MIDDLE JURASSIC FLORA FROM THE HOJEDK FORMATION OF TABAS, CENTRAL EAST IRAN: BIOSTRATIGRAPHY AND PALEOCCLIMATE IMPLICATIONS

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Abstract. The Middle Jurassic deposits of the Shemshak Group and Hojedk Formation are widespread in north, central, and central east Iran. In this paper, the Hojedk Formation in South Kouchekali, southwestern Tabas city, central east Iran was studied for palaeobotany and stratigraphy. This formation contains well preserved plant macrofossils belonging to 43 species assigned to 24 genera of various orders such as Equisetales, Filicales, Bennettitales, Cycadales, Caytoniales, Ginkgoales and Pinales. One biozone and four subzones are recognized. The lower and the upper boundaries of this assemblage biozone are identified by the first and the last observed occurrences of Coniopteris hymenophylloides (Brongniart) Seward, 1900 and Klukia exilis (Phillips) Raciborski, 1890, respectively. According to the occurrences of these index species and Ptilophyllum harrisianum Kilpper, 1968 and Nilssonia macrophylla Jacob & Shukla, 1955, an early Middle Jurassic (Aalenian-Bajocian) age is considered for this assemblage biozone. Moreover, a comparative biostratigraphy for the Middle Jurassic of Iran is suggested. As a result, the Coniopteris hymenophylloides-Klukia exilis Assemblage biozone is proposed as a biozone widespread through the whole Iranian Plate. On the basis of the relative abundance of Filicales, Pinales, Cycadales, and Equisetales and of the high diversity and abundance of macrophyllous cycadophytes (eight species), a humid sub-tropical climate is suggested for this locality. In addition, floral gradient, correspondence analysis and similarity index were considered. Therefore, it is confirmed that a uniform palaeoclimate and vegetation cover occurred in Iran during the Middle Jurassic and that Iran was located within Vakhrameev’s Euro-Sinian Region.

INTRODUCTION

Lower and Middle Jurassic terrestrial sediments of considerable thickness are widespread in north Iran (Iva, Baladeh, Rudharak, Khatumbar-gah, Ahan Sar, Vasakgh and Imam Manak, Zirah, Ziaran, Djam, Gheslalgh, Shemshak, and Ferizi, Golmakan, Shandiz, and Bazehowz), central Iran (Dashteh-Khak, Babnizu, Hashooini, Eskkelli, Pabdana in the Kerman Basin), and central east Iran (Jafar Abad, Mazino, Calshaneh, North and South Kouchekali in the Tabas Block). Moreover, large-scale coal bearing stratigraphic units such as the Shemshak and Hojedk units, ranging from Rhaetian to Bajocian, are widespread across these localities. The stratigraphic and the geographic distribution of identified species throughout Iran is summarized in the Supplementary information (Tab. 1, taken from Kilpper 1964, 1968, 1971; Alavi & Barale 1970; Bar-nard & Miller 1976; Sadovnikov 1976, 1984, 1991; Corsin & Stampfli 1977; Fakhri 1977; Schweitzer & Kirchner 1995, 1996, 1998, 2003; Schweitzer et al. 1997, 2000, 2009; Vaez-Javadi & Pour-Latifi 2004; Vaez-Javadi & Mirzaei-Ataabadi 2006; Vaez-Javadi 2008, 2011, 2012, 2014, 2015; Saadatnejad et al. 2010; Vaez-Javadi & Abbasi 2012; Popa et al. 2012; Vaez-Javadi & Allameh 2015; Vaez-Javadi & Nam-joo 2016). The plant macrofossils reported in this paper were previously recorded from several localities in the northern hemisphere (Supplementary information, Tab. 2). In this paper, I present new data obtained from a measured core-stratigraphic section of South Kouchekali, South West Tabas city (Fig. 1). 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 (Vaez-Javadi 2014, 2015) and the coal geology has been the object of scientific studies for many years (Khadem-Alhoeini et al. 1989; Aghanabati 1998). The geological setting with special emphasis on the coal seams was
first described in 1989 by the National Exploration Coal Mine Company.

The Lower and Middle Jurassic floras shared the same set of plant communities over a wide geographical area (Vakhrameev 1991). They maintained constant basic features during Middle Jurassic time throughout Europe (Vakhrameev 1964, 1991), in particular ranging from western England (Harris 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 (Scano et al. 2012, 2013, 2015), throughout the Germanic Basin to Poland, western Ukraine, the Volga area, Donbas, the southern Urals (Vakhrameev 1991) and Romania in the east (Dragastan & Bărbulescu 1980; Popa 1998, 2009; Popa & van Konijnenburg-van Cittert 2006). The aim of this paper is twofold:

• to introduce the Middle Jurassic flora from South Kouchekali in the Tabas Block, and correlate successions and studied assemblages from north, east and central east Iran during this interval.

• to determine “morphotypes”, “floral gradient”, “correspondence analysis”, and “similarity indices” of the studied floras’ assemblage zones through north, east, and central east Iran, providing high resolution floral distribution and paleoclimatic interpretations based on original data.

**Material and methods**

Material described in this work (prefixed FJHK and numbered 1 to 210) is held in the Collections of the Palaeontology Laboratory of the School of Geology, University of Tehran, Iran. Specimens were photographed and photos enhanced in quality by Photoshop CC 2014. The biozonation of the studied Middle Jurassic core-stratigraphic section was undertaken on the basis of the “First Occurrence” (FO) and the “Last Occurrence” (LO) of stratigraphically significant plant macrofossil species. The established biozones were compared with biozones from northern, central, and central eastern Iran and comparative biostatigraphic charts produced (Figs 2, 3, and 4). In addition, the approach in this study was to assemble the floral lists from twenty well-studied sections with acceptable records of floral collection in the region; they were distributed from northern to central and eastern Iran. The emphasis therefore, was put on the concept of “biome stratigraphy”, determining main morphocats, comparing floral gradient scores and considering similarity indices of the South Kouchekali floras with other locations in Iran. In this paper, I have drawn comparative high resolution diagrams of climate conditions by using the standard floral gradient list (“Floral Gradient”), determining the main “morphocats”, comparing floral gradient scores (by “Correspondence Analysis”) and comparing similarity indices of the South Kouchekali floras with elsewhere in Iran.

**Previous studies**

Ziegler et al. (1993) presented palaeobotanical reconstructions of Eurasia, showing floral patterns for seven intervals ranging throughout the Triassic and Jurassic by multivariate analysis of several hundred macrofloral lists. They interpreted climate of the localities which ranged in palaeo-latitude from about 20º N to 80º N as “dry subtropical to the warm and cool temperate biomes”. They assigned all Jurassic leaf genera to ten coarser morphological categories or “morphocats” in order to understand broad phytogeographic patterns. These are sphenophytes, ferns, pteridosperms, microphyllous cycadophytes, unassigned cycadophytes (intermediate or morphologically variable), macrophyllous cycadophytes, ginkgophytes, microphyllous conifers, unassigned conifers (intermediate or morphologically variable), 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 broad-leaved forms of cycadophytes with thick cuticles, to broad-leaved deciduous ginkgophytes and coniferophytes in near-polar positions.

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 phytogeography 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 35º N and coal temperate conditions extended up to 80º 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.

Later, Rees et al. (2000) applied Correspondence analysis (CA) to the fossil record as a method
commonly used in studies of modern ecology and vegetation succession. Correspondence analysis (CA) is a multivariate statistical technique proposed by Hirschfeld (1935) and later developed by Benzécri (1973). It is conceptually similar to principal component analysis, but applies to categorical rather than continuous data. In a similar manner to principal component analysis, it provides a means of displaying or summarizing a set of data in two-dimensional graphical form.

By this method, multi-dimensional relationships are reduced to show variance within data sets on a series of two-dimensional axis plots. The advantages of CA are that it provides the same scaling of sample (locality) and character (genus) plots, enabling direct comparison. Therefore, two-dimensional plots (one for genera and the other for localities) were produced showing the variance within data sets on the two principal axes. Genera that frequently co-occur plot closest together on axis 1, whilst those that rarely co-occur are furthest apart. The same applies to the location plot and floral elements. Localities with more common elements plot closest to one another and vice versa.

They showed how correspondence analysis could be used to interpret phytogeographic patterns based on the axis 1 scores of individual leaf genera and corresponding plant locations, due to their relative degrees of association. This lent itself to the concept of extending these climate interpretations in terms of the basic morphological characteristics of individual leaf genera and the palaeogeographic distribution of plant locations. By averaging the scaled (0 to 100) axis 1 scores of the 32 common genera, a Jurassic “floral gradient” was derived.

Rees et al. (2000) used a “morphotype approach”, once the taxonomic nomenclature was understood in terms of basic morphological characters, phytogeographic distributions and likely palaeoclimatic regimes. They determined five main climate zones or “biomes”: cold temperate at high latitudes (60°N) with low species diversity and seasonality; warm temperate (40°-60°N) with high species diversity and abundant macrophyllous cycadophytes; winter-wet with macrophyllous elements that are typical for seasonal water deficits (narrowband in N America, India, southern Hemisphere); sub-tropical desert where plants are absent; and summer-wet (tropical) around the equator with microphyllous elements, where cycads, ginkgophytes and some of the conifer families are absent. These provided a “palaeoclimate spectrum” between extreme end-member lithological indicators of climate, such as coals (precipitation>evaporation) and evaporites (evaporation>precipitation).

As a result of their studies, they assigned all Jurassic leaf genera to ten coarser “leaf morphological” categories. They concluded that two extremes of vegetation type occurred in Jurassic samples: localities comprising wholly macrophyllous forms (of conifers and cycadophytes) and or wholly macrophyllous conifers and ginkgophytes. Microphyllous plant locations and macrophyllous conifers/ginkgophyte locations occurred in low and high palaeolatitudes, representing seasonally dry biome and cool temperate biome, respectively. It is evident from the foregoing analysis that many species occurred in many localities simultaneously. As such, Sørensen (1957) introduced the Sørensen’s similarity index which compares the degree of species similarity of two populations or localities. The index ranges between “zero”, meaning no common species, and “one” meaning complete or total similarity.

**Geological Setting**

The Iranian microplate was a continental block that collided with Eurasia in the Late Triassic (Alavi et al. 1997; Zanchi et al., 2009a, 2009b, 2015, 2016; Zanchetta et al. 2013; Berra et al. 2017), as a part of the Cimmerian continent collage (Sengör 1979, 1990). Part of this Iranian microplate is represented by the Central East Iranian Microcontinent (CEIM; Takin 1972) that consists of three blocks: Yazd (western), Tabas (central) and Lut (eastern) blocks. 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), where 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 (in Berberian & King 1981), the age of the Middle Cimmerian event. Tipp (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 bear-
ing Series”. The National Stratigraphic Commit-
tee of Iran (1964, in Aghanabati 1998) introduced
the name “Hojedk Formation” for this succession.
The Hojedk Formation is comparable to the Upper
Coal Member of Assereto’s (1966) subdivisions of
the Shemshak Formation in the Alborz Mountains,
to the Dansirit Series of Alborz, Northern Iran
(Schweitzer & Kirchner 2003) and to the Dansirit
Formation of the Shemshak Group in Northern
Iran (Fürsich et al. 2009; Wilmsen et al. 2009). The
fossils of the Hojedk Formation studied in this pa-
per were collected from a measured stratigraphic
core-section of the well number 210 in the South
Kouchekali, about 67 km southwestern of the Tabas
city (coordinates: 33˚ 13’ 22’’ North latitude and 56˚
23’ 6’’ East longitude; Fig. 1). In this locality, the
Hojedk Formation is 462 m thick and consists of
sandstone (dominating in its lower part), dark gray
siltstone, shale/black shale and coal seams (Fig. 2A).
Fig 2 - Comparative biostratigraphy charts of the Hojedk Formation at the site of the studied core number 210 in South Kouchekali, SW Tabas Block (A) and in Calshaneh, NW Tabas Block (B), Central-East Iran (Vaez-Javadi 2015).
Results

The Hojedk Formation contains forty-three species of plant macrofossil remains identified as belonging to twenty-four genera of various orders such as Equisetales, Filicales, Caytoniales, Bennettitales, Cycadales, Ginkgoales, and Pinales (Pls 1, 2, 3-4). These genera were used to assess palaeoclimate, based on floral gradient scores. The identified species comprise Annulariopsis simpsonii (Phillips, 1875) Harris, 1947, Equisetites beanii Seward, 1894, cf. E. columnaris (Brongniart, 1828) Phillips, 1875 (Order Equisetales); Dictyophyllum nilssonii (Brongniart, 1824) Seward, 1900, K. exilis (Phillips, 1829) Raciborski, 1890, K. crenata Vaez-Javadi, 2006, Ferizianopteris undulata Fakhr, 1997, Lobifolia rotundifolia Corsin & Stampfli, 1997, L. iranica Fakhr, 1977, Phlebopteris sp. cf. P. muensteri (Schenk, 1867) Hirmer & Hoerhammer, 1936 (Order Filicales), Cladophlebis sp. cf. C. denticulata (Brongniart, 1828) Nathorst, 1876 (Insertae sedis ferns), Sagenopteris colpodes Harris, 1940, S. nilssoniana (Brongniart, 1824) Ward, 1900 (Order Caytoniales), Anomozamites sp., Pterophyllum feriziense Fakhr, 1977 (Order Bennettitales), Nilssonia bozorga Barnard & Miller, 1976, N. feriziensis Fakhr, 1977, N. berriesi Harris, 1946) Schweitzer, Kirchner & van Konijnenburg-van Cittert, 2000, N. ingens Schweitzer, Kirchner & van Konijnenburg-van Cittert, 2000, N. macrophylla Jacob & Shukla, 1955, Nilssonia sp. cf. N. orientalis Heer, 1878, N. tazarensis (Sadovnikov, 1991) Schweitzer, Kirchner & van Konijnenburg-van Cittert, 2000, N. undulata Harris, 1932 (Order Cy-
Middle Jurassic flora from Central East Iran


On the basis of the occurrence of index taxa (Barnard 1965; Schweitzer & Kirchner 1997; Schweitzer et al. 2000; Schweitzer et al. 2009) such as Equisetites beanii, Coniopteris hymenophylloides, Klukia exilis, Nilssonia macrophylla, and Phyllophyllum harrisianum, an Aalenian-Bajocian age is suggested for this assemblage. On the basis of the FO and LO of index species, one biozone is established in this stratigraphic core-section. It is an Assemblage Biozone named as the Coniopteris hymenophylloides-Klukia exilis Assemblage Biozone with its lower and upper boundaries identified by the FO and LO of the two eponymous Aalenian-Bajocian index species, respectively. Furthermore, four sub-biozones were recognized as follows, from base to top: the Phyllophyllum harrisianum Taxon Range zone, the Phyllophyllum harrisianum-Nilssonia bozorga Concurrent Range zone, the Ginkgoites sp. cf. G. parasingularis Taxon Range zone, and the Nilssonia macrophylla-Nilssonia ingens Assemblage zone (Fig. 2A).

**Palaeogeographic and palaeoclimate implications**

Taxonomic studies from the newly investigated localities provide valuable data for improving palaeoclimate and palaeogeographic interpretations. The climate played an important role in maintaining the persistence of the vegetation. The palaeogeographic setting of the northern margin of the Teth-
ys Ocean was important in controlling this climate condition. A humid and warm climate is suggested by the widespread occurrence of coal bearing formations ranging in age from Late Triassic to Middle Jurassic in the Euro-Sinian region and Siberia (Vakhrameev 1991). Pole (2009) reported *Coniopteris hymenophylloides* as a cosmopolitan species from the Jurassic of New Zealand. The Jurassic period in Iran is generally characterized by a uniform and stable climate and by a lack of drastic climatic events. Vakhrameev (1964, 1991) and more recently Rees et al. (2000) and Vaez-Javadi (2014) developed palaeoclimate reconstructions based on paleoecological data. On the basis of biostratigraphic correlation in SW Tabas, it can be concluded that the *Coniopteris hymenophylloides - Klukia exilis* Assemblage Biozone was widespread during the Middle Jurassic throughout Iran (Fig. 2). Distribution patterns and adaptive mechanisms of plant taxa can be interpreted on this basis. The relative abundance of the reported taxa from the South Kouchekali locality was studied as well, showing that relative abundances of Filicales, Pinales, Cycadales, Equisetales, Caytoniales, Bennettitales, and Ginkgoales are 47.12%, 18.59%, 15.70%, 8.33%, 5.13%, 3.20%, and 1.28%, respectively. Moreover, the relative abundances of *Klukia exilis*, *Coniopteris hymenophylloides*, *Nilssonia undulata*, *Elatides thomasi* and *Podozamites distans* are 10.22%, 9.90%, 6.81%, 6.81%, and 6.50%, respectively. Furthermore, relative abundances of species, genera and orders of plant macrofossils from the Rudbarak, Mazino, Jafar-Abad, Calshaneh, North Kouchekali, and Bazehowz have been already reported (Vaez-Javadi 2011, 2014, 2015; Vaez-Javadi...
These data were thus gathered in a comparative chart (Fig. 5). It shows a high relative abundance of Filicophyta and Cycadales in these areas during the early Middle Jurassic.

The differences in abundance and variety of the plant genera and higher taxonomical groups depending on their palaeogeographic position are the basis of “Correspondence analysis” and “Floral gradient” interpretations. Floral gradient scores of several localities have been estimated: scores of North Kouchekali, South Kouchekali, Mazino, Calshaneh, Jafar Abad (Tabas Block), Rudbarak, Baladeh (Alborz Mountains), Ferizi and Golmakan, Shandiz, Bazehowz (Binalud Mountains), Dashte Khak, and Hashooni mines (Kerman Basin) are 56.2, 52.93, 53.5, 58.5, 58.5, 63.4, 60.38, 64.56, 61.33, 53.57, 60.2, and 51.33, respectively (Fig. 6). The scores from Tabas Block plotted in the middle part of the “Floral Gradient” table of Rees et al. (2000), indicating warm temperate climate conditions for that interval.

The Principal Component Analysis including correlation chart and the correspondence analysis plot of data with 95% confidence interval ellipse of plant macrofossil genera composition from the various Middle Jurassic localities in Iran are figured using MVSP 3.1 (Multi Variate Statistical Package) (Figs. 7, 8). Plant macrofossil genera and localities distributed in Iran are axis components of the mentioned charts. This ellipse shows that most of the genera are grouped into similar environment conditions. Genera falling in the ellipse are those of the floral gradient list of Rees et al. (2000), such as Gink
Fig. 3 - Biostratigraphic chart of the flora of the Hojedk Formation at the site of the studied core number 169, in North Kouchekali (C), in Mazino (D), and in Rudbarak (E), in the Tabas Block, and in Tabas (F), in the Alborz Mountains, Iran (Vaez-Javadi & Namjoo 2016; Vaez-Javadi 2014, 2011).
goites, Equisitites, Sphenobaiera, Podozamites, Coniopteris, Cladophlebi, Nilssonia, and Elatides. Only three genera, namely Sagenopteris, Ptilophyllum, and Otozamites, are at the margin of ellipse or out of it. They are considered as tropical floras which were located at the lower part of floral gradient table of Rees et al. (2000) with low scores (21, 13, and 9 respectively). Moreover, this uniformity of plant fossil assemblages indicates close connection among the blocks forming Iran at Middle Jurassic times, blocks which had a Gondwanan ancestry (Sengör 1979; Berra et al. 2017 and references there in). The evolution of the Late Triassic-Jurassic sedimentary basins of the CEIM were largely governed by the Late Triassic collision of the Iran Plate and subsequent rotational and lateral movements (e.g. Davoudzadeh et al. 1981; Soffel et al. 1996; Alavi et al. 1997; Mattei et al. 2014 ). The thick post-collisional molasse-type sediments of the Upper Triassic/Lower Jurassic Shemshak Group and their wide distribution across the Iran Plate indicate that during this time the Iran Plate behaved as a more or less coherent tectonic unit (Seyed-Emami et al. 2003).

It is noteworthy that the variety and the relative abundance of the species of the genus Nilssonia as a macrophyllous cycadophyte (six species in Calshaneh, nine species in North and South Kouchekali, six species in Mazino in the Tabas Block, three species in Baladeh, two species in Rudbarak in the Alborz Mountains, five species in Bazehowz in the Binalud Mountains, and ten species in the Kerman Basin) was relatively high within the Middle Jurassic

![Fig. 4 - Biostratigraphic chart of the flora of the Dansirit Formation in Baladeh, Central Alborz Mountains, Northern Iran (F), and of the Bazehowz Formation (G), Binalud Mountains, Northeastern Iran (Vaez-Javadi & Abbasi 2012; Vaez-Javadi & Allameh 2015).](image)

Tab. 1- Similarity indices of different localities in Iran at genus and species levels.
deposits of Iran while in some localities in northern hemisphere, both the variety and abundance of Nilssonia was low (e.g. China in Vakhrameev 1991). In addition, thick coal deposits distribute through these mentioned localities. However, there were uniform environmental conditions during this interval of time through a wide area in Iran.

In order to obtain a robust comparison, the similarity index (Sorensen's index) has been used for comparing the similarity of the flora assemblages. Similarity indices between South Kouhekal and other areas are summarized in Tab. 1 and Fig. 9. It should be mentioned that some areas, such as Calshaneh and Bazehowz, contain relatively few fossils.

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**Fig. 5 -** Comparison chart of distribution of various taxa during the early Middle Jurassic in different localities in Central-East and North of Iran.

**Fig. 6 -** Floral gradient chart of different localities in Iran.
because of its fluvial paleoenvironmental condition. However, it is notable that the similarity indices especially on the species level decreased toward the Alborz and Binalud Mountains. This decrease might be related to the higher latitude of these areas. Moreover, fossil flora from Khatumbargah and Vasekgah show a very low similarity index. It might be due to more endemic plants or because of sampling; there is no record of Sphenophyta and Filicophyta from these localities (Barnard & Miller 1976).

**Plant biostratigraphy of the Middle Jurassic of Iran**

The biostratigraphy of localities such as Mazino, North Kouechekali, Calshaneh (Tabas Block), Baladeh, Rudbarak (Central Alborz Mountains), and Bazehowz (South Mashhad) were studied over several years (Vaez-Javadi 2006, 2011, 2014, 2015; Vaez-Javadi & Abbasi 2012; Vaez-Javadi & Allameh 2015, and Vaez-Javadi & Namjoo 2016). Here, I correlate the biozones of the Middle Jurassic of South Kouechekali to those of similar age sedimentary successions (Figs 2, 3, 4). Vaez-Javadi & Mirzaei-Ataabadi (2006) figured and described 39 species from the Middle Jurassic of Pabdana, Hashooni Mine, and Dashte Khak in the Kerman Basin, and these species are closely similar to other Iranian floral localities. Based on the FO and LO of the plant macrofossil index species, one biozone is established in the South Kouechekali core-stratigraphic section: the *Coniopteris hymenophylloides - Klukia exilis* Assemblage zone. The erected plant macrofossil biozone in this area is comparable with the *Klukia exilis - Nilssonia macrophylla* Assemblage zone in North Kouechekali, the *Klukia exilis - Coniopteris hymenophylloides* Assemblage zone in Mazino, the *Nilssonia sp. cf. N. bozorga - Klukia exilis* Assemblage zone in Calshaneh area, the *Coniopteris hymenophylloides - Klukia exilis* Assemblage zone in Kerman Basin (Dashte-Khak), the *Coniopteris hymenophylloides - Ptilophyllum harrisianum* Assemblage zone in Baladeh, the *Coniopteris hymenophylloides-Nilssonia sarakhs* Assemblage zone in Rudbarak, the *Klukia exilis - Coniopteris hymenophylloides* Assemblage zone in Bazehowz, and the *Nilssonia sp. cf. N. bozorga - Ptilophyllum harrisianum* Assemblage zone in the south of Zanjan (Vaez-Javadi & Abbasi 2018). Therefore, it is concluded that a single biozone characterizes the Middle Jurassic succession of Iran (Fig. 10).

**Conclusions**

In this study, new data are provided from the Middle Jurassic, South Kouechekali, SW Tabas, Central East Iran.

* The Middle Jurassic deposits in this core-stratigraphic section contain 43 plant macrofossil species belonging to 24 genera of various orders.
* Based on the occurrence of index fossils such as *Equisetites beani*, *Coniopteris hymenophylloides*,

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**Fig. 7** - Principle component analysis Correlation chart of genera assemblages from some Middle Jurassic localities (North Kouechekali, South Kouechekali, Mazino, Calshaneh, Rudbarak, Baladeh, and Bazehowz).

**Fig. 8** - Correspondence analysis plot of data from Middle Jurassic areas of the North, Central, and Central-East of Iran.
Klukia exilis, Nilssonia macrophylla, and Ptilophyllum harrisianum, an Aalenian-Bajocian age is suggested for this assemblage.

* One Assemblage zone is recognized in this core-stratigraphic section. Its lower and upper boundaries are identified by the FO and LO of Coniopteris hymenophylloides and Klukia exilis, respectively.

* The studied interval is subdivided into four subzones: I- Ptilophyllum harrisianum Taxon Range zone, II- Ptilophyllum harrisianum - Nilssonia bozorga Concurrent Range zone, III- Ginkgoites sp. cf. G. parasingularis Taxon Range zone, and IV- Nilssonia macrophylla - Nilssonia ingens Assemblage zone.

* The Coniopteris hymenophylloides - Klukia exilis Assemblage zone is widespread through northern (Golmakan, Ferizi, Baladeh, Rudbarak in the Alborz Mountains), Bazehowz (Binalud Mountains), central eastern (North and South Kouchevaki, Mazino, Jafar Abad, Calshaneh in Tabas Block) and central Iran (Kerman Basin) during the early Middle Jurassic.

* The results of this study indicate that Filicophyta, Coniferophyta and Cycadophyta are relatively abundant. The genus Nilssonia with eight species was dominant within the Middle Jurassic flora of South Kouchevaki. Its variability and relative abundance indicate that a macrophyllous cycadophyte morphocat was widespread through Iran during this interval, indicating a warm temperate climate.

* The Floral Gradient score of this area is 52.93. A comparison chart of floral gradients of other localities in Iran has been established in which the average scores of North Kouchevaki, Mazino, Calshaneh, Jafar-Abad (Tabas Block), Rudbarak, Baladeh, Bazehowz (Alborz Mountains), and Kerman Basin are 56.2, 53.5, 58.5, 58.5, 63.4, 60.38, 53.57, and 62.1, respectively. Since the floral gradient scores are in the middle part of the table of Rees et al. (2000) it is concluded that the Tabas Block and Kerman Basin were located in the warm temperate biome.

* Similarity indices among South Kouchevaki and North Kouchevaki, Mazino, Jafar-Abad, Calshaneh, Rudbarak, Baladeh, Bazehowz, Ferizi & Golmakan, and the Kerman Basin are 0.86, 0.81, 0.52, 0.57, 0.47, 0.65, 0.50, 0.47 and 0.68, respectively. This indicates that genera similarity is rather high. Therefore, climatic conditions were uniform in these areas.
* The climate of the study area was humid and sub-tropical (warm temperate biome) during the Middle Jurassic in Iran.

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