp., *Closteritetrapidites magnus*, and *Diagonalites diagonalis* of algal spores; *Echinatisporis muelleri, Magnastriatites* sp. cf. *M. grandiosus*, and *Polyapodiaceoisporites potoniei* of fern; *Cathayapollis scheuringii, Cedripites* sp., *Ephedripites tertiarius, Pinuspollenites* spp., *Cupressacites* spp., *Tsugapollenites* spp. of gymnosperm, and *Acidanthera brevicollis*, *Calliandra* spp., *Fagopsis longifolia*, *Monoporopollenites* sp., and *Retitricolporites* sp. of angiosperm evidenced herein. Moreover, botanical affinity of miospores considered. Therefore, Botryococcaceae/ Dictyosphaeriaceae, Closteriaceae, Zygnemataceae (algae); Marattiaceae, Pteridaceae, Polypodiaceae (fern); Cupressaceae, Ephedraceae, Pinaceae (gymnosperm), and Fagaceae, Fabaceae, Iridaceae, and Poaceae (angiosperm) identified.

Keywords: Miocene, Upper Red Formation, spore, pollen, Zanjan, NW Iran.

Introduction

The Upper Red Formation (URF) has extensive outcrops in the Central Iran geological zone, and generally known as alternations of continental red beds. No type section specified for URF. Thus, Alborz and Sarajeh anticlines in the Qom area (central Iran) considered as type area of URF (NIOC 1959; Gansser 1955). Lithostratigraphy and sedimentology of the URF studied in recent decades (Amini 2001; Rezaie et al. 2015; Mir Hoseini et al. 2021). In despite of diverse vertebrate ichnofossils of URF (Abbassi et al., 2021, 2022; Abbassi & Shekari 2005), the Formation usually is known as poorly preserved macro & microfossils. Sparse brackish water ostracodes, *Turritella*, and *Dreissensia*, Chara seeds, rare plant fossil remains, and rare mammalian bones reported from the lower part of URF in type area (Stöcklin & Setudehnia 1991). Based on prevailing lithofacies, there did not expect to be found palynomorph fossils in URF. However, based on the following study, we discovered a diverse and numerous palynomorph in the lowermost layers of the URF in western Zanjan, NW Iran. This report is

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important to understanding the age, sedimentary environment conditions and paleoclimatology of this part of the formation. At this step, as a preliminary report, we focused on introducing identified palynomorphs of URF, which change the general view on the paleontology data of the URF, and it does not include quantitative evaluation.

Geological setting and stratigraphy

The studied section of URF is located near the Mehr Abad village, ca. 60 km of northwestern Zanjan in the geographic coordinates: 37" 53' 36° north latitude and 39" 56' 47° east longitude (Figs. 1-3). The study section comprises 78m thickness of the lowermost layers of the URF. Both lower and upper boundaries of the studied section covered by Quaternary alluvium. URF in this section contains light red marl to dark brown marl (30m), white chalk (1m), light red marl (15m), white marl (2m), and gray marl with very thin interlayers of sandstone layer (30m) (Fig. 4).

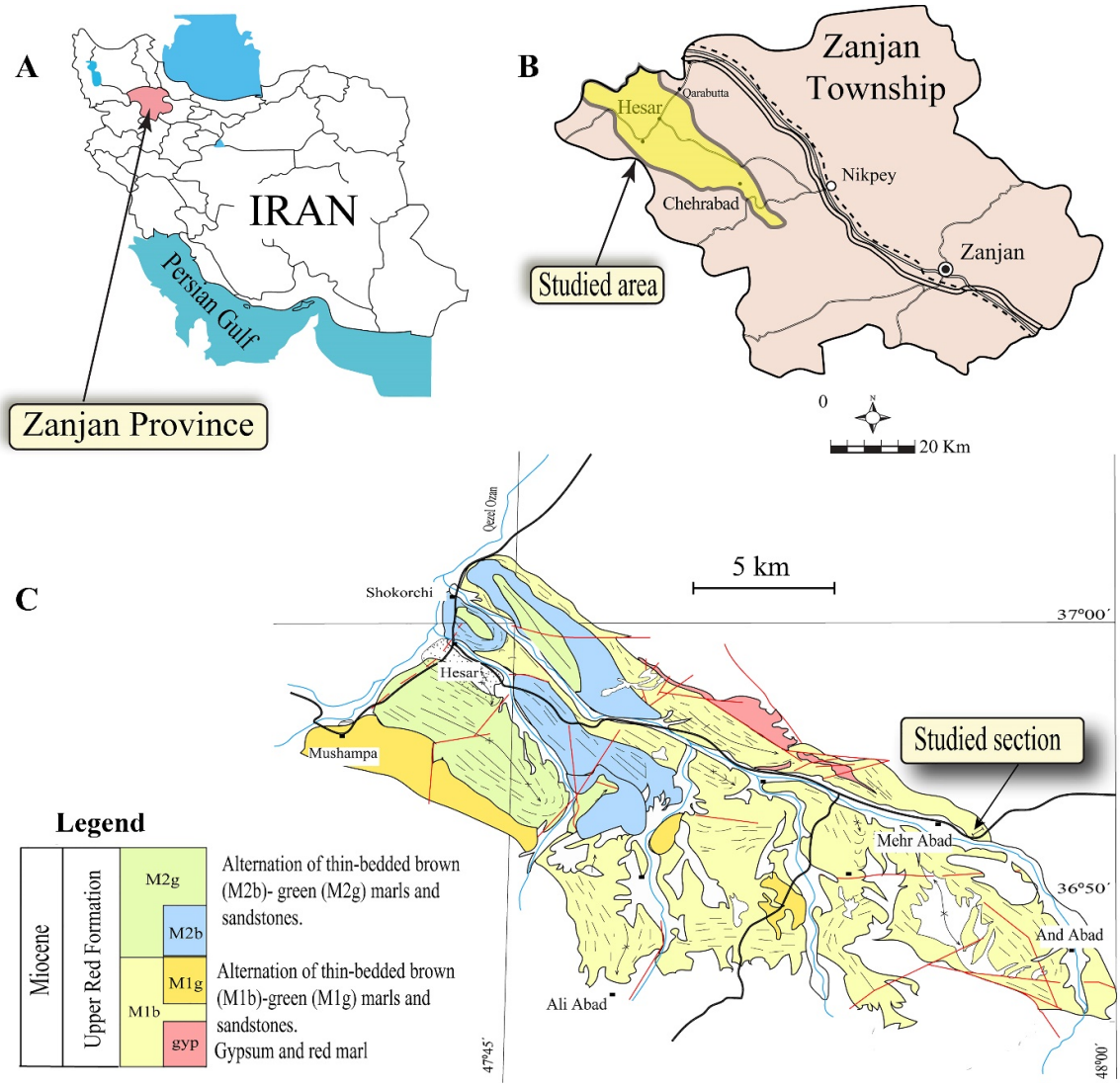

Figure 1. A, B- Sketch map of Iran and the location of the studied area and C- lithological unit outcrops of the Upper Red Formation in the Mushampa- Chehr Abad region (geological map after Abbassi, 2022, and Lotfi, 2001 with a few modifications)

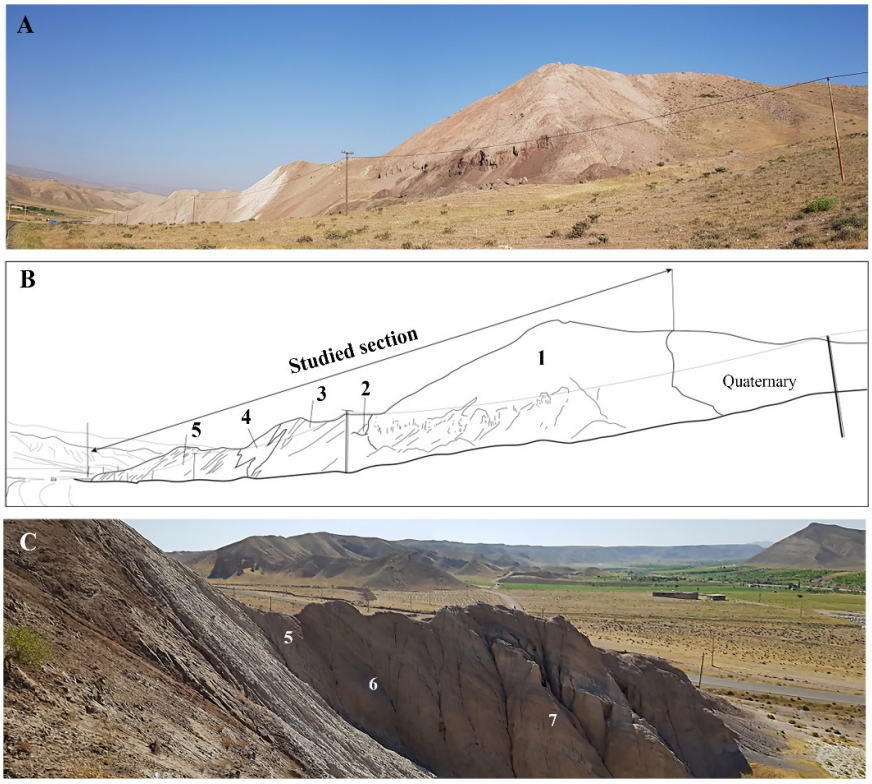

Figure 2. Satellite map of study area (after google map)

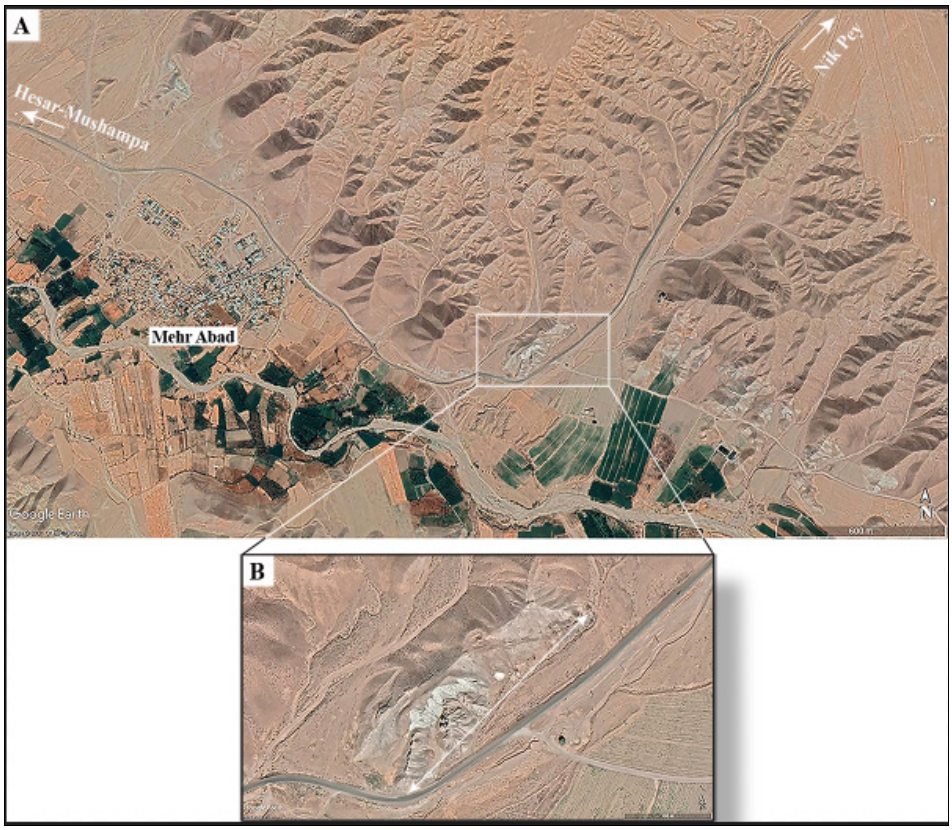

Figure 3. Outcrop of the study section

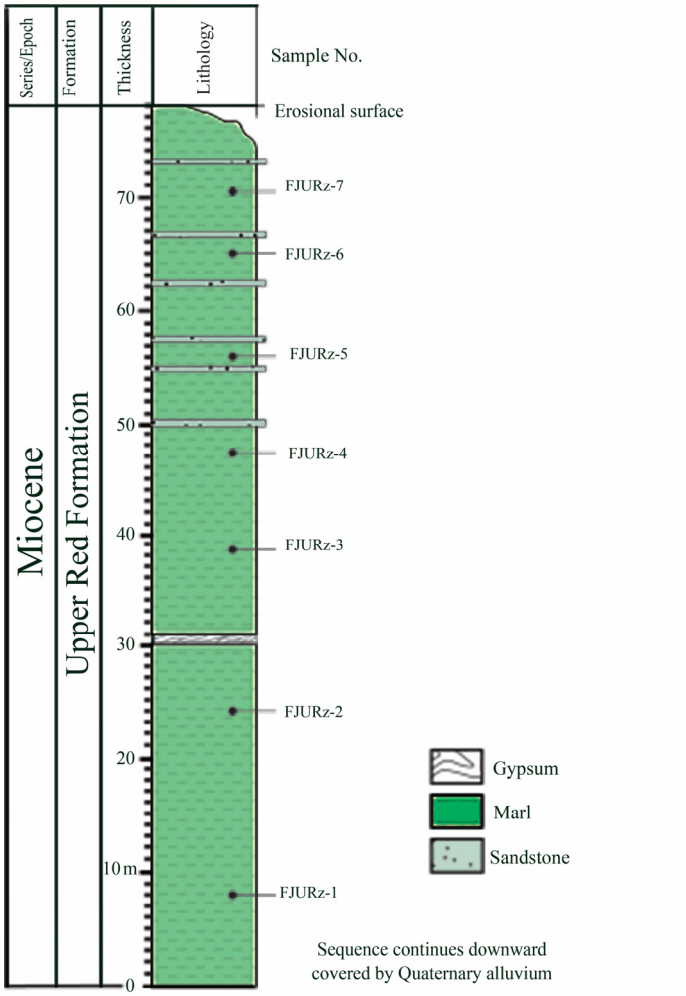

Figure 4. Lithostratigraphy of the study section

URF is well-spread in the southern and western parts of the Zanjan province. The lower boundary of this formation is paraconformity with the Qom Formation and its upper boundary is unconformity with the Pliocene-Pleistocene deposits.

URF is a well-known Miocene terrestrial rock unit in Central Iran, which extended from eastern parts of the Dasht-e Kavir in central Iran toward northwest Iran. The lower boundary of this formation is paraconformity with the Qom Formation, with performance of caprock for the small and sparse gas fields in the Qom-Kashan area, central Iran. The upper boundary of the formation is unconformity a braided river, were distinguished in the Avaj area, Hamadan province, northwest Iran (Rafiei et al., 2011).

The sequence of URF comprises marls with dominantly red in color with interbedded sandstone, mudstone, and conglomerate and evaporites. These rock facies are more or less maintained throughout the formation exposures, and lithostratigraphically National Iranian Oil Company (INOC) geologists divided URF into two rock units. The lower part of the formation includes 300 t0 500m of evaporates, thin bedded claystone and marls in dark red, brown colors. The upper part comprises colored gypsum marls and sandstones with interbedded green marls, 4000 to 5000m in thickness (NIOC 1959). The URF conformably overlies the Qom Formation (Chattian-Burdigalian) via intercalation of evaporitic sediments and weathered sandstones. These layers have been considered as the last layers of the Qom Formation and were named as g-Member (Abaie et al., 1964). However, the thickness of this evaporate interval between Qom Formation and URF was considerable and was named as a part of informal rock unit “Ahi Chai”

formation by Lescuyer and Riou (1976) in the Miyaneh area, west Zanjan. Thickness of the whole sequence of URF involves more than 2700m and the studied section belongs to the lowermost part of the URF, before evaporite deposits of "Ahi Chai".

Moreover, Stöcklin & Eftekhar-Nezhad (1969) divided the URF into two subunits in the southern parts of the province. The lower subunit (M1, 600-700 m thick) characterized by its alternating of colorfully banded white-green, white-pink, purple, violet and brown marls with thin siltstone and sandstones, and relatively high content of evaporites such as gypsum. An andesitic crystal tuff (4m thick) is also present in the lower subunit M1. The uniform, red-colored upper subunit (M2, 1500-2000 m thick) consists of clayey, marly, and sandy shales with sandstone intercalations. Local to regional conglomerate layers and lenses occur in this subunit.

The lithofacies of the URF include a wide variation in lithology, which formed in the warm and dry conditions of different environments such as, local non-oxidan pools, evaporitic lakes, playas and fluvial system (Amini, 1997, 2001; Rahimzadeh, 1994; Abbassi, 2022).

Along the Qezel Owzan River, western part of Zanjan Province, lower rock subunit of the URF Outcrops includes 1000-2000m of light red- to brown-colored marls with a distinctive gypsum layer at the lower boundary with the Qom Formation. Upper part of the URF consists of dark brown-green marls with sandstone layers. The URF commonly is middle to late Miocene in age and based on the magnetostratigraphic data dated between 17.5 and 7.5 Ma in the adjacent to the southern Alborz Mountains ranges (Ballato et al., 2008). Moreover, based on 40Ar/39Ar dating, a 15.0 ± 0.3 Ma to 25.0 ±1.3 Ma, and zircon U-Pb dating, a 10.7±0.2 Ma to 19.8±0.9 Ma estimated in the Qezel Ozan area, west Zanjan (Ballato et al., 2016).

Both M1 and M2 in the west of Zanjan province characterized by numerous and diverse vertebrate fossil footprints (Abbassi, 2022; Abbassi et al., 2021). These footprints include small to large, webbed or unwebbed bird footprints, artiodactyl, carnivorans, and proboscidean tracks and swimming trace and tracks of small to large reptiles (Abbassi, 2022). The reconstruction of the paleoenvironment and paleoclimate of this vertebrate wildlife are always interesting for paleontologists. To achieve the ancient conditions of the environment in these outcrops of URF, the palynology studies considered. It seems that the studied section deposited in the interval zone of the marine Qom Formation to evaporite the environment of "Ahi Chai", such as mangrove environment. Despite the lack of expectation for finding the palynomorphs in the red beds, there are numerous miospore species, which are useful data to reconstruct paleoenvironmental conditions herein.

Materials and methods

A survey of the area for geology purposes resulted in the collecting of Miocene samples. These strata in Mahneshan, Zanjan yielded the specimens studied in this paper. Seven samples gathered and numbered as FJURz (the acronym of Fatemeh, Javadi, Upper Red Formation, and Zanjan). Standard palynological procedures (e.g., Phipps & Playford, 1984) used for retrieval and for the concentration of palynomorphs. After a mild surface washing the samples crushed and ca.60g were separated. This fraction of the material 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 then washed in water and sieved on a 20μm filter. The organic residues were evaluated attention paid on the palynomorph content for systematics. In this context, the optimal conditions for microscopically observations are clean preparations with transparent light brown palynomorphs. The palynomorphs, if too dark, bleached with 5% KOH. All slides studied and photographed with Olympus microscope and Canon camera. All rock samples, residues, and mounted slides used herein permanently housed in the Paleontology Collection at the Department of Soft rock geology, College of Science, University of Tehran, Tehran, IR Iran.

Results

The studied sediments in northwestern Zanjan contain various species of palynomorphs referable to the middle Miocene. The Upper Red Formation samples contain 3 species of algae spore (in 3 genera), 7 species of fern (in 7 genera) and 28 species of pollen (in 15 genera). Selected better-preserved taxa illustrated in Plates 1-4. Four assemblages of algae, spore, and pollen recognized herein. The overall palynological assemblage dominated by diverse gymnosperm and angiosperm pollen grains throughout the interval, followed by fern and algae spores (Appendix A).

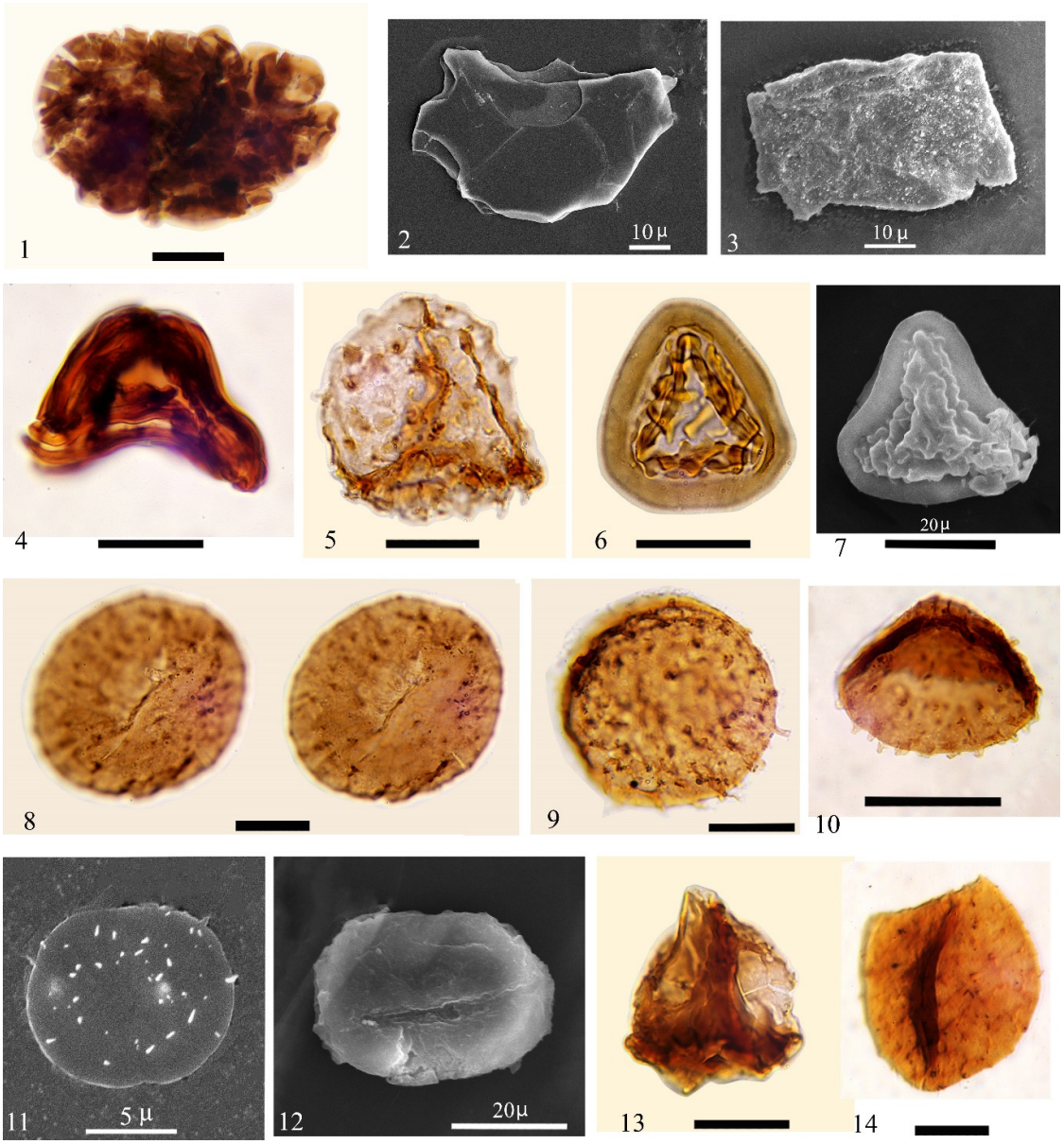

Plate 1. Fig. 1- *Botryococcus* sp., FJURz-4; Fig. 2- *Closteritetrapidites magnus*, FJURz-4; Fig. 3- *Diagonalites diagonalis*, FJURz-4; Fig. 4- *Magnastriatites* sp. cf. *M. grandiosus*, FJURz-2; Fig. 5- *Echinatisporis muelleri*, FJURz-1; Figs. 6, 7- *Polyapodiaceoisporites potoniei*; FJURz-4; Figs. 8, 11- *Echinosporis* sp. cf. *E. densiechinatus*, FJURz-1; Figs. 9, 10- *Baculatisporites primarius*, FJURz-4; Fig. 12- *Acidanthera brevicollis*, FJURz-4; Fig. 13- *Gleicheniidites* sp.; Fig. 14- *Echinosporis* sp., FJURz-4. LM photograph scale bar is 20µ

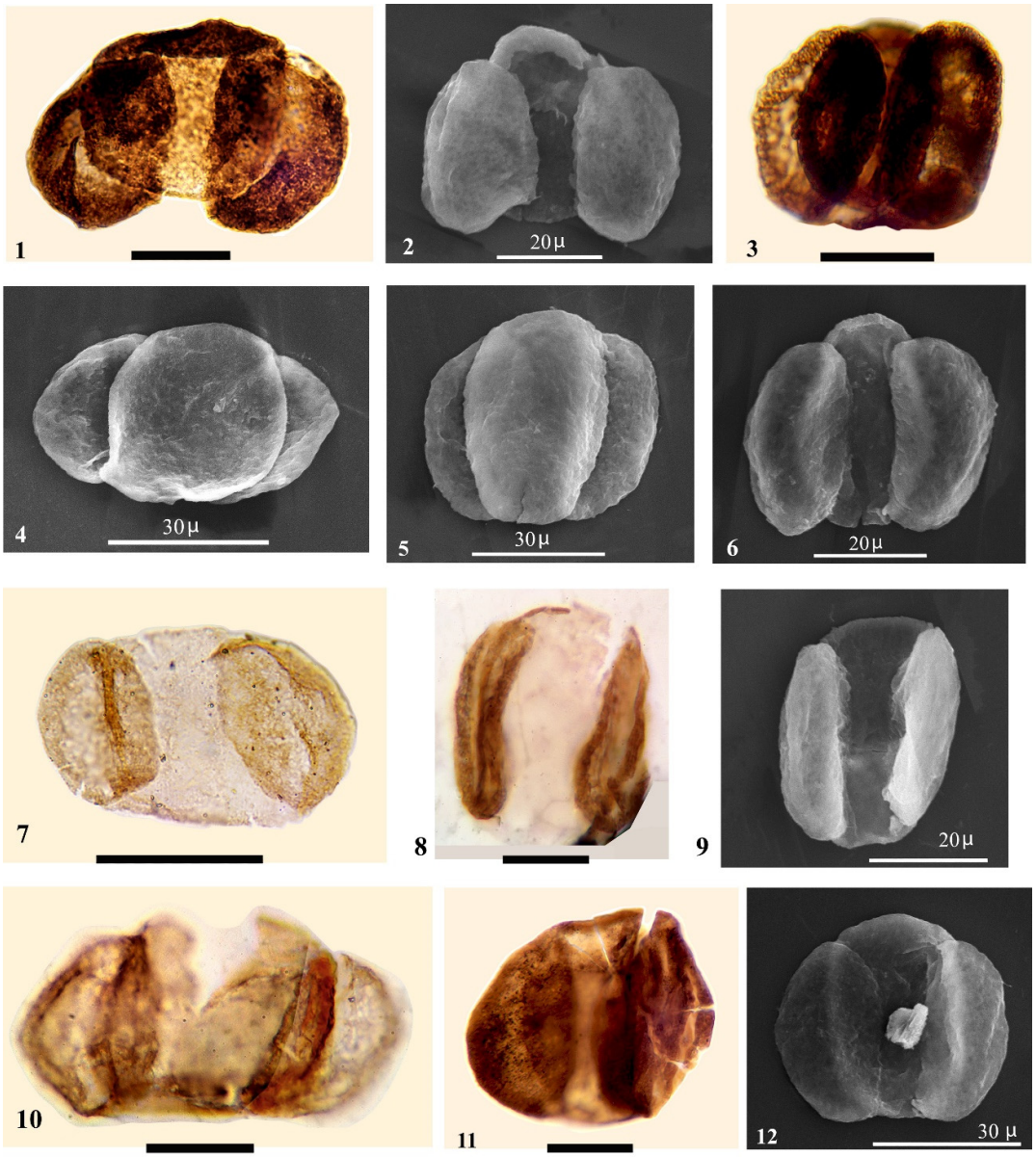

Plate 2. Fig. 1- *Cedripites* sp., FJURz-1; Figs. 2, 3, 5, 6- *Pinuspollenites* sp., FJURz-4; Figs. 4, 7- *Pinuspollenites* Subgenus *Pinus* sp. (Haploxylon type), FJURz-4; Figs. 8, 9- *Pseudolaterix* sp., FJURz-4; Fig. 10- poorly preserved Pinaceae, Figs. 11, 12- *Pinuspollenites* subgenus *Strobus* (Diploxylon type), FJURz-4. LM photograph scale bar is 20µ

Assemblage A: algae spore

Algal spores identified herein are *Botryococcus* sp., *Closteritetrapidites magnus*, and *Diagonalites diagonalis.*

Assemblage B: fern spore

This assemblage contains the following species: *Baculatisporites primarius*, *Distaverrusporites margaritatus*, *Echinatisporis muelleri*, *Echinosporis* sp. cf. *E. densiechinatus*, *Gleicheniidites*, *Magnastriatites grandiosus*, and *Polyapodiaceoisporites potoniei*.

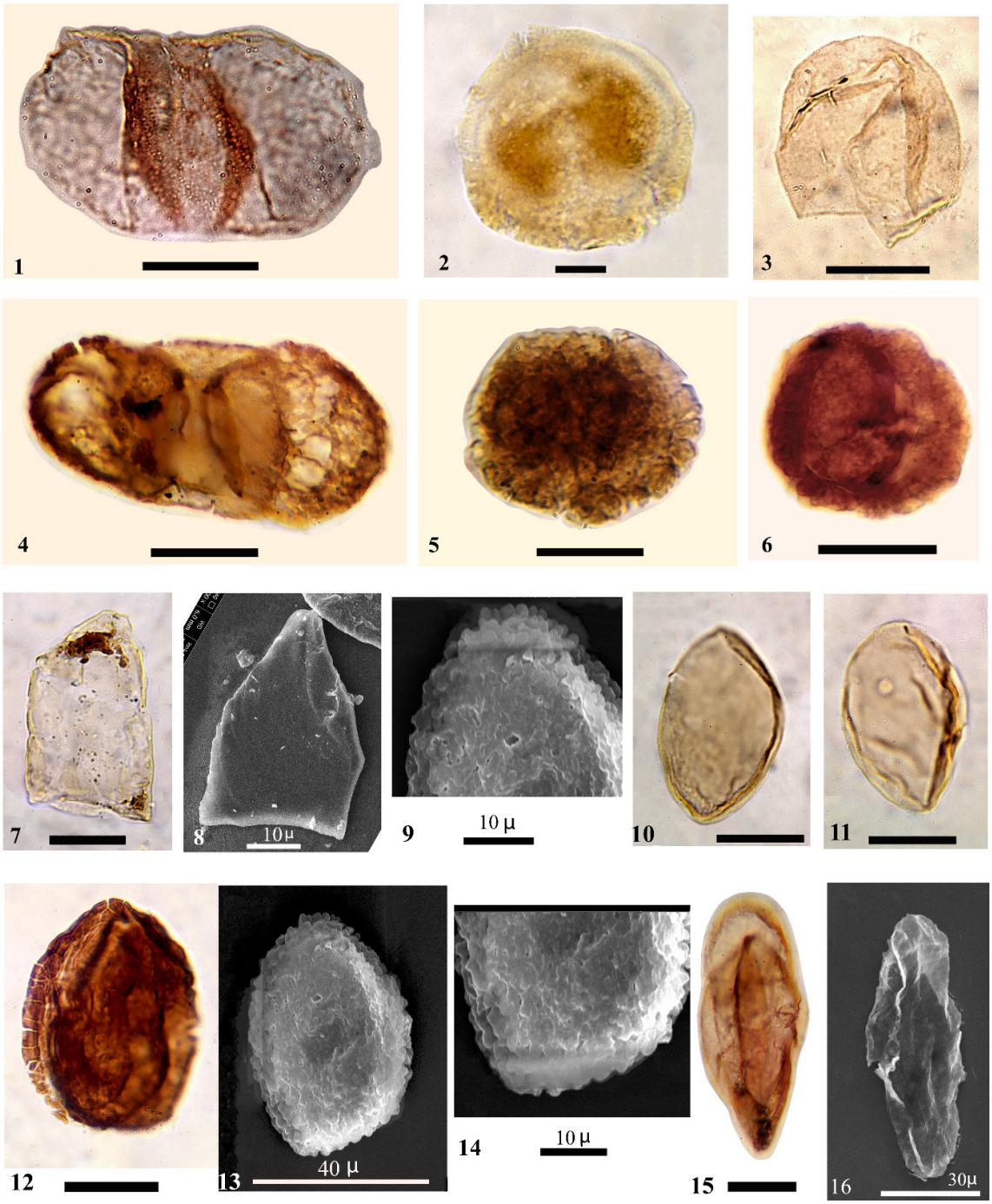

Plate 3. Fig. 1- *Cathayapollis scheuringii*, FJURz-4; Fig. 2- *Tsugapollenites igniculus*, FJURz-4; Fig. 3- *Cupressacites* sp. A, FJURz-4; Fig. 4- *Pinuspollenites* sp. cf. *P. lobatus*, FJURz-4A; Figs. 5, 6, 9, 13, 14- *Tsugapollenites* spp., FJURz-4; Figs. 7, 8- *Cupressacites* sp. B, FJURz-4; Figs. 10, 11- *Monoporopollenites* sp., FJURz-4; Fig. 12- *Fagopsis longifolia*, FJURz-4; Figs. 15, 16- *Ephedripites* (Distachyapites) *tertiarius* FJURz-4. LM scale bar is 20µ

Assemblage C: gymnosperm pollen grain

The gymnosperm pollen assemblage contains the following species: *Abiespollenites* sp., *Cathayapollis scheuringii*, *Cedripites* sp., *Cupressacites* spp., *Ephedripites* (*Distachyapites*) *tertiarius*, *Pinuspollenites* sp. cf. *P. lobatus*, *Pinuspollenites* Subgenus *Pinus* sp.,

Pinuspollenites Subgenus *Strobus* sp., *Pinuspollenites* sp., *Pseudolaterix* sp., *Tsugapollenites igniculus*, and *Tsugapollenites* spp.

Assemblage D: angiosperm pollen grain

The angiosperm pollen assemblage contains the following species: *Acidanthera brevicollis*, *Calliandra* sp. A, *Calliandra* sp. B, *Diospyros* sp., *Fagopsis longifolia*, *Monoporopollenites* sp., and *Retitricolporites* sp. In order to understand palaeoenvironment of parent plant of identified miospores herein, botanical affinities organized in Table 1.

Table 1. Taxa recognized in the present study and corresponding pollen and spore phenotypes documented in previous studies

Plant	Botanical affinity	Taxa	References
Algae	**Botryococcaceae/ Dictyosphaeriaceae**	*Botryococcus* sp.	Worobiec, 2014
	Closteriaceae	*Closteritetrapidites magnus*	Worobiec, 2014; Worobiec et al., 2021
	Zygnemataceae	*Diagonalites diagonalis*	Worobiec, 2014; Worobiec et al., 2021
	Osmundaceae	*Baculatisporites primarius*	Worobiec, 2009; Worobiec et al., 2021
	Gleicheniaceae	*Gleicheniidites* sp.	Mandaokar & Mukherjee, 2012; Carpenter et al., 2015
	Marattiaceae	*Echinosporis* sp. cf. *E. densiechinatus*	D'Apolito et al., 2021
	Pteridaceae	*Magnastriatites* sp. cf. *M. grandiosus*	Germeraad et al., 1968; Dueñas, 1980; D'Apolito et al., 2018
	Polypodiaceae	*Polyapodiaceoisporites potoniei*	Jaramillo and Rueda, 2020; D'Apolito et al., ,2018, 2021
Gnetales	**Ephedraceae**	*Ephedripites tertiarius*	Bouchal, 2019
Angiosperm	**Cupressaceae**	*Cupressacites* spp.	Aboulaïch et al., 2008
	Pinaceae	*Abiespollenites* sp.	Bouchal et al., 2016; Worobiec et al., 2021
		Cathayapollis scheuringii	Bouchal, 2019; Worobiec et al., 2021
		Pinuspollenites Subgenus *Pinus* sp.	Bouchal et al., 2016
		Pinuspollenites sp. cf. *P. lobatus*	Gosling et al., 2019
		Pinuspollenites Subgenus *Strobus* sp.	Bouchal et al., 2016; Bouchal, 2019
		Pseudolaterix sp.	Shang & Zavada, 2003
		Tsugapollenites spp.	Worobiec, 2009; Bouchal et al., 2016; Miao et al., 2017
	Iridaceae	*Acidanthera brevicollis*	Gosling et al., 2013
	Fagaceae	*Fagopsis longifolia*	Gortemaker, 1986; Liu et al., 1998; Grímsson et al., 2015; Miao et al., 2017; Hofman et al., 2019; Worobiec et al., 2021
	Fabaceae	*Calliandra* sp.	Antonio-Domingues et al., 2018
	Poaceae/ Restionaceae	*Monoporopollenites* sp.	
	Rubiaceae	*Retitricolporides* sp.	Salamanca-Villegas et al., 2016; D'Apolito et al., 2021

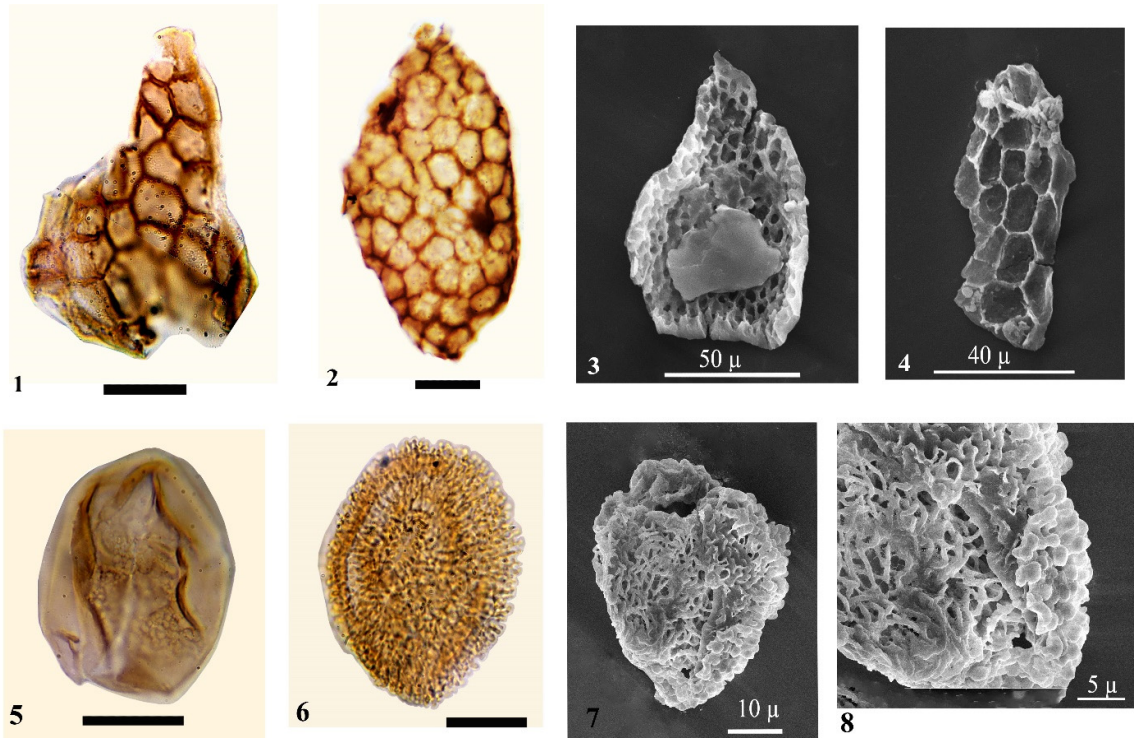

Plate 4. Figs. 1-4 *Calliandra* spp., FJURz-4; Fig. 5- *Diospyros* sp., FJURz-4; Figs. 6-8- *Retitricolporites* sp., FJURz-4. LM photograph scale bar is 20µ

Conclusions

The Miocene sediments of Upper Red Formation in northwestern Zanjan city, NW Iran studied herein. This formation consists of rich assemblage of various palynofloras, in which thirty-one species identified. It contains three algae spores (in three genera), seven fern species (in seven genera), fourteen species of gymnosperms (in nine genera) and seven species of angiosperm pollen (in six genera). Parent plant of these miospores divided into four categories: Algae (Family Botryococcaceae/ Dictyosphaeriaceae, Closteriaceae, and Zygnemataceae); Pteridophyta (Family Gleicheniaceae, Marattiaceae, Pteridaceae, and Polypodiaceae); Gymnosperm (Cupressaceae, Ephedraceae, and Pinaceae), and Angiosperm (Fagaceae, Fabaceae, Iridaceae, and Rubiaceae).

Disclosure statement

There is no conflict of interest.

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Appendix A; Systematic

Algae

Botryococcus sp. (Plate 1, Fig. 1)
Closteritetrapidites magnus Krutzsch & Pacltová 1990 (Plate 1, Fig. 2)
Diagonalites diagonalis Krutzsch & Pacltová 1990 (Plate 1, Fig. 3)

Spore

Baculatisporites primarius (Wolf 1934) Thompson & Pflug 1953 (Plate 1, Figs. 9, 10)
Echinatisporis muelleri Krutzsch 1967 (Plate 1, Fig. 5)
Echinosporis sp. cf. *E. densiechinatus* D'Apolito et al. 2021 (Plate 1, Figs. 8, 11)
Echinosporis sp. (Plate 1, Fig. 14)
Gleicheniidites sp. (Plate 1, Fig. 13)
Magnastriatites sp. cf. *M. grandiosus* (Kedves & Sole de Porta 1963) Dueñas 1980 (Plate 1, Fig. 4)
Polyapodiaceoisporites potoniei Kedves 1961 (Plate 1, Figs. 6, 7)

Gymnosperm Pollen

Cathayapollis scheuringii (Sivak) Ziembinska-Tworzydło 2002 (Plate 3, Fig. 1)
Cedripites sp. (Plate 2, Fig. 1)
Cupressacites sp. A (Plate 3, Fig. 3)
Cupressacites sp. (Plate 3, Figs. 7, 8)
Ephedripites (*Distachyapites*) *tertiarius* Krutzsch 1970 (Plate 3, Figs. 15, 16)
Pinuspollenites subgenus *Pinus* sp. (Plate 2, Figs. 4, 7)
Pinuspollenites subgenus *Strobus* sp. (Plate 2, Figs. 11, 12)
Pinuspollenites sp. cf. *P. lobatus* (Plate 3, Fig. 4)
Pinuspollenites spp. (Plate 2, Figs. 2, 3, 5, 6)
Pseudolaterix sp. (Plate 2, Figs. 8, 9)
Tsugapollenites igniculus Thiergart 1938 emend. Gravendyck et al. 2023 (Plate 3, fig. 2)
Tsugapollenites spp. (Plate 3, Figs. 5, 14)

Angiosperm pollen

Acidanthera brevicollis Baker 1876 (Plate 1, Fig. 12)
Calliandra spp. (Plate 4, Figs. 1-4)
Diospyros sp. (Plate 4, Fig. 1)
Fagopsis longifolia (Lesquereux 1872) Hollick & Torreya 1909 (Plate 3, Fig. 12)
Monoporopollenites sp. (Plate 3, Figs. 10, 11)
Retitricolporites sp. (Plate 4, Figs. 6-8)