

Middle Jurassic plant macro and microfossils from Shahreza, South West Isfahan, Central Iran: Palaeoclimate influences

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Abstract

Jurassic deposits have been found in the Shahreza area, southwest of Isfahan city, central Iran. They yield plant macrofossils belonging to 22 species assigned to 17 genera of various orders such as Equisetales, Filicales, Bennetitales, Cycadales, Ginkgoales, and Coniferales. According to the occurrence of *Annulariopsis simpsonii*, *Cladophlebis aktashensis*, *Nilssonia macrophylla*, and *Elatides thomasii*, late Early–Middle Jurassic age is suggested for this assemblage. The relative abundance of Filicales, Coniferales, and Cycadales are 49.98%, 27.19%, and 8.77%, respectively. Although Iran was located in a humid and warm temperate biome during the Middle Jurassic, the flora of Shahreza area indicates that it occurred at various environments: upland, wetter/drier lowland, river and coastal with a temperate and humid climate. Moreover, 16 miospore species belonging to 13 genera, and seven dinocyst species assigned to three genera were identified from the studied area. Therefore, it is concluded that Shahreza reflects a coastal plain along a shallow water environment where plant macrofossil remains and miospores were sedimented.

Keywords: Jurassic, Plant macro and microfossils, Shahreza, Iran

Introduction

Early and Middle Jurassic continental sediments of considerable thickness are widespread in the northern (Zirab, Tazareh, Iva, Baladeh, Rudbarak, Khatumbargah, Vasekgah and Imam Manak, Ziaran, Djam, Gheshlagh, Shemshak, Ferizi, Golmakan, Shandiz, Jajarm, and Bazehowz), central and eastern-central (Dashte-Khak, Babnizu, Hashooni, Eshkelli, Pabdana in the Kerman Basin, and Jafar Abad, Mazino, Calshaneh, North and South Kouchekali in the Tabas Block) Iran. Palaeobotanical contributions were published among others by Boureau *et al.* (1950), Asereto *et al.* (1968), Kilpper (1964, 1968, 1971, 1975), Alavi & Barale (1970), Barnard & Miller (1976), Bragin *et al.* (1976), Sadovnikov (1976, 1983, 1991), Corsin & Stampfli (1977), Fakhr (1977), Schweitzer & Kirchner (1995, 1996, 1998, 2003), Schweitzer *et al.* (1997, 2000, 2009), Vaez-Javadi & Pour-Latifi (2002, 2004), Vaez-Javadi & Ghavidel-Syooki (2002), Saadat Nejad (2005, 2010), Vaez-Javadi & Mirzaei-Ataabadi (2006), Vaez-Javadi (2008, 2011, 2012, 2014, 2015, 2017, 2018a), Saadat Nejad *et al.* (2010), Fadaiey Khojasteh *et al.* (2010), Popa *et al.* (2012), Vaez-Javadi & Abbasi (2012, 2018), Ameri *et al.* (2013, 2014), Vaez-Javadi & Allameh (2015), Vaez-Javadi & Namjoo (2015), Mehdizade *et al.* (2016), and Ameri (2018).

Iranian Jurassic palynological assemblages have

been investigated by Arjang (1975), Ashraf (1977), Kimyai (1968, 1974, 1977), Achilles *et al.* (1984), Bharadwaj & Kumar (1986), Wheeler & Sarjeant (1990), Vaez-Javadi *et al.* (2003), Vaez-Javadi & Ghavidel-Syooki (2005), Sajjadi *et al.* (2010), Dehbozorgi *et al.* (2013), Navidi-Izad *et al.* (2015), Hashemi-Yazdi *et al.* (2014), and Vaez-Javadi (2017, 2018b).

Large-scale coal-bearing group or formation such as Shemshak and Hojedk, ranging from Rhaetian to Bajocian are well spread throughout the Iranian Plate, but the bulk of fossil localities are concentrated in the northern and east-central areas of the country. Herein we report a florule from the Shahreza area, southwest of Isfahan city, a new fossil plant locality in central Iran.

Asereto (1966) established the Shemshak Formation based on a type section to the east of Shemshak village, North of Tehran. He divided it into four informal members (A to D) represented by the lower sandstone, the lower carbonaceous series, the upper sandstone, and the upper carbonaceous series. Fürsich *et al.* (2009a, b) raised the Shemshak Formation to a group status. The base of this group rests unconformably on a succession of strata beginning with the Elika Formation (Middle Triassic). The Dalichai Formation unconformably overlays the Shemshak Group in central Alborz. Wilmsen *et al.* (2009) studied a Lower Jurassic–early Bajocian continental sequence in the Binalud

Mountains, equivalent to "the Jurassic succession of the Shemshak Group in the southern Alborz Mountains". Zahedi (1976) and Aghanabati (2008) only reported Triassic and Cretaceous strata from the studied area.

The aim of this paper is twofold:

To introduce the flora from Shahreza section, Southwest Isfahan, Central Iran in order to recognize the strata bearing floras age.

To determine "morphocats", "floral gradient", and "similarity indices" of the studied floras' assemblage zones through North, East, and Central-East Iran and interpret palaeoclimate conditions based on original data.

Geological settings

The plant macrofossils and palynomorphs examined

herein were collected from the Shahreza area, southwest Isfahan city, at N 32° 04' 50", and E 51° 58' 14"(Figs. 1, 2). There is no evidence of Jurassic sediments in the geological map of Shahreza and we noticed this evidence of Jurassic sediments for the first time.

Materials and methods

A recent survey of the area for economic geology purposes resulted in the discovery of Jurassic fossil plants. These strata in Shahreza yielded the specimens studied in this paper. Fifty-nine samples gathered from the upper part of succession. Sample numbers include JMSS (the acronym of Javadi, Mirzaie, Shemshak, and Shahreza). The specimens were photographed and the images were enhanced using Photoshop CC 2014.

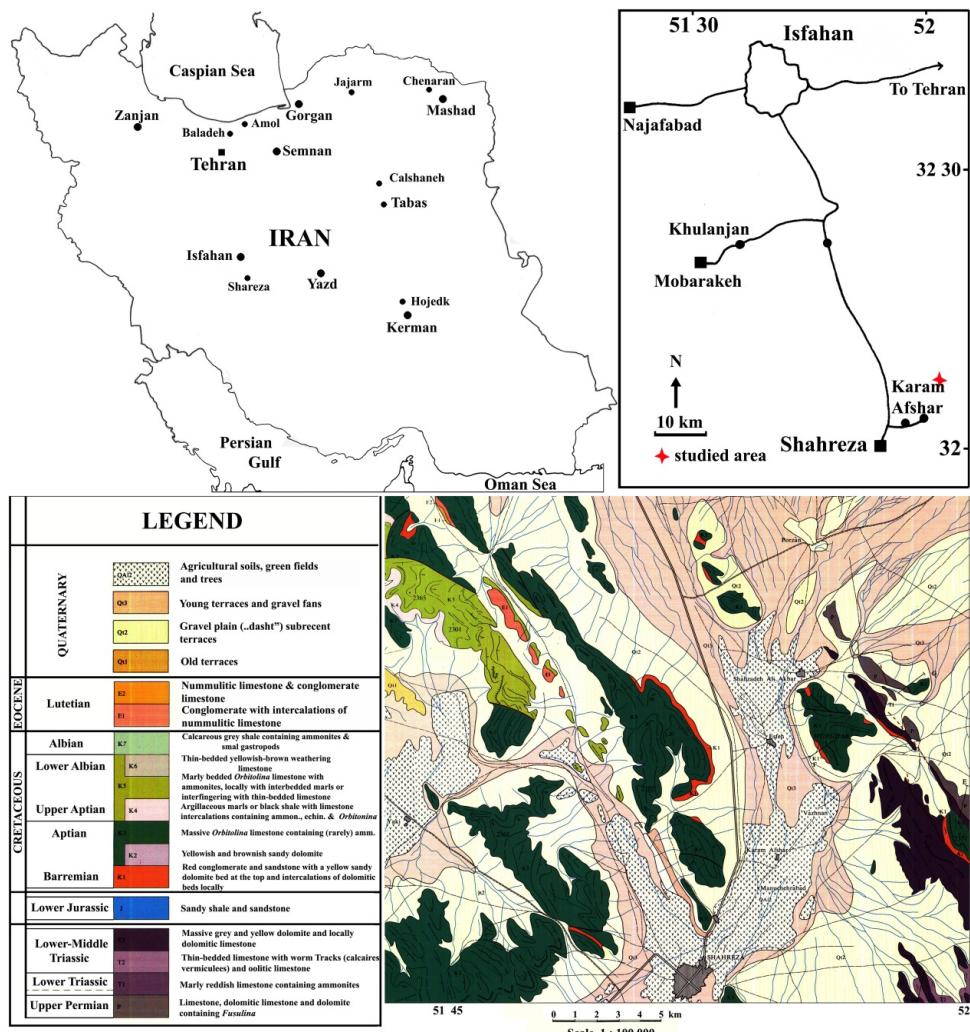


Figure 1. Geological map (scale: 1/100,000) and location of the studied area in Shahreza, southwest of Isfahan (after Zahedi, 1976)

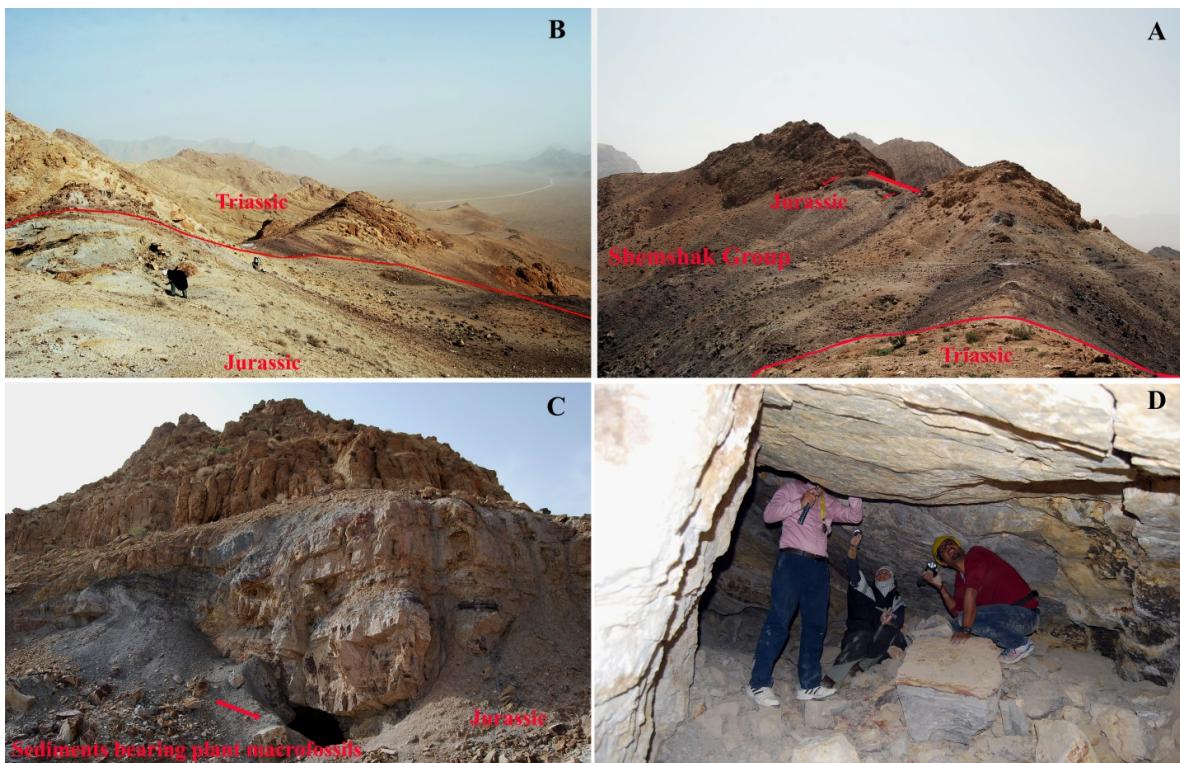


Figure 2. Landscapes of the studied section and locality of sediments bearing plant macro and microfossil sediments in Shahreza.

Moreover, the approach in this study was to assemble the floral lists from seven well-studied sections with acceptable records of fossil plants; these sections are distributed from northern to central and east-central Iran, following the concept of "biome". Ziegler *et al.* (1993) assigned all Jurassic leaf genera to ten coarser morphological categories or 'morphocats' in order to understand broad phytogeography patterns. These categories are sphenophytes, ferns, pteridosperms, microphyllous cycadophytes, unassigned (intermediate or morphologically variable) cycadophytes, macrophyllous cycadophytes, ginkgophytes, microphyllous conifers, unassigned (intermediate or morphologically variable) conifers, and macrophyllous conifers. Their ordination studies on the floras demonstrated a gradual replacement of morphological types: from coniferophytes and cycadophytes with thick cuticles and small leaves in low latitudes, through broadleaved forms of cycadophytes with filicopsids, to broad-leaved deciduous ginkgophytes and coniferophytes in near-polar positions. These groups reflect the individual physiognomic strategies of their original plants. Ziegler *et al.* (1996) made two-dimensional plots of localities and the taxa, showing variance within the data sets on the two principal axes. The locality

plots showed that axis 1 was generally correlated with paleolatitude whereas the taxa plots showed that the axis 2 was correlated with an obvious transformation in foliar physiognomy from coniferophytes and cycadophytes with small leaves and thick cuticles at the low-latitude end to broad-leaved deciduous ginkgophytes at the high-latitude end. Taken together, these patterns were interpreted to indicate warm and dry conditions centered at about 35° N and cool temperate conditions extended up to 80° N, with the highest-diversity warm temperate floras in the middle of the range. The score for each taxon represented its "centroid" in the latitudinal spectrum across Eurasia ranging from about 30°N to 80°N. Thus, *Phoenicopsis* occurred at the locations assigned to the cool temperate biome and *Zamites* at the dry subtropical locations. These two studies made a "floral spectrum through time" during the Mesozoic. Rees *et al.* (2000) explained a method commonly used in studies of modern ecology and vegetation succession. By using this method, multi-dimensional relationships showed the variation within data sets on a series of two-dimensional axis plots. In this way, the climate can be interpreted using the basic morphology of individual leaf genera and the palaeogeographic distribution of plant localities. By

averaging the scaled (0 to 100) scores of the 32 common genera, a Jurassic 'floral gradient' has been derived. However, they distinguished five "vegetation biomes" for the Jurassic: a) cold temperate at high latitudes ($N60^{\circ}$) with low species diversity and seasonality; b) warm temperate ($40-60^{\circ}$) with high species diversity and abundant macrophyllous cycadophytes; c) winter-wet with microphyllous elements that are typical for seasonal water deficits (narrowband in N-America, India, southern Hemisphere); d) sub-tropical desert where plants are absent; and e) summer-wet (tropical) around the equator with microphyllous elements, where cycads, ginkgophytes and some of the conifer families are absent.

Furthermore, we used Sørensen-Dice similarity index (Dice, 1945; Sørensen, 1948) as a statistical method used for comparing the degree of similarity between two populations or localities using the following equation:

$S_i = 2 \times C / A+B$ (Where A= Number of plant macrofossils in locality A, B= Number of plant macrofossils in locality B, C= Number of Common taxa between A and B). It was independently developed by the botanists Thorvald Sørensen and Lee Raymond Dice who published in 1948 and 1945, respectively.

The index ranges between "zero", meaning no common species, and "one" meaning complete or total similarity. Finally, by using the standard floral gradient list, determining main morphocats and comparing floral gradient scores and similarity indices of the Shahreza florula with other areas in Iran, comparative diagrams were drawn and a conclusion was produced.

Three palynological samples were also studied. Standard palynological procedures (e.g., Phipps & 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. 20 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 20 μm 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. The palynomorphs, if too dark, were bleached with 5% KOH. All slides were studied and photographed with an 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 Sciences, University of Tehran, Tehran, I. R. Iran.

Results

The studied sediments in Shahreza contain various species of plant macrofossils and palynomorphs (spores, pollen, and dinoflagellate cysts) referable to the Jurassic. Two assemblages of plant macrofossils and palynomorphs are recognized herein from the upper part of succession.

Assemblage 1

Twenty-two species of macrofossil remains belonging to 17 genera of various orders such as Equisetales, Filicales, Cycadales, Ginkgoales, and Coniferales were identified. They are *Annulariopsis simpsonii* (Phillips 1875) Harris 1947, *Equisetites columnaris* (Brongniart 1828) Phillips 1875, *Marattiopsis intermedia* (Muenster 1936) Kilpper 1964, *Marattiopsis muensteri* (Goeppert 1842) Schimper 1874, *Coniopteris hymenophylloides* (Brongniart 1828) Seward 1900, *Cladophlebis aktashensis* Turutanova-Ketova 1930, *Taeniopteris intermedia* Muenster 1936, *Nilssonia ingens* Schweitzer, Kirchner & van Konijnenburg-van Cittert 2000, *N. macrophylla* Jacob & Shukla 1955, *Nilssonia* sp. cf. *N. bozorga* Barnard & Miller 1976, *N. sp.* cf. *N. tenuicaulis* (Phillips 1829) Fox-Strangways 1829, *Nissonia* sp., *Beania mamayi* Thomas & Harris 1960, *Sphenobaiera longifolia* (Pomel 1849) Florin 1936, *Ginkgoites* sp. cf. *G. khorassanicus* Fakhr 1977, *Ginkgoites parasingularis* Kilpper 1971, *Chamaetaxus orientalis* Schweitzer & Kirchner 1996, *Elatides thomasii* Harris 1979, *Elatocladus zamioides* (Leckenby 1864) Seward 1919, *E. sp.* cf. *E. ramosus* (Florin 1958) Harris 1979, *Cyparissidium rudlandicum* Harris 1979, and *Podozamites distans* (Presl 1838) Braun 1843 (Fig. 3, Plates 1-4).

Biostratigraphically, the species *Nilssonia ingens* and *Nilssonia macrophylla* have been reported from the Middle Jurassic of Iran (Schweitzer *et al.*, 2000, Vaez-Javadi, 2014, 2018a). *Equisetites columnaris*, *Annulariopsis simpsonii*, *Cladophlebis aktashensis*, *Nilssonia macrophylla*, and *Elatides thomasii* have been reported from late Early-early Middle Jurassic of Iran and Afghanistan (Fakhr, 1977, Schweitzer & Kirchner, 1996, Schweitzer *et al.*, 1997, 2000, 2009, Barnard, 1967, Vaez-Javadi, 2014, 2018a).

Since there is no evidence of Triassic plant macrofossils, and based on the occurrence of the above-mentioned species, the late Early-early Middle Jurassic age is suggested for this assemblage at the upper part of the succession.

Systematic palaeobotany

Division Sphenophyta

Class Sphenopsida

Order Equisetales

Genus *Annulariopsis* Zeiller 1903

Type species: *Annulariopsis inopinata* Zeiller 1903
Annulariopsis simpsonii (Phillips 1875) Harris 1947
 Plate 1, Fig. 4
 1875 *Marzaria simpsonii* Phillips; p. 204.

- 1947 *Annulariopsis simpsonii* (Phillips) Harris; p. 654, figs. 3, 4A-D.
 1964 *Annulariopsis simpsonii*: Kilpper; p. 16, pl. I, figs. 2, 3; text-fig. 1.
 1968 *Annulariopsis simpsonii*: Asereto *et al.*; table 1a.
 1977 *Annulariopsis simpsonii*: Fakhr; p. 36, pl. I, fig. 9; text-fig. 1D.
 1997 *Annulariopsis simpsonii*: Schweitzer *et al.*; pp. 149-150, pl. 10, figs. 5-10.
 2014 *Annulariopsis simpsonii*: Vaez-Javadi; p. 72, pl. 2, fig. 2; Fig. 4:1.
 2018a *Annulariopsis simpsonii*: Vaez-Javadi; p. 304.

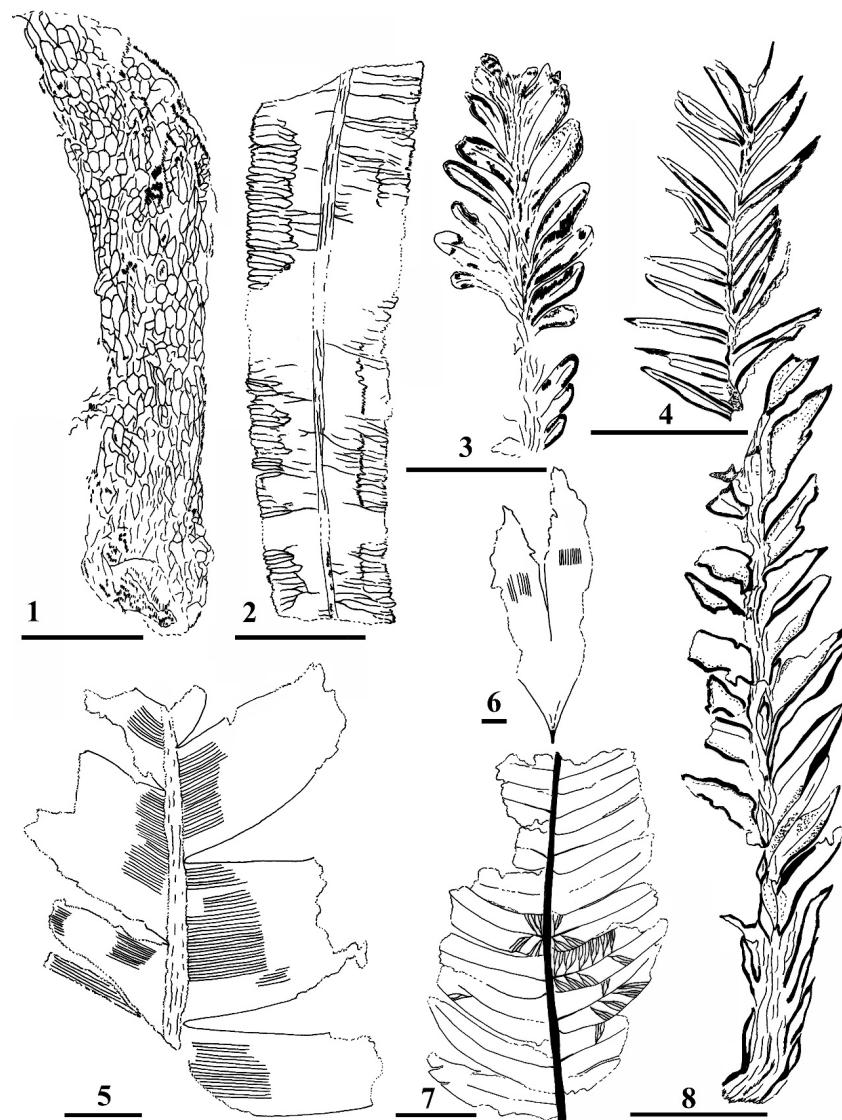


Figure 3. 1- *Equisetites columnaris*, 2- *Marattiopsis muensteri*, 3- *Chamaetaxus orientalis*, 4- *Elatocladus zamioides*, 5- *Nilssonia macrophylla*, 6- *Ginkgoites parasingularis*, 7- *Cladophlebis aktashensis*, 8- *Chamaeotaxus* sp. Scale bars= 10 mm.

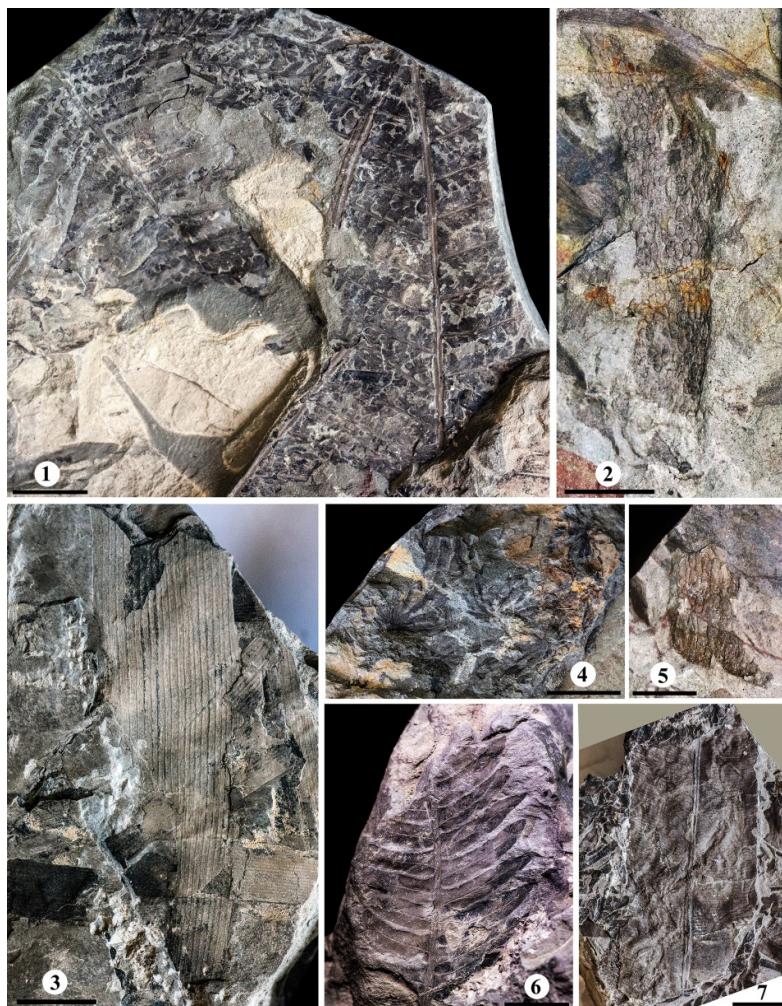


Plate 1. Fig. 1- *Coniopteris hymenophylloides* (Brongniart 1828) Seward 1900, Figs. 2-5- *Equisetites columnaris* (Brongniart 1828) Phillips 1875, Fig. 3- *Equisetites* sp., Fig. 4- *Annulariopsis simpsonii* (Phillips 1875) Harris 1947, Fig. 6- *Cladophlebis aktashensis* Turutanova-Ketova 1930, Fig. 7- *Taeniopterus intermedius* Muenster 1836. Scale bars are 1 cm.

Description. The material consists of about 4 incomplete leafy-whorls. Microphylls are linear-spatulate, 15 mm long and 1–2 mm width, slightly undulate margins with one vein at the median of the leaf.

Material: JMSS-1, JMSS-2.

Genus *Equisetites* Sternberg 1833
Equisetites columnaris (Brongniart 1828) Phillips 1875

Plate 1, Figs. 2, 5; Figure 3: 1

1828 *Equisetum columnare* Brongniart; p. 115, pl. 3, figs. 4–6.

1875 *Equisetites columnaris* (Brongniart) Phillips; p. 197.

1997 *Equisetites columnaris*: Schweitzer *et al.*; pp. 135–137, pl. 15, figs. 1–7; pl. 6, figs. 1–3; text–fig.

15.

2006 *Equisetites* cf. *columnaris*: Vaez-Javadi & Mirzaie-Ataabadi; pp. 66, 69, figs. 3A–B, 8C, 12A.

2011 *Equisetites columnaris*: Vaez-Javadi; p. 79, figs. 3A, B, D, 4A, E, H.

2012 *Equisetites columnaris*: Vaez-Javadi & Abbasi; p. 41, pl. I, figs. 1, 2; text–fig. 4: 1.

2014 *Equisetites* sp. cf. *E. columnaris*: Vaez-javadi; p. 122, pl. 1, fig. 4.

Description. This material is an elongate ellipsoid cone, ca. 56 mm long and 9.5–11 mm width. It consists of whorls of up to 112 sporangiophores. The sporangiophores heads are clearly visible from the outside. The heads are hexagonal–ellipsoid in the general outline, 2.2–2.5 mm x 0.9 mm in size, like a honeycomb.

Material: JMSS-3, JMSS-4.

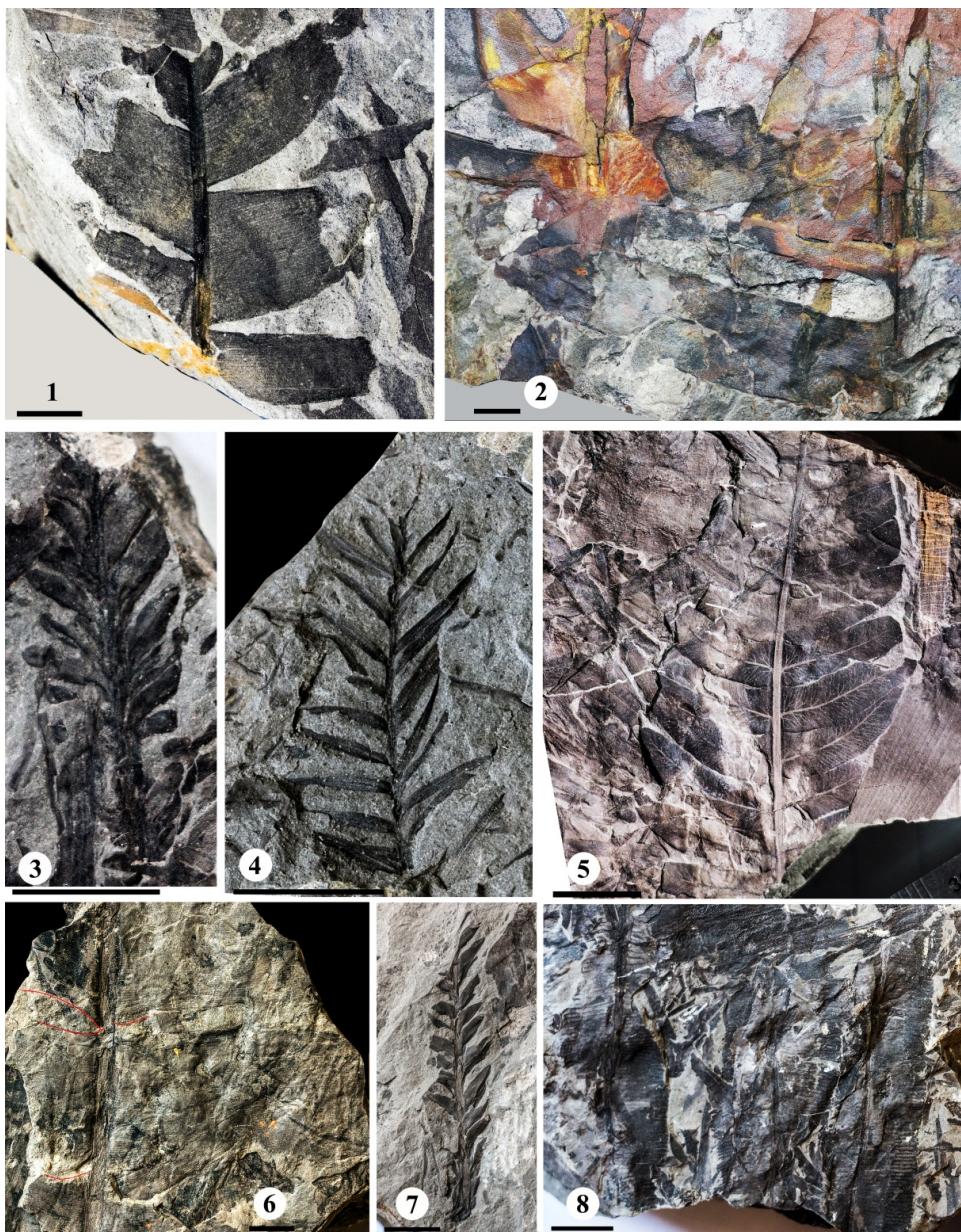


Plate 2. Fig. 1- *Nilssonia* sp. cf. *N. bozorga* Barnard & Miller 1976, Figs. 2, 6- *Nilssonia ingens* Schweitzer, Kirchner & van Konijnenburg-van Cittert 2000, Fig. 3- *Chamaetaxus orientalis* Schweitzer & Kirchner 1996, Fig. 4- *Elatocladus zamioides* (Leckenby 1864) Seward 1919, Fig. 5- *Cladophlebis aktashensis* Turutanova-Ketova 1930, Fig. 7- *Chamaetaxus* sp., Fig. 8- *Marattiopsis intermedia* (Muenster 1836) Kilpper 1964. Scale bars are 1 cm.

Division Filicophyta
 Class Eusporangiopsida
 Order Marattiales
 Family Marattiaceae
 Genus *Marattiopsis* Schimper 1869
 Type species: *Marattiopsis dentata* (Sternberg)
 Schimper 1869
Marattiopsis intermedia (Muenster 1836) Kilpper
 1964
 Plate 2, Fig. 8

1836 *Taeniopteris intermedia* Muenster; p. 510.
 1964 *Marattia intermedia* (Muenster) Kilpper; p.
 22, pl. 3, figs. 6–13; pl. 4, figs. 1–11, text–figs. 2–4.
 1976 *Marattia intermedia*: Bragin et al.; p. 39.
 1997 *Marattia intermedia*: Schweitzer et al.,
 pp. 153–155, pl. 11, figs. 1–4; pl. 12, figs. 1–9; text–
 fig. 21.
 2006 *Marattiopsis intermedia*: Vaez–Javadi; p. 398,
 pl. 5, fig. 1; text–fig. 3B.
 2011 *Marattia intermedia*: Vaez–Javadi; p. 82, figs.

3E, 6C.

2014 *Marattiopsis intermedia*: Vaez-Javadi; p. 123, pl. IV, fig. 3; fig. 1: 10.

Description. The Frond is entire and undivided, linear, 55 mm long and 17–18 mm wide with 16 synangia per cm. Lateral veins are simple or forked only once near the midrib, 12–14 per cm. Venuli recurrentes present and usually conspicuous.

Material: JMSS–5, JMSS–6, JMSS–7, JMSS–8, JMSS–9, JMSS–10, JMSS–11, JMSS–12, JMSS–13.

Marattiopsis muensteri (Goeppert 1842) Schimper 1874

Plate 3, Fig. 6; Fig. 3: 2

1842 *Taeniopteris muensteri* Goeppert, p. 51, pl. IV, figs. 1–3.

1874 *Marattiopsis muensteri* (Goeppert) Schimper; p. 514.

1977 *Marattiopsis muensteri*: Fakhr; pp. 38–39, pl. II, figs. 1–3; fig. 1E, F.

Description. This specimen is a fertile leaf. Pinna is entire, 54 mm long (whole length unknown) and 9–12.5 mm width, with 18 synangia per cm. Midrib sharp, increasing in width from the base (0.5 mm) upward (1 mm), longitudinally striated.

Material: JMSS–14, JMSS–15.

Class Leptosporangiopsida

Order Gleicheniales

Family Dicksoniaceae

Genus *Coniopteris* Brongniart 1849

Type species: *Coniopteris murrayana* Brongniart 1849

Coniopteris hymenophylloides (Brongniart 1828) Seward 1900

Plate 1, Fig. 1

1828 *Sphenopteris hymenophylloides* Brongniart; p. 189, pl. 56, fig. 4.

1900 *Coniopteris hymenophylloides* (Brongniart) Seward; p. 99, pl. 16, figs. 4–6; pl. 17, figs 6?, 7, 8?; pl. 20, figs. 11, 12; pl. 21, figs. 1–4.

1950 *Coniopteris hymenophylloides*: Boureau *et al.*; pp. 214–215, pl. I, figs. 1, 2.

1964 *Coniopteris hymenophylloides*: Kilpper; pp. 65, 66, pl. 15, figs. 1–12, text–figs. 36, 37.

1976 *Coniopteris hymenophylloides*: Sadovnikov; p. 130, pl. 10, figs. 3–5.

1977 *Coniopteris hymenophylloides*: Fakhr; pp. 56–57, pl. XI, figs. 1c–d; pl. XII, figs. 3–5; figs. 5A–D.

1977 *Coniopteris hymenophylloides*: Corsin & Stampfli; pp. 525–526, pl. 10, figs. 2–6.

1984 *Coniopteris hymenophylloides*: Vassiliev; p.

10, pl. 5, figs. 1–3.

2004 *Coniopteris hymenophylloides*: Vaez-Javadi & Pour-Latifi; pp. 99–100, pl. 1, fig. 4.

2008 *Coniopteris hymenophylloides*: Vaez-Javadi; pp. 64–65, pl. 9, fig. 3; text–fig. 11: 6.

2006 *Coniopteris hymenophylloides*: Vaez-Javadi & Mirzaie-Ataabadi; p. 71, fig. 12E.

2009 *Coniopteris hymenophylloides*: Schweitzer *et al.*; pp. 69–74, pl. 28, fig. 3; pl. 29, figs. 1–3; pl. 30, figs. 1, 2; pl. 31, figs. 1–4; pl. 32, figs. 1–3; text–figs. 28–31a, b.

2010 *Coniopteris hymenophylloides*: Saadat Nejad *et al.*; p. 179, pl. 1, fig. 2.

2011 *Coniopteris hymenophylloides*: Vaez-Javadi; p. 85, figs. 3F; 4F; 5C.

2012 *Coniopteris hymenophylloides*: Vaez-Javadi & Abbasi; p. 41, pl. I, fig. 5; pl. III, figs. 2a, 4; text–fig. 4: 2–4.

2014 *Coniopteris hymenophylloides*: Vaez-Javadi; pp. 75–77, pl. 3, figs. 1–3, 5; Fig. 2:1; Fig. 8: 4.

2015 *Coniopteris hymenophylloides*: Vaez-Javadi; p. 108, pl. 2, figs. 3, 6, 7; text–fig. 6:6.

2015 *Coniopteris hymenophylloides*: Vaez-Javadi & Allameh; p. 29, pl. 1, figs. 1, 2, 5.

2018a *Coniopteris hymenophylloides*: Vaez-Javadi; p. 304, pl. 1, fig. B.

Description. Sterile pinnae are present but incomplete, bipinnate, ca. 52 mm long. Pinnae lanceolate, alternate, 16.6 mm long (whole length unknown). Pinnules are small in size, 3.3 mm x 2.5 mm, sub–alternate, contracted bases, rounded apices and lobate margins.

Material: JMSS–16.

Filicales Incertae sedis

Genus *Cladophlebis* Brongniart 1849

Type species: *Cladophlebis haiburnensis* (Lindley & Hutton) Brongniart 1849

Cladophlebis aktashensis Turutanova–Ketova 1930

Plate 1, Fig. 6, Plate 2, Fig. 5; Fig. 3: 7

1930 *Cladophlebis aktashensis* Turutanova–Ketova; p. 322, pl. 3, fig. 7; pl. 4, fig. 7; pl. 5, fig. 8; text–fig. 1.

1997 *Cladophlebis aktashensis*: Schweitzer *et al.*; pp. 176–179, pl. 21, figs. 1–5; text–figs. 25 B, 27.

2006 *Cladophlebis aktashensis*: Vaez-Javadi & Mirzaie-Ataabadi; p. 75, figs. 4C, G; 12D.

2011 *Cladophlebis aktashensis*: Vaez-Javadi; p. 85, figs. 5D, 10D, E.

2012 *Cladophlebis aktashensis*: Vaez-Javadi; p. 229, pl. 2, fig. 1.

2012 *Cladophlebis aktashensis*: Vaez-Javadi &

Abbasi; p. 44, pl. II, figs. 2–4; text–fig. 4: 5.
 2014 *Cladophlebis aktashensis*: Vaez–Javadi; p. 127, pl. IV, fig. 7; fig. 1: 9.
Description. Two specimens were photographed. The specimen of plate 2, fig. 5 is a small fragment of a pinna 52 mm long. Pinnules attach at an angle of 60°–65°, 19 mm x 5 mm in size, almost parallel margins which converge only near the apex ending obtuse, slightly curved forwards. The basiscopic margin is straight whilst acroscopic margin is straight or slightly expanded. Veins are forked twice.
Material: JMSS–17, JMSS–18, JMSS–19, JMSS–20, JMSS–21, JMSS–22.

Division Gymnospermophyta

Class Cycadopsida

Order Cycadales

Family Nilssoniacae

Genus *Nilssonia* Brongniart 1826

Nilssonia sp. cf. *N. bozorga* Barnard & Miller 1976
 Plate 2, Fig. 1; Fig. 3: 5
 1976 *Nilssonia bozorga* Barnard & Miller, p. 82; pl. 11, Figs. 1–5; Fig. 19 A–I.
 2000 *Nilssonia bozorga*: Schweitzer *et al.*; p. 26, pl. 6, figs. 1, 2; text–fig. 5 a–c, 6.
 2014 *Nilssonia bozorga*: Vaez–Javadi; pp. 131–132, pl. VII, fig. 1; fig. 2: 5.
 2015 *Nilssonia* sp. cf. *N. bozorga*: Vaez–Javadi & Allameh; p. 29, pl. 3, fig. 1.
 2018 *Nilssonia bozorga*: Ameri, p. 5; pl. 1a, b.
Description. Leaf is once pinnate, ca. 5 cm long, lamina irregularly divided to the midrib into segments of varying proportions. The pinnae arise at 65°–75° angle. They are triangular near the base. Veins are fine and simple with a density of 21–22 per cm.
Material: JMSS–23, JMSS–24, JMSS–25, JMSS–26.

Nilssonia ingens Schweitzer, Kirchner & van Konijnenburg van–Cittert 2000
 Plate 2, Figs. 2, 6

2000 *Nilssonia ingens* Schweitzer *et al.*; pp. 42–43; pl. 15, figs. 3–6; text–figs. 15 a–f, 16; fold–outs 4, 5.

2006 *Nilssonia ingens*: Vaez–Javadi & Mirzaie–Ataabadi; p. 79, figs. 5E, 17A.

2010 *Nilssonia ingens*: Saadat Nejad *et al.*; p. 186, pl. 3, figs. 2, 3.

2014 *Nilssonia ingens*: Vaez–Javadi; p. 93, pl. XV, figs. 1, 2; fig. 8: 3.

Description. These specimens are part of pinnae,

over 7 cm long; rachis 5 mm wide. Pinnae arise almost perpendicularly, over 9 cm long (full length unknown), opposite–sub–opposite, distinctly variable width. Both basiscopic and acroscopic pinnae bases are almost expanded. Veins are fine, simple and parallel with a concentration from 27–29 per cm basally.

Material: JMSS–27.

Nilssonia macrophylla Jacob & Shukla 1955 emend. Schweitzer, Kirchner & van–Konijnenburg van–Cittert 2000

Plate 3, Fig. 1; Plate 4, Fig. 2

1955 *Nilssonia macrophylla* Jacob & Shukla; p. 27, pl. 9, figs 72, 73.

2000 *Nilssonia macrophylla* emend. Schweitzer *et al.*; p. 44, pl. 16, figs. 1–3; text–figs. 17, 18, 19.

2004 *Nilssonia macrophylla*: Vaez–Javadi & Pour–Latifi; p. 101, pl. 3, figs. 1, 4.

2006 *Nilssonia macrophylla*: Vaez–Javadi & Mirzaie–Ataabadi; p. 79, figs. 5F, 12G.

2012 *Nilssonia macrophylla*: Vaez–Javadi & Abbasi; p. 45, pl. V, fig. 5; pl. VI, fig. 1; pl. VIII, fig. 3b; text–fig. 4: 7.

2014 *Nilssonia macrophylla*: Vaez–Javadi, pp. 93–94, pl. XVI, fig. 1; pl. XVII, fig. 1; Fig. 2: 7

2015 *Nilssonia macrophylla*: Vaez–Javadi, p. 108, pl. 3, fig. 1a; pl. 4, fig. 6b.

2018a *Nilssonia macrophylla*: Vaez–Javadi, p. 304.
Description. Leaf is once pinnate, 6.4 cm long; rachis concealed. Pinnae arise almost perpendicularly, over 4.5 cm long (full length unknown), opposite–sub–alternate, distinctly variable width. Pinnae bases are almost straight. Veins are fine, simple and parallel with a concentration of 21 per cm basally.

Material: JMSS–28, JMSS–29, JMSS–30.

Nilssonia sp. cf. *N. tenuicaulis* (Phillips 1829) Fox–Strangways 1829

Plate 3, Fig. 7

1829 *Cycadites tenuicaulis* Phillips, pp. 148, 189, pl. 7, fig. 19.

1892 *Nilssonia tenuicaulis* (Phillips) Fox–Strangways & Barrow, p. 219.

2000 *Nilssonia tenuicaulis*: Schweitzer *et al.*, pp. 27–29, pl. 7, figs 1–3, text–fig. 7.

2006 *Nilssonia tenuicaulis*: Vaez–Javadi & Mirzaie–Ataabadi, p. 81, figs 4K–L, 13B, 14A.

2011 *Nilssonia tenuicaulis*: Vaez–Javadi; p. 88, fig. 5E.

2015 *Nilssonia tenuicaulis*: Vaez–Javadi; pl. 4, fig. 3; text–fig. 6:9.

Description. Leaf fragment is once pinnate, 14 cm

long; blade dissected into closely spaced segments, variably sized, 3.5–3.7 cm long and 18.7–10.5 mm wide, rectangular in shape, margins parallel, slightly curved forward, truncate to rounded apices, veins unknown.

Material: JMSS–31.

Genus *Beania* Carruthers 1869

Type species: *Beania gracilis* Carruthers 1869

Beania mamayi Thomas & Harris 1960

Plate 3, Fig. 5

1960 *Beania mamayi* Thomas & Harris; p. 143, pl. 2, fig. 15; pl. 3, figs. 17, 22; text–fig. 1.

2006 *Beania mamayi* Vaez–Javadi & Mirzaei–Ataabadi; p. 84, figs. 6E, 8D.

Description. This specimen is a female cone, finely, longitudinally striated axis, 45 mm long, 15 mm wide; 21 sporangiophores are spirally arranged along the axis at 80°–90°. Their stalks are 2.7–3.6 mm long and 0.6–1 mm wide, basally expanded. They terminate in a more or less ovate or rhomboidal head. Two seeds were attached to the head, but one has usually fallen off or smaller.

Material: JMSS–32.

Division Ginkgophyta

Order Ginkgoales

Genus *Ginkgoites* Seward 1900

Type species: *Ginkgoites obovata* (Nathorst) Seward 1919

Ginkgoites khorassanicus Fakhr 1977

Plate 4, Fig. 1

1977 *Ginkgoites khorassanicus* Fakhr; p. 130, pl. XLIII, figs. 1–3; pl. XLIV, fig. 2; fig. 17 A–E.

2014 *Ginkgoites khorassanicus*: Vaez–Javadi; p. 135, pl. X, fig. 1; fig. 3: 6, 10.

Description. Leaf is petiolate. The lamina is almost flabelliform, 5 cm long with a basal angle of 80°, divided into four segments which are probably forked once. Veins are simple at the middle part of lobes with a density of 7 per lobe. Since there is not enough evidence we prefer to use “cf.”

Material: JMSS–33.

Ginkgoites parasingularis Kilpper 1971

Plate 3, Fig. 2; Fig. 3: 6

1971 *Ginkgoites parasingularis* Kilpper; p. 90, pl. 25, figs. 1–2; pl. 27, figs. 2–4; text–figs. 1, 2.

1995 *Ginkgoites parasingularis*: Schweitzer & Kirchner; pp. 10–13, pl. 1, figs. 1–4; text–figs. 5a–k, 6.

2006 *Ginkgoites* cf. *parasingularis*: Vaez–Javadi & Mirzaie–Ataabadi; p. 88, fig. 16 E.

2012 *Ginkgoites parasingularis*: Vaez–Javadi; p. 230, pl. 5, figs. 2, 3.

2014 *Ginkgoites parasingularis*: Vaez–Javadi; pp. 135–136, pl. IX, fig. 7; fig. 3: 3.

2015 *Ginkgoites parasingularis*: Vaez–Javadi & Allameh; p. 29, pl. 3, fig. 4; pl. 5, fig. 5.

2018a *Ginkgoites* sp. cf. *G. parasingularis*: Vaez–Javadi; pp. 305, 307, pl. 4, fig. Aa.

Description. Leaf is petiolate, 11 cm long (whole length unknown), 16 mm width. Basal angle is 60°. The petiole is 3.5 mm long. The lamina is deeply divided into two lobes. Veins are simple or dichotomous, 11–12 per cm.

Material: JMSS–34, JMSS–35, JMSS–36, JMSS–37.

Genus *Sphenobaiera* Florin 1936 emend. Harris & Millington 1974

Type species: *Sphenobaiera spectabilis* (Nathorst) Florin 1936

Sphenobaiera longifolia (Pomel 1849) Florin 1936 emend. Harris & Millington 1974

Plate 4, Figs. 5, 6

1849 *Dicroidteris longifolia* Pomel, p. 339 (name and description only).

1936 *Sphenobaiera longifolia* (Pomel) Florin, p. 108.

1977 *Sphenobaiera longifolia*: Fakhr, p. 134, pl. XLVI, figs 4, 5, text–figs 18A, B.

2004 *Sphenobaiera longifolia*: Vaez–Javadi & Pour–Latifi, p. 102, pl. 2, figs 1, 5.

2011 *Sphenobaiera longifolia*: Vaez–Javadi; p. 92, figs. 5B, 6F, 10A, 11A.

2015 *Sphenobaiera longifolia*: Vaez–Javadi; p. 108, pl. 3, fig. 1d; plate 4, figs. 1, 6a; text–fig. 6: 7

Description. Leaf is wedge-shaped, without petiole, 10.5 cm long and 1–1.1 mm wide, with a basal angle of 35° to the primary axis. Lamina of leaves is more or less deeply divided into four linear segments (whole length unknown). The vein concentration is 5 per segment.

Material: JMSS–38, JMSS–39, JMSS–40.

Division Coniferophyta

Order Coniferales

Genus *Elatides* Heer 1876

Type species: *Elatides ovalis* Heer 1876

Elatides thomasi Harris 1979

Plate 3, Fig. 3, Plate 4, Fig. 7

1979 *Elatides thomasi* Harris; pp. 74–77, pl. 2, figs. 8–13; text–figs. 33E, J, 35 A–G, K, L.

1996 *Elatides thomasi*: Schweitzer & Kirchner.;

pp. 103–113, pl. 5, figs. 1–5; pl. 6, figs. 1–8; pl. 7, figs. 1–10; pl. 8, figs. 1–7; text–figs. 11, 12a, b, 13–17, 18a–b, 19a–c, 20.

2006 *Elatides thomasii*: Vaez–Javadi & Mirzaie–Ataabadi; p. 92, figs. 6F, 14F, 15C.

2012 *Elatides thomasii*: Vaez–Javadi; p. 231, pl. 4, fig. 2.

2015 *Elatides thomasii*: Vaez–Javadi; p. 109, pl. 2, fig. 2; plate 3, fig. 1b)

2018a *Elatides thomasii*: Vaez–Javadi; p. 304, pl. 4, fig. B.

Description. The shoot is branched, 8 cm long. Leaves are 4–6 mm long and 1 mm wide basally, tapering to obtuse–acute apices, strongly falcate in shape, the free part of leaf forming half to one third of the whole length of the leaf.

Material: JMSS–41, JMSS–42, JMSS–43, JMSS–44, JMSS–45, JMSS–46.

Genus *Cyparissidium* Heer 1874

Type species: *Cyparissidium gracile* Heer 1874

Cyparissidium rudlandicum Harris 1979

Plate 4, Fig. 3b

1979 *Cyparissidium rudlandicum* Harris; p. 78, pl. 4, fig. 9; text–fig. 36.

2008 *Cyparissidium* sp.: Vaez–Javadi; p. 69, text–fig. 11: 3.

2012 *Cyparissidium rudlandicum*: Vaez–Javadi & Abbasi; p. 48, pl. VII, fig. 1; text–fig. 5: 1.

Description. This specimen is a shoot, bearing leaves helically, 44 mm long. Leaves are mostly close to stem but free it to near their base. Leaf in abaxial view is nearly rhomboidal, length up to 5.6 mm, width 1.6 mm, tapering to obtusely pointed apex, but attachment to basal cushion usually overlapped and concealed.

Material: JMSS–47.



Plate 3. Fig. 1- *Nilssonia macrophylla* Jacob & Shukla 1955, Fig. 2- *Ginkgoites parasingularis* Kilpper 1971, Fig. 3- *Elatides thomasii* Harris 1979, Fig. 4- *Elatocladus* sp. cf. *E. ramosus* (Florin 1958) Harris 1979, Fig. 5- *Beanii mamayi* Thomas & Harris 1960, Fig. 6- *Marattiopsis muensteri* (Goeppert 1842) Schimper 1874, Fig. 7- *Nilssonia* sp. cf. *N. tenuicaulis* (Phillips 1829) Fox-Strangways 1829. Scale bars are 1 cm.

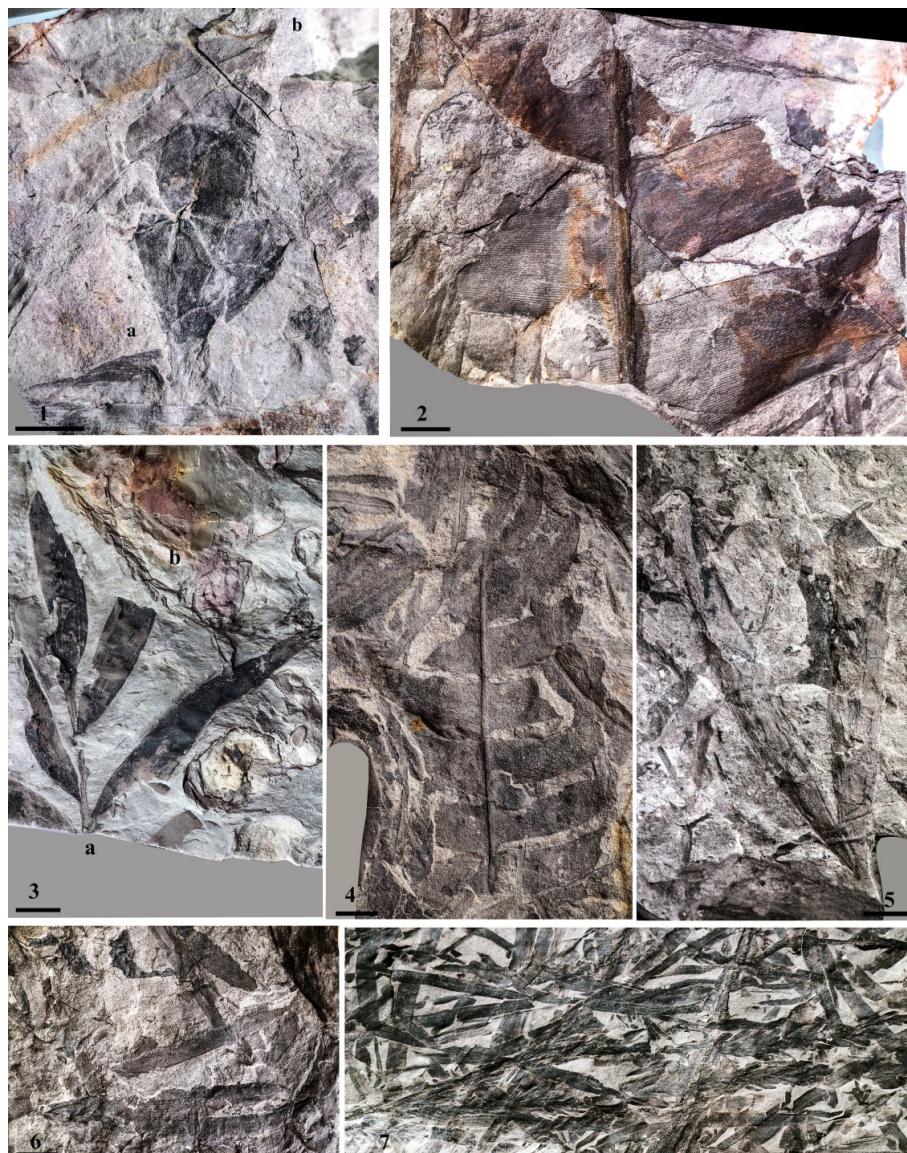


Plate 4. Fig. 1- *Ginkgoites* sp. cf. *G. khorassanicus* Fakhr 1977, Fig. 2- *Nilssonia macrophylla* Jacob & Shukla 1955, Fig. 3- a- *Podozamites distans* (Presl 1838) Braun 1843 emend. Barnard 1967, b- *Cyprissidium rudlandicum* Harris 1979, Fig. 4- *Nilssonia* sp., Figs. 5, 6- *Sphenobaiera longifolia* (Pomel 1849) Florin 1936, Fig. 7- *Elatides thomasii* Harris 1979. Scale bars= 1 cm.

Genus *Elatocladus* Halle 1913

Type species: *Elatocladus heterophylla* Halle 1913
Elatocladus sp. cf. *E. ramosus* (Florin 1958) Harris 1979

Plate 3, Fig. 4

1958 *Tomharrisia ramosa* Florin; p. 297, pl. 16, figs. 1-7; pl. 18, figs. 1-6; pl. 19, figs. 1-6.
 1979 *Elatocladus ramosus* (Florin) Harris; pp. 117-118, fig. 53.

Description. This specimen is a leaf, 9.6 cm long, spreading regularly in a horizontal plane by bending and twisting of their bases, typically diverging at 45° to stem; straight or curving slightly

towards stem apex. Dimensions are 57-61 mm x 3.8-4.5 mm. Leaf is linear lanceolate, widest in basal third, at extreme base narrowing to midrib and attached to basal cushion probably without forming distinct petiole; lamina tapering distally to acute or occasionally acuminate apex, margins entire and sharply angular. The midrib is broad and conspicuous towards leaf base, projecting abaxially; tapering distally but then enlarging just below the apical point.

Material: JMSS-48, JMSS-49, JMSS-50, JMSS-51, JMSS-52, JMSS-53, JMSS-54.

Genus *Podozamites* Braun 1843

- Type species: *Podozamites distans* (Presl 1838) Braun 1843
Podozamites distans (Presl 1838) Braun 1843
 Plate 4, Fig. 3a
 1838 *Zamites distans* Presl in Sternberg; p. 196, pl. 4, fig. 1.
 1843 *Podozamites distans* (Presl) Braun; pp. 33, 36.
 1950 *Podozamites distans*: Boureau *et al.*; p. 227, pl. VII, fig. 36.
 1967 *Podozamites distans*: Barnard; pp. 572–573, text–fig. 5A.
 1977 *Podozamites distans*: Corsin & Stampfli; p. 536, pl. 1, fig. 2.
 1977 *Podozamites distans*: Fakhr; p. 141, pl. XLVIII, figs. 1–2.
 1996 *Podozamites distans*: Schweitzer & Kirchner; pp. 88–91, pl. 1, figs. 1–5; text–fig. 2 a–f.
 1999 *Podozamites distans*: Vozentin–Serra & Franceschi; p. 43, pl. 19, fig. 4; pl. 20, figs. 1, 3.
 2002 *Podozamites distans*: Vaez–Javadi & Ghavidel–Syooki; p. 70, pl. 4, text–fig. 3, fig. 8.
 2006 *Podozamites distans*: Vaez–Javadi & Mirzaie–Ataabadi; p. 92, fig. 17 D.
 2008 *Podozamites distans*: Vaez–Javadi; p. 71.
 2010 *Podozamites distans*: Saadat Nejad *et al.*; p. 21, pl. 4, fig. 1.
 2011 *Podozamites distans*: Vaez–Javadi; pp. 95–96, fig. 7 J.
 2012 *Podozamites distans*: Vaez–Javadi; p. 231, pl. 6, fig. 1.
 2012 *Podozamites distans*: Vaez–Javadi & Abbasi, p. 50, pl. VII, fig. 6.
 2014 *Podozamites distans*: Vaez–Javadi; pp. 99, pl. XIII, figs. 2, 5.
 2015 *Podozamites distans*: Vaez–Javadi; p. 109 pl. 4, fig. 8.
 2015 *Podozamites distans*: Vaez–Javadi & Namjoo; p. 223, pl. 13, fig. 1.
 2015 *Podozamites distans*: Vaez–Javadi & Allameh; p. 30, pl. 4, fig. 3.
- Description. The frond is over 3 cm long; leaves spirally arranged but most spread in two ranks, brought into the horizontal plane by twisting of the leaf base. Leaves are elongate elliptic–lanceolate in shape, contracted bases, obtuse apices, 71 mm long (whole length unknown) and 10–10.5 mm width. Veins are parallel, simple or forked once near the base of the leaf, 16–17 per cm.
- Material: JMSS–47, JMSS–55, JMSS–56, JMSS–57, JMSS–58, JMSS–59.

Assemblage 2

The sediments also include diverse palynomorphs of various groups, in which 16 miospore species belonging to 13 genera, and seven dinoflagellate cyst species belonging to three genera were identified (Plate 5). The palynomorph species are: *Dictyophyllidites harrisii* Couper 1958, *Kluksporites* sp., *Granulatisporites asper* Playford & Dettmann, 1965, *Cingulatisporites lathiensis* Srivastava 1966, *Classopollis torosus* (Reissinger 1950) Couper 1958, *Ginkgocycadophytus* sp., *Cycadopites follicularis* Wilson & Webster 1946, *Chasmatosporites* sp., *Cycadopites fusiformis* (Nilsson 1958) Arjang 1975, cf. *Alisporites* sp., *Aratrisporites* sp. cf. *A. minimus* Schulz 1967, *Eucommiidites* sp., *Monosulcites minimus* Cookson 1947, *Cyathidites* sp. cf. *minor* Couper 1953, *Vitreisporites pallidus* (Reissinger 1950) Nilsson 1958, *Vitreisporites jurassicus* Pocock 1970, *Kalyphea stegasta* (Sarjeant 1961) Wiggins 1975, *Nannoceratopsis raunsgaardi* Poulsen 1996, *Nannoceratopsis symmetrica* Bucefalo Palliani & Riding 2000, *Nannoceratopsis triceras* Drug 1978, *Nannoceratopsis gracilis* Alberti 1961 emended Evitt 1962, *Pareodinia ceratophora* Deflandre 1947, and *Pareodinia halosa* (Filatoff 1975) Prauss 1989.

Moreover, the taxonomic identification of the dinoflagellate cysts enables recognition of one distinct dinoflagellate assemblage—*Nannoceratopsis gracilis*–*Nannoceratopsis triceras* Assemblage biozone. *Nannoceratopsis gracilis* was a cosmopolitan species during Jurassic (Van Helden, 1977; Davies, 1983). Among dinocyst zonal subdivisions of the Jurassic strata in northwest Europe summarized by Riding & Thomas (in Powell, 1992), the zones are indicative of short time intervals. They erected *Nannoceratopsis gracilis* (Ngr) Interval Biozone from the early Toarcian–early Bajocian age. The Ngr Interval Biozone is equivalent to the erected biozone—*Nannoceratopsis gracilis*–*Nannoceratopsis triceras* Assemblage Zone herein.

Bucefalo Palliani and Riding (2000) studied Jurassic (Sinemurian–Aalenian) dinocyst biostratigraphy. They considered *Liasidium variabile* zone for Sinemurian and *Nannoceratopsis deflandrei*–*Nannoceratopsis gracilis* Assemblage Zone for Toarcian to Aalenian. They also stated that *Nannoceratopsis triceras* and *Nannoceratopsis symmetrica* were present in Toarcian strata and *Nannoceratopsis ambonis* in Aalenian strata. This biozone is comparable with the Shahreza dinoflagellate cyst zone herein.

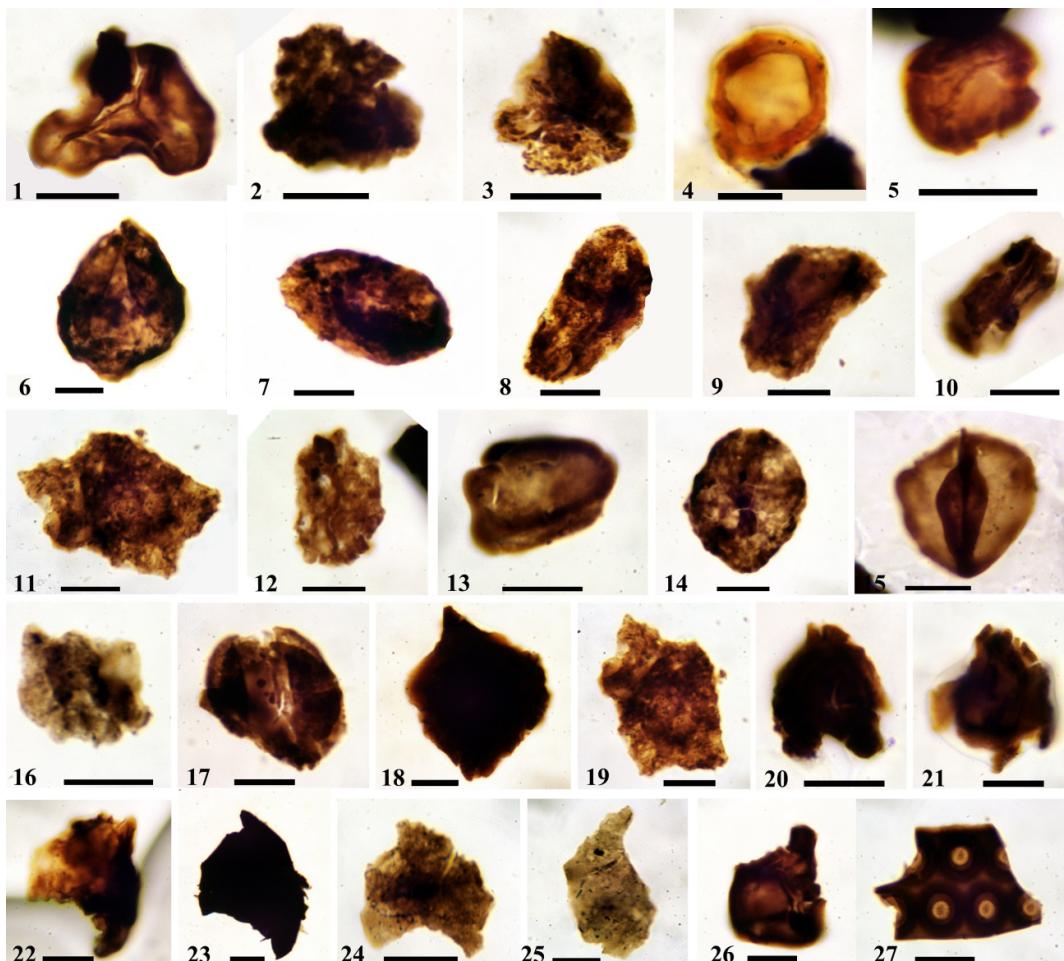


Plate 5. Fig. 1- *Dictyophyllidites harrisii* Couper 1958, Fig. 2- *Klukisporites* sp., Fig. 3- *Granulatisporites asper* Playford & Dettmann, 1965, Fig. 4- *Cingulatisporites lathiensis* Srivastava 1966, Fig. 5- *Classopollis torosus* (Reissinger 1950) Couper 1958, Fig. 6-, Fig. 7- *Ginkgocycadophytus* sp., Fig. 8- *Cycadopites follicularis* Wilson & Webster 1946, Fig. 9- *Chasmatosporites* sp., Fig. 10- *Cycadopites fusiformis* (Nilsson 1958) Arjang 1975, Fig. 11- cf. *Alisporites* sp., Fig. 12- *Aratrisporites* sp. cf. *A. minimus* Schulz 1967, Fig. 13- *Eucommiidites* sp., Fig. 14- *Monosulcites minimus* Cookson 1947, Fig. 15- *Cyathidites* sp. cf. *minor* Couper 1953, Fig. 16- *Vitreisporites pallidus* (Reissinger 1950) Nilsson 1958, Fig. 17- *Vitreisporites jurasicus* Pocock 1970 , Fig. 18- *Kalyptea stegasta* (Sarjeant 1961) Wiggins 1975, Fig. 19- *Nannoceratopsis raunsgaardii* Poulsen 1996, Figs. 20, 24- *Nannoceratopsis symmetrica* Bucefalo Palliani & Riding 2000 , Fig. 21- *Nannoceratopsis triceras* Drugg 1978, Figs. 22, 23- *Nannoceratopsis gracilis* Alberti 1961 emend. Evitt 1962, Fig. 25- *Pareodinia ceratophora* Deflandre 1947, Fig. 26- *Pareodinia halosa* Filatoff 1975 emend. Prauss 1989, Fig. 27- Tracheid. Scale bars= 1cm.

The erected dinocyst biozone from Shahreza is comparable with *Nannoceratopsis gracilis* zone (late Toarcian–early Aalenian) from Bagå Formation in Bornholm, Denmark (Koppelhus & Nielsen, 1994), *Nannoceratopsis gracilis*–*Nannoceratopsis senex* Assemblage Zone from the Aalenian–early Bajocian from the Sortehat in East Greenland (Koppelhus & Hanson, 2003). Riding *et al.* (1999) reported *Nannoceratopsis gracilis* from Lower Toarcian–Lower Callovian of East Siberia.

Since our samples gathered from the upper part of the outcrop, therefore, the results indicate that these sediments belong to the upper part of the

Shemshak Group.

Relative abundance of plant macrofossil species

Totally, 48 specimens from Shahreza were collected and the relative abundance of plant macrofossil remains was provided. The relative abundance of *Marattiopsis intermedia*, *Elatocladus* sp. cf. *E. ramosus*, *Cladophlebis aktashensis*, and *Elatides thomasii* are 39.47%, 10.52%, 8.77%, and 8.77%, respectively (Table 1, Figs. 4, 5). Based on the relative abundance of different morphocats, it is concluded that filicophytes, macrophyllous cycadophytes, macrophyllous and unassigned

coniferophytes, ginkgophytes, and microphyllous coniferophytes with 49.98%, 24.4%, 7.27%, and

12.26%, respectively were dominant in Shahreza area during its sedimentation (Fig. 6).

Table 1. Relative abundance chart of plant macrofossil species from Shahreza.

List of species	Number of counted species	Relative abundance %	Orders	Relative abundance %
<i>Annulariopsis simpsonii</i>	6	5.26		
<i>Equisetites columnaris</i>	2	1.75	Equisetales	7.02
<i>Marattiopsis intermedia</i>	42	36.84	Ferns	49.98
<i>Marattiopsis muensteri</i>	3	2.63		
<i>Coniopteris hymenophylloides</i>	1	0.87		
<i>Taeniopteris intermedia</i>	1	0.87		
<i>Cladophlebis aktashensis</i>	10	8.77		
<i>Sphenobaiera longifolia</i>	3	2.63	Ginkgoales	7.02
<i>Ginkgoites</i> sp. cf. <i>G. khorassanicus</i>	1	0.87		
<i>Ginkgoites parasingularis</i>	4	3.51		
<i>Nilssonia bozorga</i>	4	3.51	Nilssoniales	8.77
<i>Nilssonia ingens</i>	1	0.87		
<i>Nilssonia macrophylla</i>	3	2.63		
<i>Nilssonia</i> sp. cf. <i>N. tenuicaulis</i>	1	0.87		
<i>Beania mamayi</i>	1	0.87		
<i>Chamaetaxus orientalis</i>	1	0.87		
<i>Elatides thomasi</i>	10	8.77		
<i>Elatocladus zamiooides</i>	1	0.87		
<i>Cyparissidium rudlandicum</i>	1	0.87		
<i>Elatocladus</i> sp. cf. <i>E. ramosus</i>	11	9.65	Coniferales	27.19
<i>Chamaetaxus</i> sp.	1	0.87		
<i>Podozamites distans</i>	6	5.26		

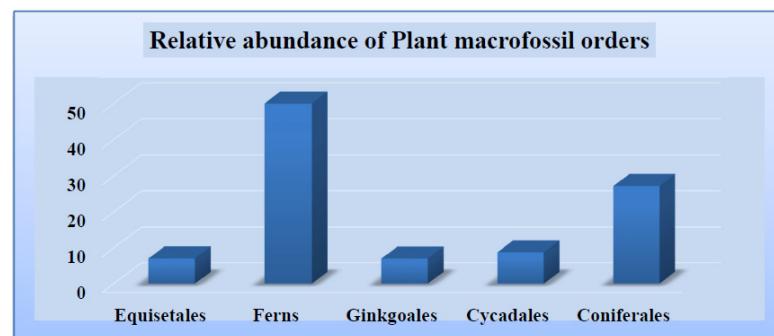


Figure 4. Relative abundance chart of various plant macrofossil orders.

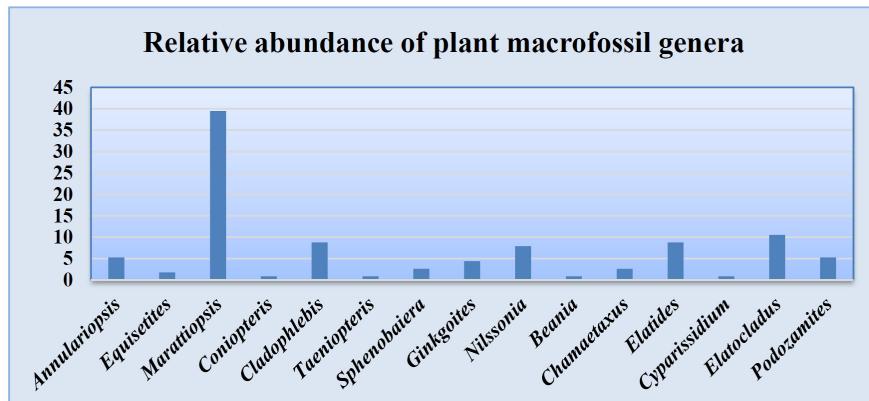


Figure 5. Relative abundance chart (in percent) of plant macrofossil genera from Shahreza.

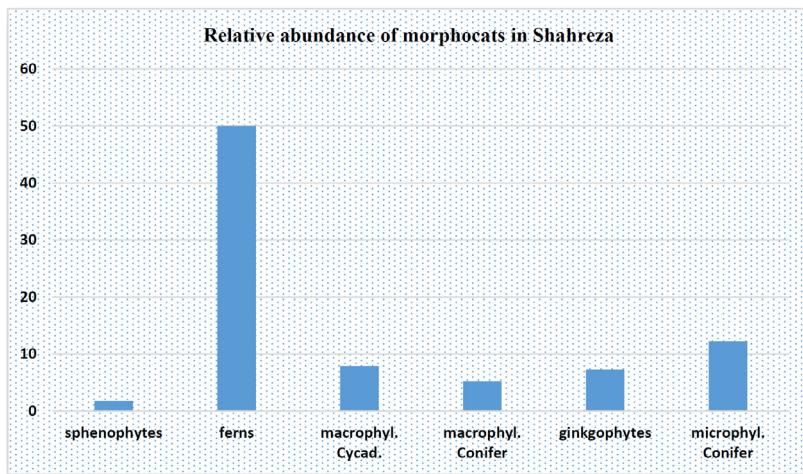


Figure 6. Relative abundance chart of morphocats from Shahreza

Paleogeography and palaeoclimate interpretation

The Jurassic period is generally characterized by a uniform and stable climate and by a lack of drastic climatic events. Vakhrameev (1991) and more recently Rees *et al.* (2000) and Vaez-Javadi (2014, 2018a) proposed palaeoclimate reconstructions based on palaeobotanical data. The distribution patterns of plant taxa are interpreted in this framework. Some of the plant macrofossil species reported here was also reported from several localities in Iran and the northern hemisphere. Early and Middle Jurassic floras shared the same set of plant communities over a wide geographical area (Vakhrameev, 1991). Several authors maintained constant, basic floral successions during the Middle Jurassic time throughout Europe (Vakhrameev, 1964), in particular ranging from England (Harris, 1961, 1964, 1969, 1979; Harris *et al.*, 1974; Van Konijnenburg-van Cittert & Morgans, 1999; Cleal *et al.*, 2001; Van Konijnenburg-van Cittert, 2008), Portugal (Pais, 1998) in the South-West, Sardinia in the South (Scanu *et al.*, 2012, 2013, 2015, 2016, Kustatscher *et al.*, 2016, Costamagna *et al.*, 2018,

Buosi *et al.*, 2018), throughout the Germanic Basin to Poland, western Ukraine, the Volga area, Donbas, the southern Urals (Vakhrameev, 1991), Romania in the East (Dragastan & Barbulescu, 1980; Popa & van Konijnenburg-van Cittert, 2006) and Iran (Kilpper, 1964, 1968, 1971; Alavi & Barale, 1970; Barnard & Miller, 1976; Sadovnikov, 1976, 1983, 1991; Corsin & Stampfli, 1977; Fakhr, 1977; Schweitzer & Kirchner, 1995, 1996, 1998, 2003; Schweitzer *et al.*, 1997, 2000, 2009; Vaez-Javadi & Pour-Latif, 2002, 2004; Vaez-Javadi & Ghavidel-Syooki, 2002; Saadat Nejad, 2005; Vaez-Javadi & Mirzaie-Ataabadi, 2006; Vaez-Javadi

2008, 2011, 2012, 2014, 2015, 2017, 2018a; Saadat Nejad *et al.*, 2010; Fadaiey Khojasteh *et al.*, 2010; Popa *et al.*, 2012; Vaez-Javadi & Abbasi, 2012, 2018; Ameri *et al.*, 2013, 2014; Vaez-Javadi & Allameh, 2015; Vaez-Javadi & Namjoo, 2015; Mehdizade *et al.*, 2016; Ameri, 2018). Barbacka *et al.* (2014) stated that The Jurassic floras of Europe show considerable diversity and affinities between different localities are based on environmental factors.

The floral gradient reported from the Middle Jurassic strata of Shahreza area is compared to the floral gradient from Rudbarak (Vaez-Javadi, 2011), Baladeh (Vaez-Javadi & Abbasi, 2012), Mazino (Vaez-Javadi, 2014), North Kouchehali (Vaez-Javadi & Namjoo, 2015), Bazehowz (Vaez-Javadi & Allameh, 2015), Calshour (Mehdizade *et al.*, 2016), South Kouchehali (Vaez-Javadi, 2018a), Lenjan (Ameri, 2018), and Babhutk (Ameri *et al.*, 2013) (Table 2). The floral gradient scores of these areas are 56.2, 55.5, 55.8, 58.5, 65.5, 63.4, 53.57, 46.33, 64.2, 66.4, and 66.3, respectively. Table 2 shows *Phoenicopsis* and *Zamites*, two end members of the floral gradient table, were absent during the Rhaetian to Middle Jurassic of Shahreza area.

The average Floral gradient score in Shahreza area during the late Early–Middle Jurassic is determined to be 66.3 (Table 2). This suggests different climatic conditions, compared with various plant localities in Iran during this period of time. Iran had a warm temperate biome (40–60°), with a high species diversity and with abundant macrophyllous cycadophytes in the most localities. Vakhrameev (1991) stated that in the Early and Middle Jurassic of Eurasia rapid coal formation occurred involving both the Siberian and the bulk

of the Asiatic part of the Euro-Sinian region. He subdivided the Euro-Sinian region into three provinces: European, Middle Asiatic with three sub-provinces and East Asiatic. Iran was located in the most southerly of the Middle Asia province and in the Transcaspian subprovince during the late Early-Middle Jurassic. The flora of this sub-province comprises of *Coniopteris*, *Dictyophyllum*, *Marattiopsis*, *Cladophlebis* (ferns), *Equisetites beanii* (horsetails), *Nilssonia* (cycads), *Pterophyllum*, *Ptilophyllum*, *Anomozamites* (Bennettitales), *Ginkgo* and *Sphenobaiera* (Ginkgoales), *Elatocladus*, *Pityophyllum* and *Podozamites* (conifers). Vakhrameev (1991) stated that the migration of temperate elements of the Siberian region southwards proceeded across the border of the region. Such elements included Ginkgoales, Czekanowskiales and ancient Pinaceae. The absence of Bennettitales suggests a slight climatic cooling as well as significant humidification in the Bajocian of this sub province (Vakhrameev, 1991). Therefore, since there are not any pieces of evidence of coal seams and Bennettitales, and the presence of Ginkgoales and

slight cooler elements such as *Nilssonia* among plant fossil assemblage of Shahreza, it can conclude a temperate climate dominate during the Middle Jurassic in this area.

Similarity index between plant macrofossil genera of Shahreza and South Kouchekali, North Kouchekali, Mazino, Calshaneh, Jafar-Abad, Kerman Basin, Baladeh, Shandiz, Bazehowz, Babhutk, and Lenjan are 0.34, 0.45, 0.4, 0.52, 0.15, 0.48, 0.33, 0.19, 0.37, 0.42, and 0.43, respectively. This indicates a slightly low level of similarity between the floral assemblages (Table 3).

In order to interpret these data, we also consider palynological data. Palynological data have been 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 co-Palynological data obtained from the Shahreza section are listed together with the related taxa of plant macro-remains in Table 4.

Table 2. The floral gradient chart of different localities in Iran (Basic chart is after Rees *et al.*, 2000).

Genus	Score	Latitude/Locality										
		33° 17' N. Kouchekali	33° 33' S. Kouchekali	33° 21' Mazino	33° 5' Calshour	34° 7' Calkhaneh	36° 2' Rudbarak	36° 14' Baladeh	36° 3' Bazehowz	30° 39' Lenjan	31° 21' Babhutk	32° 4' Shahreza
<i>Raphaelia</i>	100											
<i>Lycopodites</i>	91											
<i>Phoenicopsis</i>	89											
<i>Czekanowskia</i>	87						*	*				
<i>Desmophyllum</i>	85						*					
<i>Pityophyllum</i>	84						*					
<i>Sphenobaiera</i>	81		*			*	*	*				*
<i>Ginkgo</i>	78	*	*			*			*			*
<i>Taxocladus</i>	78											
<i>Baiera</i>	78											
<i>Hausmannia</i>	77											
<i>Pseudotorellia</i>	76											
<i>Equisetites</i>	76	*	*	*	*	*	*	*	*	*	*	*
<i>Podozamites</i>	72	*	*	*	*	*	*	*	*	*	*	*
<i>Coniopteris</i>	72	*	*	*	*	*	*	*	*	*	*	*
<i>Cladophlebis</i>	70	*	*	*	*		*	*		*		*
<i>Anomozamites</i>	64	*	*									
<i>Ctenis</i>	60	*				*						
<i>Elatides</i>	57	*	*	*		*				*	*	*
<i>Nilssonia</i>	55	*	*	*	*	*	*	*	*	*	*	*
<i>Elatocladus</i>	52	*	*							*		*
<i>Toides</i>	52	*	*	*								
<i>Sphenopteris</i>	51											*
<i>Taeniopteris</i>	50		*									
<i>Pterophyllum</i>	45	*	*	*			*	*				
<i>Pagiophyllum</i>	28											
<i>Sagenopteris</i>	21	*	*	*		*						
<i>Pachypterus</i>	17											
<i>Ptilophyllum</i>	13	*	*	*	*	*	*	*	*			
<i>Brachiphyllum</i>	9											
<i>Otozamites</i>	9											*
<i>Zamites</i>	0											
Average score	56.2	55.5	55.8	46.33	58.5	65.5	63.4	53.57	64.2	66.4	66.3	

Table 3. The similarity index generic and species levels between plant macrofossil assemblage of Shahreza and various Middle Jurassic localities in Iran.

Localities *	South Kouchekali ¹	North Kouchekali ²	Mazino ³	Calshaneh ⁴	Jafar-Abad ⁵	Kerman Basin ⁶
Si index: Genus level	0.34	0.45	0.4	0.52	0.15	0.48
Si index: species level	027	0.3	0.25	0.37	0.11	0.4
Localities *	Baladeh ⁷	Shandiz ⁸	Bazehowz ⁹	Babutk ¹⁰	Lenjan ¹¹	
Si index: Genus level	0.33	0.19	0.37	0.42	0.43	
Si index: species level	0.19	0.14	0.26	0.14	0.07	

* 1- Vaez-Javadi, 2018a, 2- Vaez-Javadi & Namjoo, 2015, 3- Vaez-Javadi, 2014, 4- Vaez-Javadi, 2015, 6- Vaez-Javadi & Mirzaei-Ataabadi, 2006, 7- Vaez-Javadi & Abbasi, 2012, 8- Saadat Nejad *et al.*, 2010, 9- Vaez-Javadi & Allameh, 2015, 10- Ameri *et al.*, 2013, and 11- Ameri, 2018.

Table 4. Botanical affinity of the various sporomorph genera in relation to the Sporomorph Ecogroups (after Abbink, 2004, Götz *et al.*, 2011).

Upland	Warmer lowland	Drier lowland	Wetter lowland	River	Plant macroremains	Author(s)
Bisaccates spp./ <i>Alisporites thomasii</i>	Bisaccates/ <i>Alisporites thomasii</i> spp.	Pteridospermales Coniferales	Van Konijnenburg-van Cittert, 1971, Balme, 1995			
	<i>Calamospora tener/ C. mesozoica</i>		<i>Calamospora tener/ C. mesozoica</i>		<i>Equisetites, Neocalamites</i>	Balme, 1995
		<i>Chasmatospor. apertus</i>	<i>Chasmatospor. apertus</i>		Cycadales (<i>Nilssonia, Ctenis</i>), Ginkgoites	Tralau, 1968, Götz <i>et al.</i> , 2011
	<i>Cyathidites minor</i>	<i>Cyathidites minor</i>			Dicksoniaceae (<i>Coniopteris</i>), Cyathaceae	Van Konijnenburg-van Cittert, 1989, 1993, Balme, 1995
	<i>Dictyophyll. harrisii</i>	<i>Dictyophyll. harrisii</i>	<i>Dictyophyll. Harrisii</i>		Dicksoniaceae/ Matoniaceae (<i>Dictyophyllum</i>)	Van Konijnenburg-van Cittert, 1989, 1993, Balme, 1995
	<i>Todisporites major</i>		<i>Todisporites major</i>		<i>Todites, Cladophlebis</i>	
<i>Corollina</i> spp.		<i>Corollina</i> spp.			Cheirolepidaceae <i>Brachyphyllum, Pagiophyllum, Hirmeriella</i>	Van Konijnenburg-van Cittert, 1987, Balme, 1995, Götz <i>et al.</i> , 2011
	<i>Eucommiidites troedssonii</i>	<i>Eucommiidites troedssonii</i>	<i>Eucommiidites troedssonii</i>		Cycadales/Bennettitales (<i>Anomozamites, Pterophyllum</i>)	Van Konijnenburg-van Cittert, 1971, Balme, 1995, Götz <i>et al.</i> , 2011
Ginkgo-cycadophytes spp.					<i>Ginkgoites, Baiera, Sphenobaiera</i>	Götz <i>et al.</i> , 2011
<i>Vitreisporites pallidus</i>				<i>Vitreisporites pallidus</i>	Caytoniales (Pteridosperms) <i>Sagenopteris</i>	Van Konijnenburg-van Cittert, 1971

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* was related to wet and warm, even swamp environments (Barbacka, 2009; Costamagna *et al.*, 2018). Ferns with large leaves such as *Clathropteris* and *Dictyophyllum* correspond well with wet habitats such as marshes or river banks (van Konijnenburg-van Cittert, 2002), while *Cladophlebis/Todites* (Plate 2, Fig. 5) prefer wet or slightly drier conditions. In general, the presence of fern spores indicates more or less humid conditions preferably in warm environments. 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 grouped to Bisaccates spp. represent Pteridospermales and certain Coniferales and are, according to Abbink's model, characteristic of highland vegetation. *Corollina* spp. grew in upland or drier lowlands (Götz *et al.*, 2011). Cycadales (Nilssoniaceae) grew during the Mesozoic as lowland plants in subtropical areas with a warm climate or co-occurred with ginkgophytes and conifers in open forests (Batten, 1974; Van Konijnenburg-van Cittert & Van der Burgh, 1989; Vakhrameev, 1991; Kustatscher *et al.*, 2010). *Elatocladus* of Coniferophyta grew, together with sphenophytes, in shallow water along river or lake banks or in swamps (Barbacka, 2009, 2011; Costamagna *et al.*, 2018).

There are various data of plant macro and microfossils and dinoflagellate cysts that demonstrate a unique condition prominent in Shahreza with several types of ecogroups. It should be considered that there were several environments of upland, warmer (drier?) lowland, wetter lowland, rivers, and delta. Thus, microphyllous conifers such as *Elatides thomasi*, "ginkgocycadophytes" spp. and miospores such as *Classopollis/Corollina torosus* show an upland environment. Equisetales and ferns indicate a lowland and river-side environments. Moreover, based on the occurrence of index dinoflagellate cysts, we conclude that during the late Early–Middle Jurassic, the Shahreza area was located close to a coastal plain. However, more sedimentological investigation is needed for this area.

Conclusions

In this study, new palaeobotanical and palynological data sets are provided from Shahreza area, south west of Isfahan city, central Iran. We propose that in Shahreza, the florula occurs in the upper part of Shemshak Group, and it is late Early–Middle Jurassic in age.

The sediments in the Shahreza section yield 22 plant macrofossil species belonging to 17 genera of various orders.

The relative abundance of *Marattiopsis intermedia*, *Elatocladus* sp. cf. *E. ramosus*, *Cladophlebis aktashensis*, and *Ealtides thomasi* are 39.47%, 9.65%, 8.77%, and 8.77%, respectively.

The results of this study indicate that the relative abundance of Filicophyta, Coniferophyta, Cycadophyta, and Ginkgophyta are 49.98%, 27.19%, 8.77%, and 7.27%, respectively.

Based on the relative abundance of different morphocats, it is concluded that filicophytes, macrophyllous cycadophytes, macrophyllous and unassigned coniferophytes, ginkgophytes, and microphyllous coniferophytes with 49.98%, 24.4%, 7.27%, and 12.26%, respectively were dominant in Shahreza area during its sedimentation.

The floral gradient score of this area is estimated to 66.3. A comparison chart of floral gradients from several localities in Iran is established, with an average score of North Kouchekali, South Kouchekali, Mazino, Calshour, Calshaneh, Rudbarak, Baladeh, and Bazehowz being 56.2, 55.5, 55.8, 46.33, 58.5, 65.5, 63.4, and 53.57, respectively.

The similarity indices of plant macrofossil genera between Shahreza and South Kouchekali, North Kouchekali, Mazino, Calshaneh, Jafar-Abad, Kerman Basin, Baladeh, Shandiz, Bazehowz, Babhutk, and Lenjan are 0.34, 0.45, 0.4, 0.52, 0.15, 0.48, 0.33, 0.19, 0.37, 0.42, and 0.43, respectively. Therefore, a relatively low level of similarity between the floral assemblages is demonstrated.

In conclusion, despite the fact that Iran was located in a humid and warm temperate biome during the late Early–Middle Jurassic, there were several environments of upland, wetter/ drier? lowland, river, and delta close a marine environment in Shahreza. Therefore, a humid and temperate climate for the coastal environment and cool temperate for upland is suggested.

Since there are not any pieces of evidence of coal seams and Bennettitales, and presence of Ginkgoales (*Ginkgoites* and *Sphenobaiera*) and

slight cooler elements such as *Nilssonia* among plant fossil assemblage of Shahreza, it can conclude a temperate climate dominate in this area.

According to plant macrofossil assemblage, Iran was part of the Transcaspian sub-province of the Euro-Sinian province of Vakhrameev's climatic subdivisions during the Toarcian–Bajocian.

The palynomorphs of these sediments included 16 miospore species belonging to 13 genera, and seven dinoflagellate cyst species belonging to three genera.

The assemblage of palynomorphs indicates that

Shahreza was located along a coastal plain along a shallow water environment.

The geological map of Shahreza should be edited and the Jurassic sediments showed.

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