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

FATEMEH VAEZ-JAVADI

School of Geology, College of Science, University of Tehran, Tehran, Islamic Republic of Iran. E-mail: vaezjavadi@ut.ac.ir

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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, Rudbarak, Khatumbargah, Ahan Sar, Vasekgah and Imam Manak, Zirab, Ziaran, Djam, Gheshlagh, Shemshak, and Ferizi, Golmakan, Shandiz, and Bazehowz), central Iran (Dashte-Khak, Babnizu, Hashooni, Eshkelli, 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; Barnard & Miller 1976; Sadovnikov 1976, 1984, 1991; Corsin & Stampfli 1977; Fakhr 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 & Namjoo 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-Alhoseini et al. 1989; Aghanabati 1998). The geological setting with special emphasis on the coal seams was

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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 (Scanu 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 biostratigraphic 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 central 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 filicopsids, 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 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 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 leant 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 microphyllous 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 microphyllous 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. Tipper (1921) called this succession, typically consisting

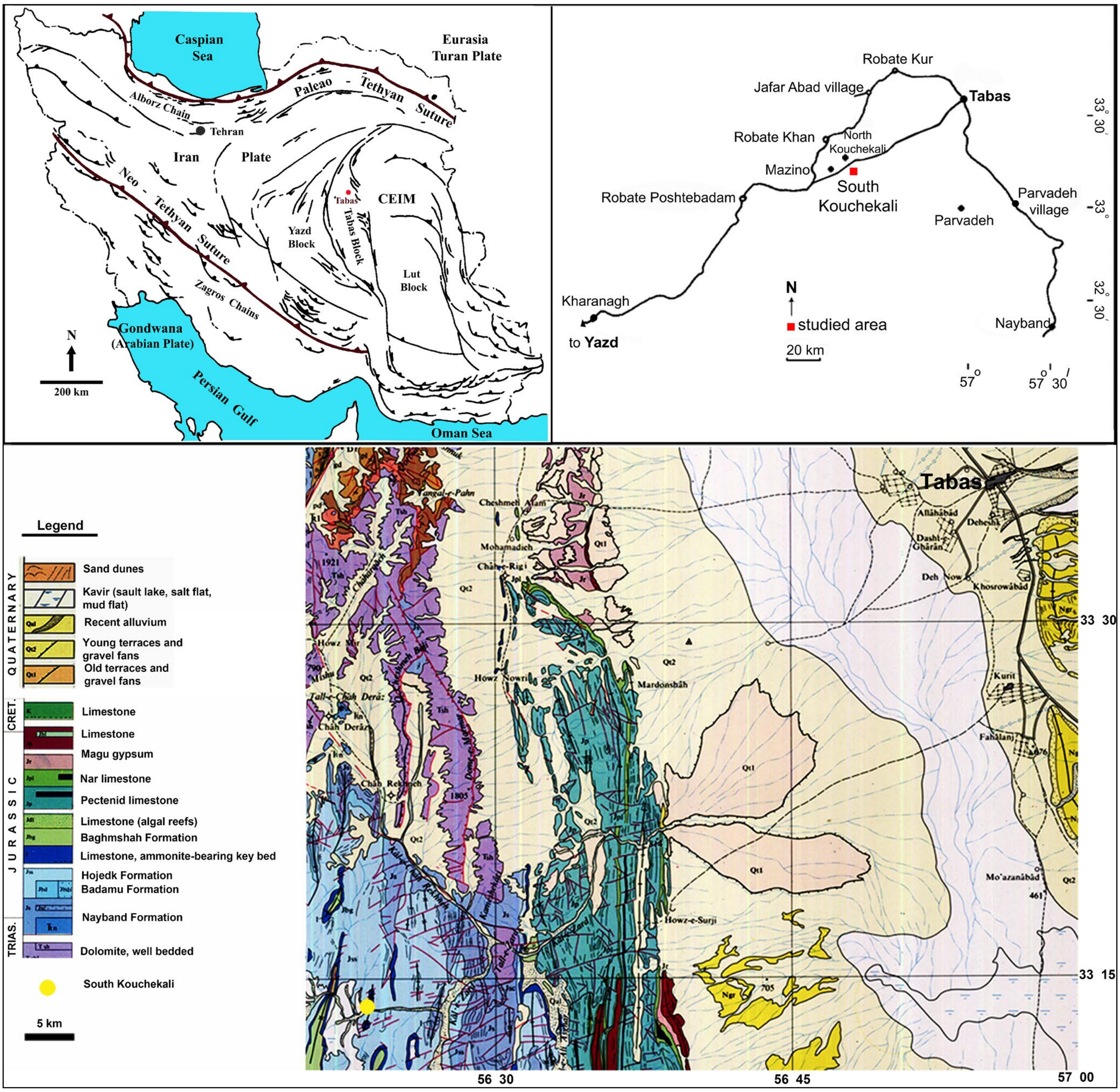


Fig. 1 - Sketch map of Iran and the location of the studied core section of South Kouchekali and the geological map of Tabas Block (Simplified tectonic map of Iran showing the main structures; CEIM= Central East Iranian Microcontinent; modified from Alavi et al. 1997; geological map after Aghanabati & Haghipour 1978).

of sandstone and shale deposits with coal seams, the "Jurassic Plant bearing Series" in the Kerman Basin. Beckett (1956) named these deposits the "Coal bearing Series". The National Stratigraphic Committee of Iran (1964, in Aghanabati 1998) introduced the name "Hojedk Formation" for this succession. The 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 paper 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).

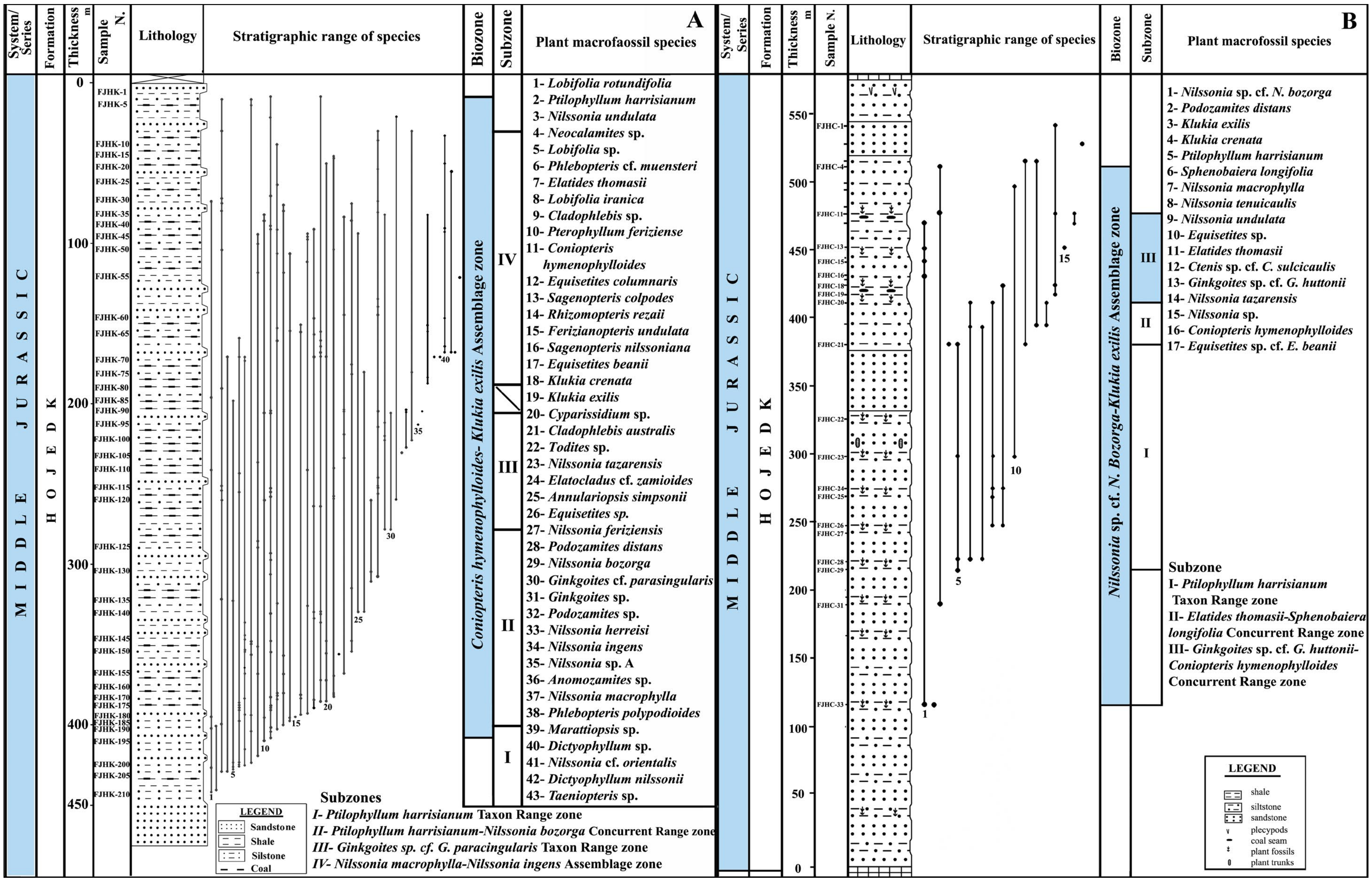


Fig. 2 - Comparative biostratigraphy charts of the Hojedk Formation at the site of the studied core number 210 in South Kouchekali, SW Tabas Block (A) and in Calshaneh, NW Tabas Block (B), Central-East Iran (Vaez-Javadi 2015).

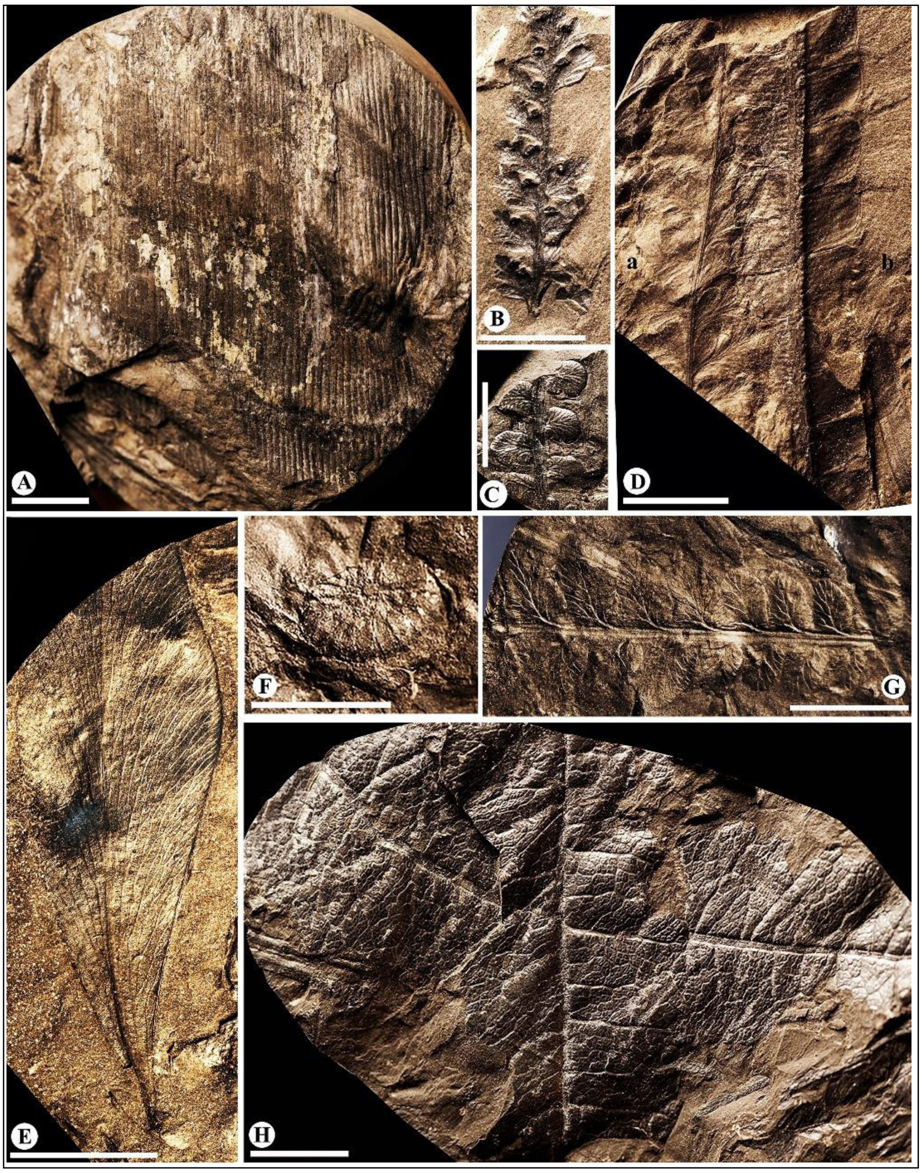


Plate 1

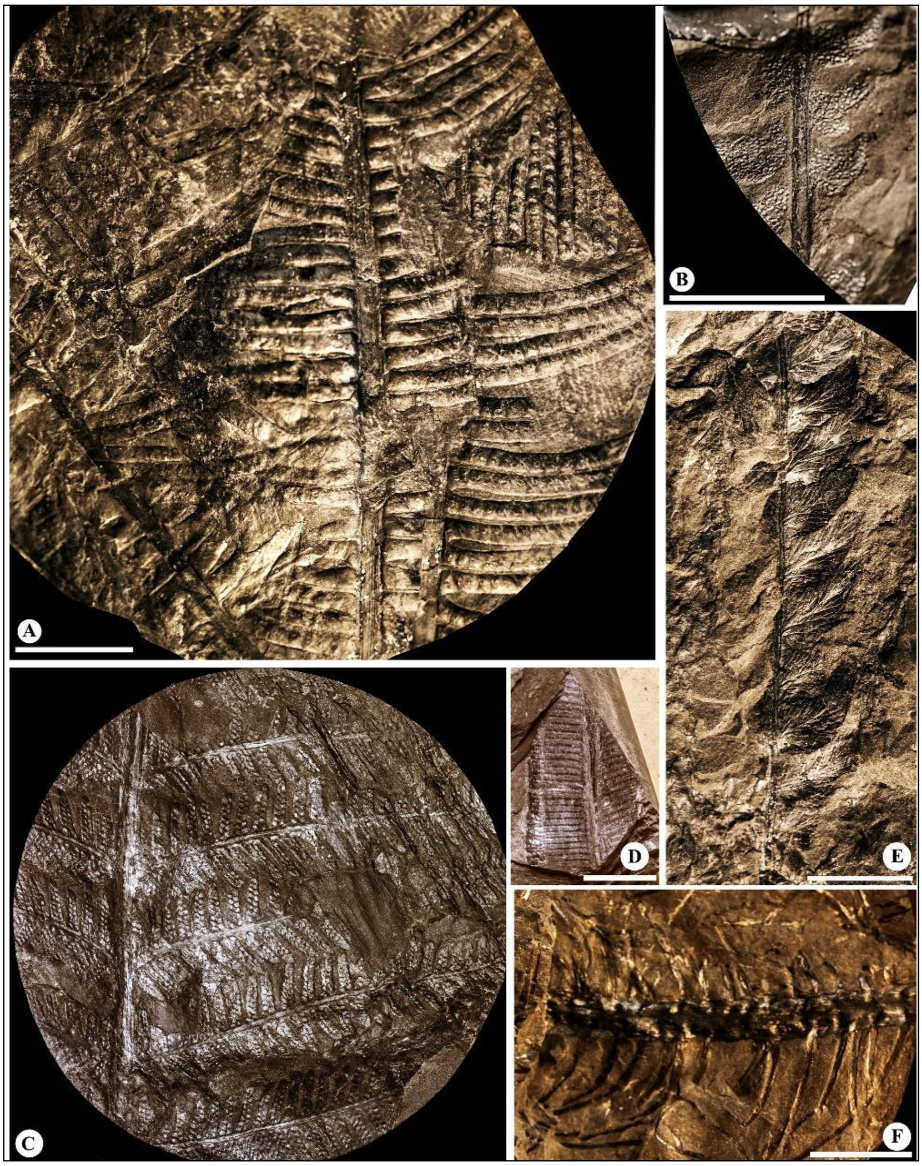
A - *Equisetites beanii*, FJHK-137;
B - *Coniopteris hymenophylloides*, FJHK-118;
C - *Ferizienopteris undulata*, FJHK-180;
D - a) *Coniopteris hymenophylloides*, b) *Anomozamites* sp., FJHK-90;
E - *Sagenopteris nilssoniana*, FJHK-179;
F - diaphragm of cf. *Equisetites columnaris*, FJHK-26;
G - *Lobifolia rotundifolia*, FJHK-179;
H - *Dictyophyllum* sp., FJHK-41.
Scale bars: 1 cm.

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, 1836) Goeppert, 1846, *Coniopteris hymenophylloides* (Brongniart, 1828) Seward, 1900, *Klukia 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. herriesi* (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-

Plate 2

A - *Phlebopteris muensteri*, FJHK-177;
B - *Todites* sp., FJHK-156;
C - *Klukia exilis*, FJHK-4;
D - *Marattiopsis* sp., FJHK-69;
E - *Lobifolia iranica*, FJHK-148;
F - *Rhizomopteris rezaii*, FJHK-183.
Scale bars: 1 cm.



cadales), *Ginkgoites* sp. cf. *G. parasingularis* Kilpper, 1971 (Order Ginkgoales), *Cyparissidium* sp., *Elatides thomasii* Harris, 1979, *Elatocladus* sp. cf. *E. zamioides* (Leckenby, 1864) Seward, 1919, and *Podozamites distans* (Presl, 1838) Braun, 1843 (Order Pinales).

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 *Ptilophyllum 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 *Ptilophyllum harrisianum* Taxon Range zone, the *Ptilophyllum 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-

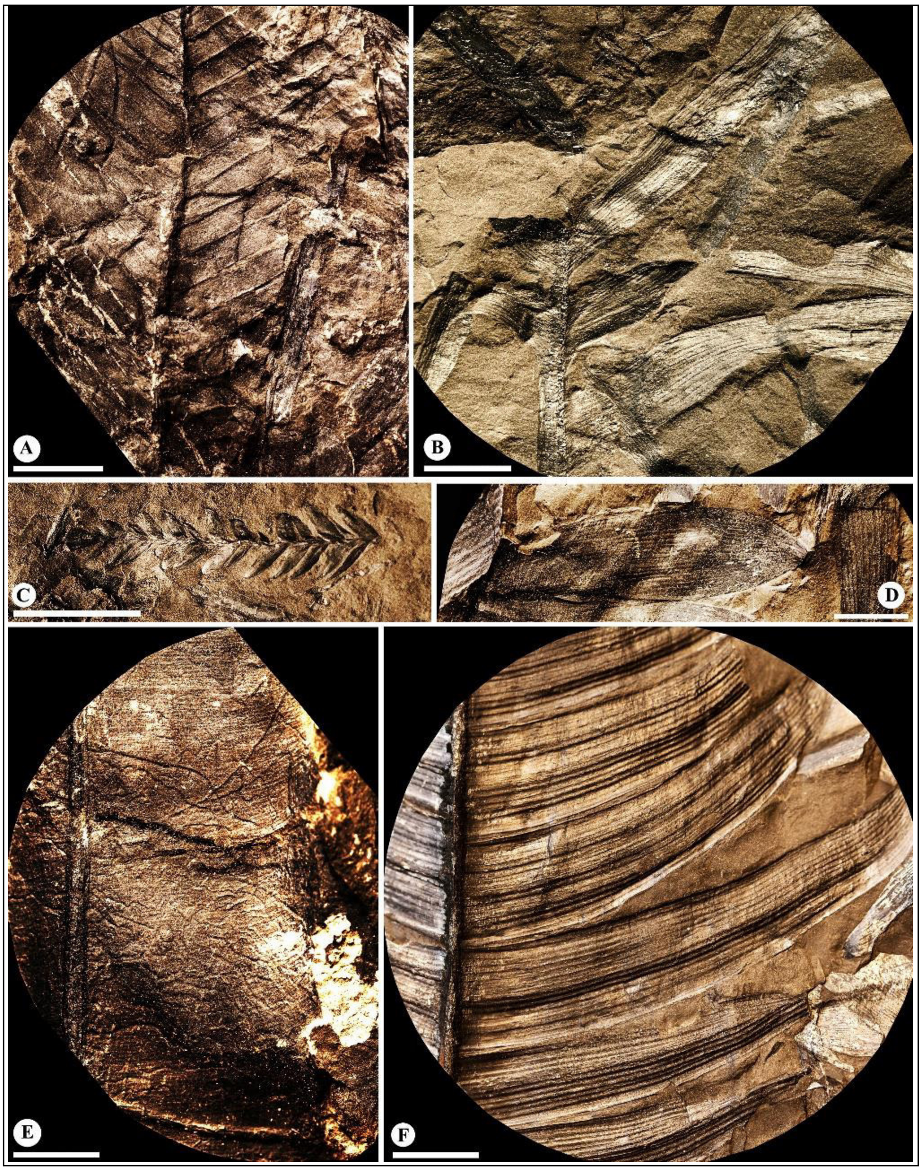


Plate 3

A - *Ptilophyllum harrisianum*, FJHK-188;
B - *Nilssonia herriesi*, FJHK-103;
C - *Elatocladus* sp., FJHK-153;
D - *Podozamites distans*, FJHK-96;
E - *Nilssonia orientalis*, FJHK-30;
F - *Nilssonia tazarensis*, FJHK-132.
Scale bars: 1 cm.

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 paleophytoecological 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 thomasii* 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

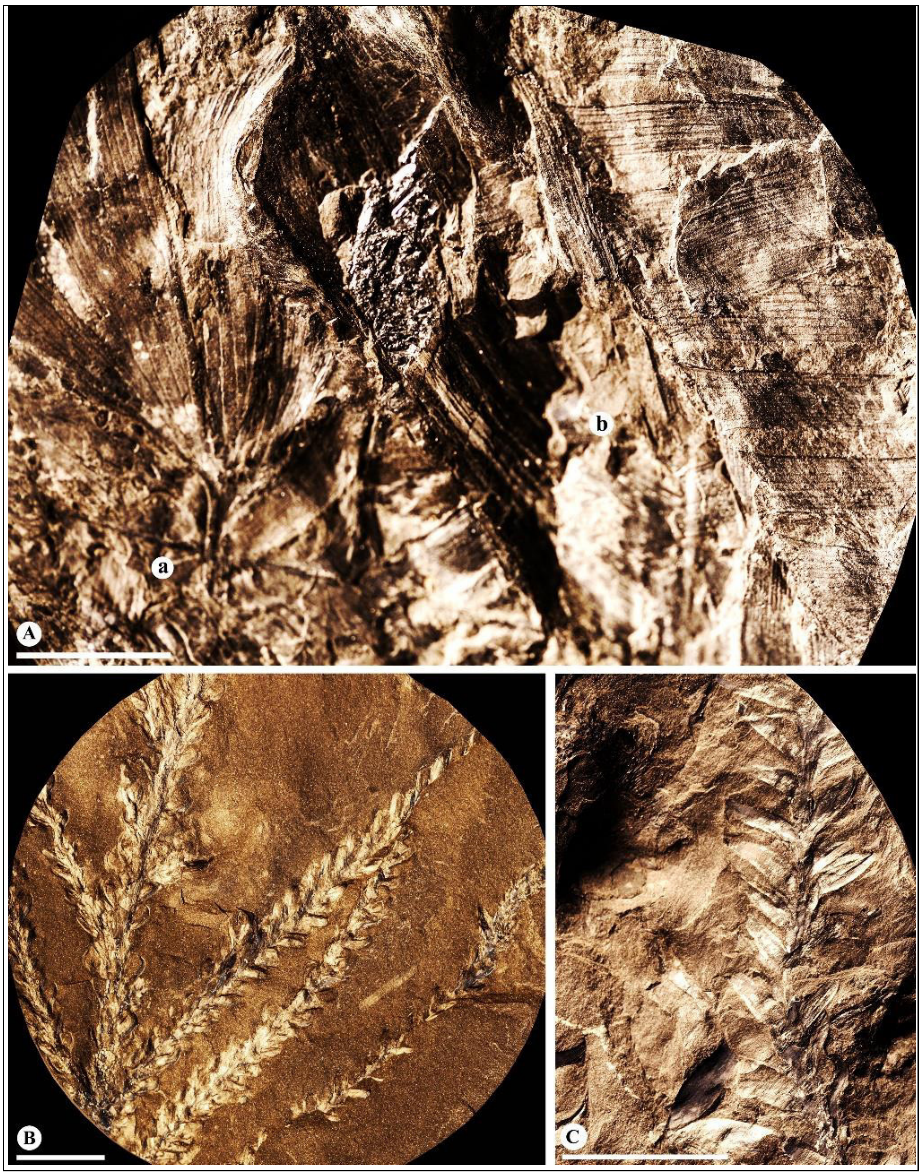


Plate 4

A - a) *Ginkgoites* sp. cf. *G. parasingularis*, b) *Nilssonia herriesi*, FJHK-91;
B - *Elatides thomasii*, FJHK-154;
C - *Elatocladus zamioides*, FJHK-146b.
Scale bars: 1 cm.

& Namjoo 2015, and Vaez-Javadi & Allameh 2015). 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-

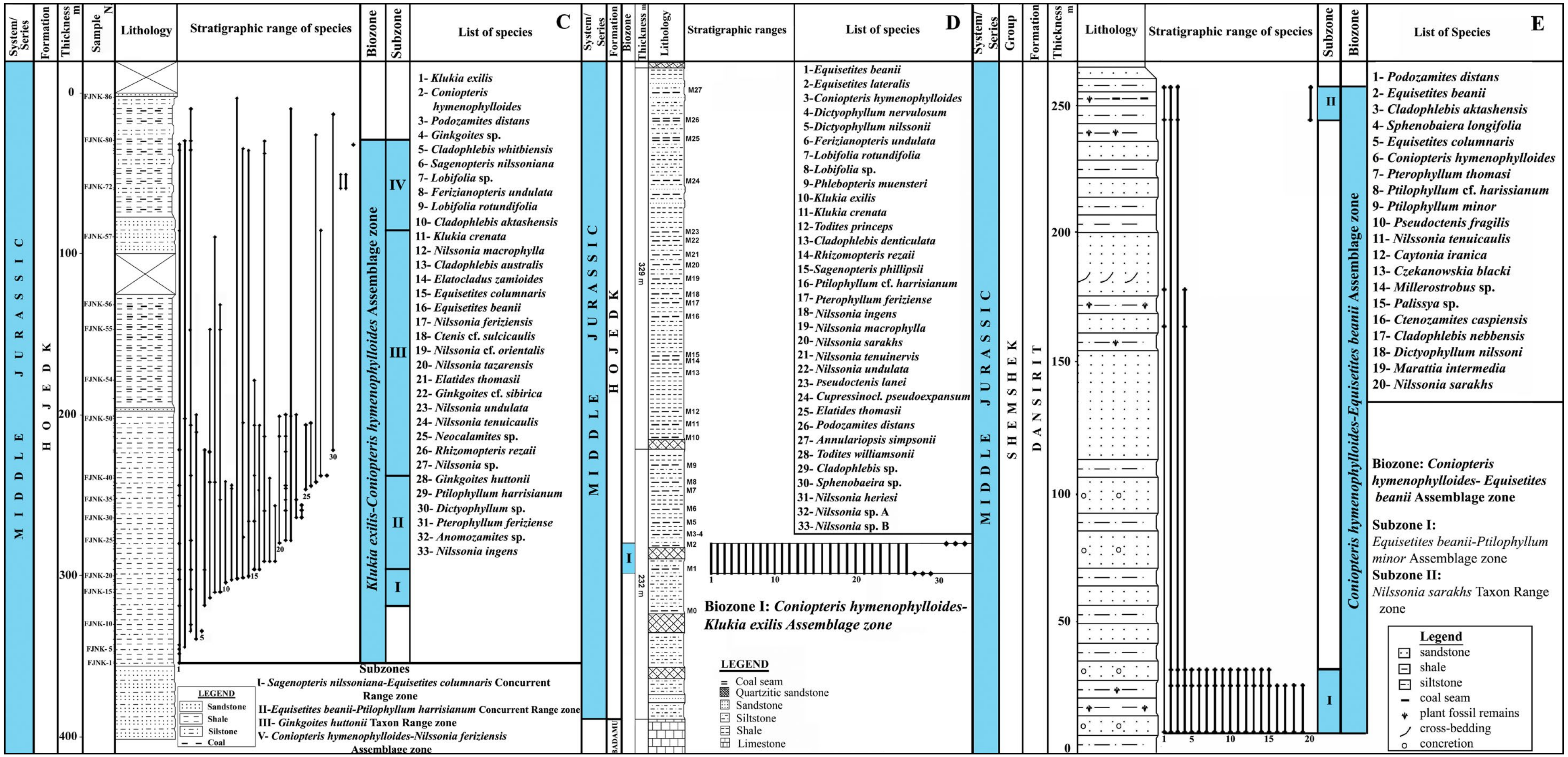


Fig. 3 - Biostratigraphic chart of the flora of the Hojedk Formation at the site of the studied core number 169, in North Kouchekali (C), in Mazino (D), both of the Tabas Block, and in Rudbarak (E), Alborz Mountains, Iran (Vaez-Javadi & Namjoo 2016; Vaez-Javadi 2014, 2011).

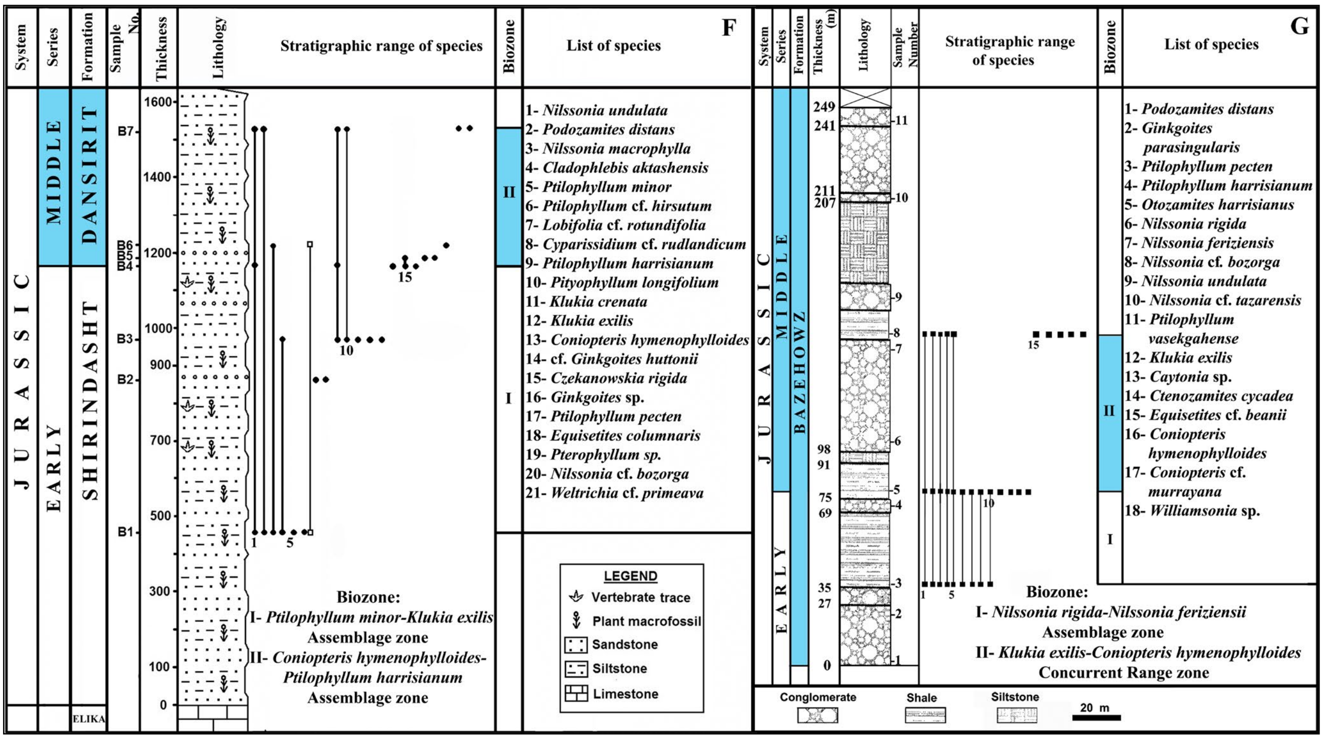


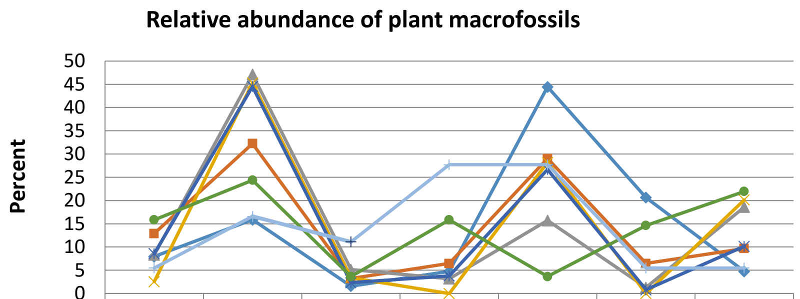
Fig. 4 - Biostratigraphic chart of the flora of the Dansirit Formation in Baladeh, Central Alborz Mountains, Northern Iran (F), and of the Bazehowz Formation (G), Binalud Mountains, Northeastern Iran (Vaez-Javadi & Abbasi 2012; Vaez-Javadi & Allameh 2015).

goites, *Equisetites*, *Sphenobaiera*, *Podozamites*, *Coniopteris*, *Cladophlebis*, *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

Localities	North Kouchekali	Mazino	Calshaneh	Kerman Basin (Hashooni, Pabdana, Dashte-Khak)	Baladeh	Rudbarak	Ferizi & Golmakan	Jafar-Abad	Khatumbargah & Vasekgah	Bazehowz
Si index at genus level	0.76	0.64	0.48	0.50	0.44	0.25	0.47	0.57	0.06	0.41
Si index at species level	0.86	0.81	0.52	0.68	0.65	0.47	0.27	0.38	0.1	0.50

Tab. 1- Similarity indices of different localities in Iran at genus and species levels.



	Equisetales	Filic.,Mar., Osmun.	Cayt., Coryst.	Bennettital.	Cycadales	Ginkg., Czek.	Coniferales
Calshaneh	7,94	15,87	1,59	4,76	44,44	20,64	4,76
N. Kouchekali	12,9	32,26	3,22	6,45	29,03	6,45	9,67
S. Kouchekali	8,33	47,12	5,13	3,2	15,7	1,28	18,59
Jafar-Abad	2,56	45,3	3,42	0	28,2	0	20,15
Mazino	8,59	44,53	2,34	3,8	26,69	0,78	10,16
Rudbarak	15,85	24,39	3,66	15,85	3,66	14,63	21,95
Bazehowz	5,5	16,6	11,1	27,7	27,7	5,5	5,5

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

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 Kouchekali 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

Genus	score	Locality																			
		North Kouchekali	South Kouchekali	Mazino	Calshaneh	Jafar-Abad	Babnizu	Pabdana	Dashte-Khak	Hashooni	Eshkelli	Zirab	Tazareh	Rudbarak	Baladeh	Sangrud	Khatumbar. & Vasekgah	Djam	Ferizi & Golmakan	Shandiz	Bazehowz
Raphaelia	100																				
Lycopodites	91																				
Phoenicopsis	89																				
Czekanowskia	87								❉			❉		❉	❉				❉		
Desmiophyllum	85																				
Pityophyllum	84														❉						
Sphenobaiera	81			❉	❉			❉						❉					❉		
Ginkgo	78	❉	❉		❉				❉	❉		❉	❉		❉				❉	❉	❉
Taxocladus	78																				
Baiera	78																				
Hausmannia	77																				
Pseudotorellia	76																				
Equisetites	76	❉	❉	❉	❉	❉	❉				❉	❉	❉	❉	❉						❉
Podozamites	72	❉	❉	❉	❉		❉	❉			❉	❉		❉	❉	❉		❉	❉	❉	❉
Coniopteris	72	❉	❉	❉	❉	❉			❉			❉		❉	❉			❉	❉	❉	❉
Cladophlebis	70	❉	❉	❉		❉		❉			❉	❉	❉	❉	❉	❉		❉	❉	❉	
Anomozamites	64	❉	❉				❉					❉	❉			❉					
Ctenis	60	❉			❉											❉					
Elatides	57	❉	❉	❉	❉	❉						❉	❉								
Nilssonia	55	❉	❉	❉	❉	❉			❉	❉		❉	❉	❉	❉	❉	❉	❉	❉	❉	❉
Elatocladus	52	❉	❉													❉					
Todites	52	❉	❉	❉				❉	❉			❉	❉			❉					
Sphenopteris	51																				
Taeniopteris	50		❉																		
Pterophyllum	45	❉	❉	❉								❉		❉					❉		
Pagiophyllum	28			❉																	
Sagenopteris	21	❉	❉	❉	❉	❉	❉			❉		❉				❉	❉		❉	❉	
Pachypteris	17		❉														❉				
Ptilophyllum	13	❉	❉	❉	❉						❉	❉	❉	❉	❉		❉				❉
Brachyphyllum	9																				
Otozamites	9								❉		❉	❉	❉			❉	❉	❉			
Zamites	0																				
Average score		56.2	52.93	53.5	58.5	58.5	58.25	68.75	60.2	51.33	48	55.07	52.67	63.4	60.38	50.55	23	55.6	64.56	61.33	53.57

Fig. 6 - Floral gradient chart of different localities in Iran.

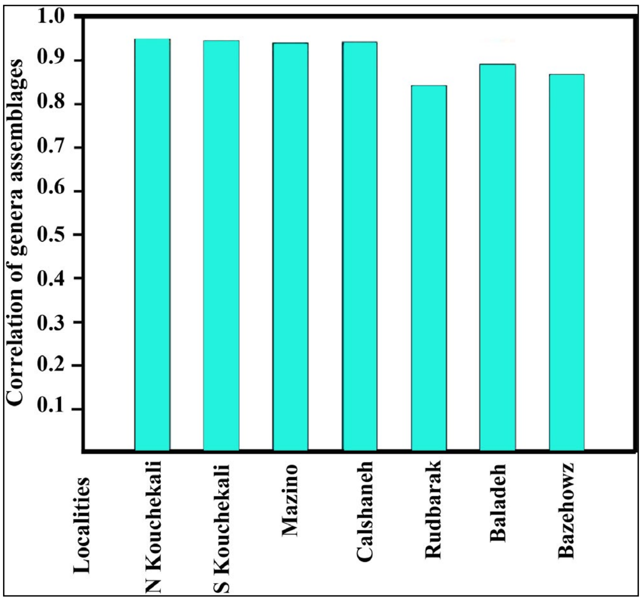


Fig. 7 - Principle component analysis Correlation chart of genera assemblages from some Middle Jurassic localities (North Kouchekali, South Kouchekali, Mazino, Calshaneh, Rudbarak, Baladeh, and Bazehowz).

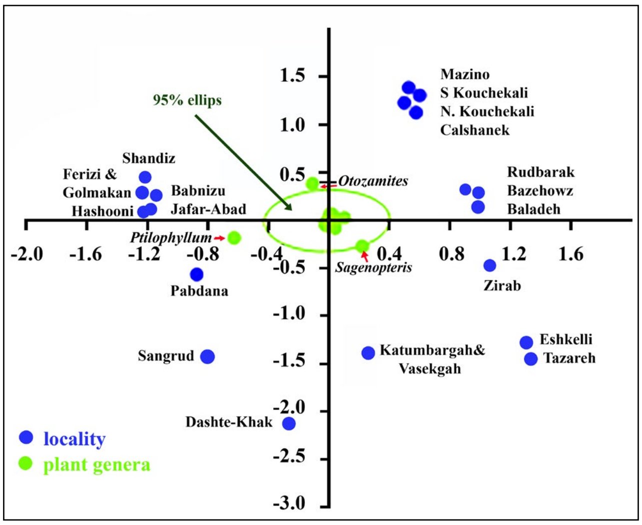


Fig. 8 - Correspondence analysis plot of data from Middle Jurassic areas of the North, Central, and Central-East of Iran

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 Kouchekali, 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 Kouchekali 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 Kouchekali 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 Kouchekali, 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 Baze-Howz, 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 Kouchekali, 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 beanii, Coniopteris hymenophylloides,*

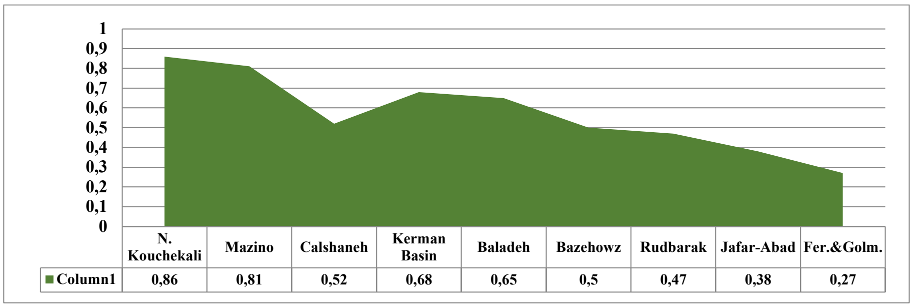


Fig. 9 - Similarity chart among the South Kouchekali and elsewhere in Iran.

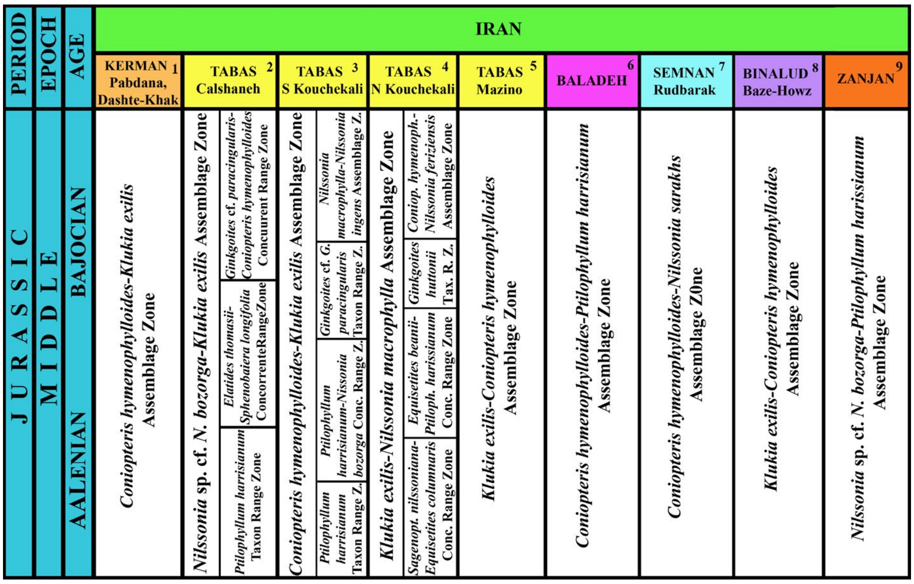


Fig. 10 - Plant macrofossils biostratigraphy of the Middle Jurassic (Aalenian-Bajocian) sedimentary successions of Iran (1: Vaez-Javadi & Mirzaei-Ataabadi 2006, 2: Vaez-Javadi 2015, 3: Vaez-Javadi 2016, 4: Vaez-Javadi & Namjoo 2015, 5: Vaez-Javadi 2014, 6: Vaez-Javadi & Abbasi 2012, 7: Vaez-Javadi 2011, 8: Vaez-Javadi & Allameh 2015, and 9: Vaez-Javadi & Abbasi 2018).

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 Kouchekali, 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 Kouchekali. 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 Kouchekali, 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 Kouchekali and North Kouchekali, 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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References

Aghanabati A. (1998) - Jurassic stratigraphy of Iran, Vol. 1. Geological Survey of Iran, Tehran, 355 pp. (Persian)

Aghanabati A. & Haghipour A. (1978) - Geological map of Tabas, 1:250000, No. 17, Report 3(4), *Geol. Sur. Iran,* Tehran (Persian).

Alavi M. & Barale G. (1970) - Étude prèliminaire de la flore de la formation de Shemshak dans la region de Djam. *Bull. Soci. Linn. Lyon*, 39 (8): 241-252.

Alavi M., Vaziri H., Seyed-Emami K. & Lasemi Y. (1977) - The Triassic and associated rocks of the Nakhlak and Aghdarband areas in central and northeastern Iran as remnants of the southern Turanian active continental margin. *Geol. Soc. Amer. Bull.*, 109: 1563-1575.

Antevs E. (1919) - Die liassische Flora des Hörsandsteins. Kung. *Svens. Vetens. Handl.*, 59 (8): 1-71.

Arber E.A.N. (1917) - The earlier Mesozoic floras of New Zealand. *Palaeont. Bull. New Zealand Geol. Sur.*, 6: 1-80.

Assereto R. (1966) - The Jurassic Shemshak Formation in Central Elburz (Iran). *Riv. It. Paleontol. Strat.*, 72(4): 1133-1182.

Barnard P.D.W. (1965) - The geology of the upper Djadjerud and Lar valleys (North Iran) II. Palaeontology. Flora of the Shemshak Formation Part 1. Liassic plants from Dorud. *Riv. It. Paleontol. Strat.*, 71(4): 1123-1168.

Barnard P. D.W. & Miller J.C. (1976) - Flora of the Shemshak Formation (Elburz, Iran), Part 3. Middle Jurassic (Dogger) plants from Khatumbargah, Vasekgah and Imam Manak. *Palaeontogr. B*, 155: 31-117.

Beckett P.H.T. (1956) - Coal deposits near Kerman, South Persia. *Econ. Geol.*, 51: 197-198.

Benda L. (1964) - Die Jura-Flora aus der Saighan-Serie Nord-Afghanistans. *Beih. Geol. Jahr.*, 70: 99-152.

Benzécri J.-P. (1973) - L'Analyse des Données. Volume II. L'Analyse des Correspondances. Paris, France: Dunod.

Berberian N. & King G.C.P. (1981) - Towards a paleogeography and tectonic evolution of Iran. *Canad. J. Earth Sci.*, 18: 210-265.

Berger A.C. (1832)- Die Versteinerungen der Fischer und Pflanzen im Sandsteine der Coburger Gegend, Coburg.

Berra F., Angiolini, L., Zanchi A., Vezzoli G., Zanchetta S., Bergomi M., Vachard D., Javadi H.R., Kouhpeyma M. (2017) - The upper Palaeozoic Godar-e-Siah Complex of Jandaq: Evidence and significance of a North Palaeotethyan succession in Central Iran. *J. Asian Earth Sci.,* 138: 272-290.

Braun C.F.W. (1843) - Beiträge zur Urgeschichte der Pflanzen. *Beitr. Petr.-Kun.*, 6(7): 1-46.

Brick M.I. (1937) - La flore Mésozoique du Ferghana Méridional, II. Fougères (fin) Equisétinées. *Trans. Geol. Tru. Cent. Asia*, Tashkent, 3: 1-75 [Russian with French summary].

Brick M.I. (1953) - Mesozoic Flora of the East-Ferghana Coal Basin. *Ferns. Trud. VSEGEI, Gosg.*, 1-112 [in Russian].

Brongniart A. (1828-1838) - Histoire des végétaux fossiles, ou recherches botaniques et géologiques sur les végétaux renfermés dans les diverses couches du globe. Paris. 1 (1828-1837), XII + 488 pp; 2 (1837-1838), 72 pp.

Bunbury C.J.F. (1851) - On some fossil plants from the Jurassic strata of the Yorkshire Coast. *Quar. J. Geol. Soc. London,* 7: 179-194.

Cleal C.J., Thomas B.A., Batten D.J. & Collinson M.E. (2001) - Mesozoic and Tertiary palaeobotany of Great Britain. Geological Conservation Review Series 22, Joint Nat. Cons. Comm., Petersburg, 335 pp.

Corsin P. (1950) - Les divisions paléontologiques du Stéphanien du Bassin de la Loire. *Com. Ren. Acad. Sci.*, Paris.

Corsin P. & Stampfli G. (1977) - La formation de Shemshak dans l'Elburz oriental (Iran) flore - stratigraphie - paléogéographie. *Geobios,* 10: 509-571.

Davoudzadeh M., Soffel H. & Schmidt K. (1981) - On the rotation of the Central-East-Iran microplate. *N. Jb. Geol. Paläont.*, 3: 180-192.

Delle G.V. (1967) - The Middle Jurassic Flora of the Tkvarchelian coal-basin (Transcaucasia). *Paleobotanika,* 6: 51-132.

Dragastan O. & Bărbulescu A. (1980) - La flore medio-Jurassique de la Dobrogea Centrale. Dări de Seamă ale Ședințelor, LXV.

Duan S. (1987) - The Jurassic flora of Zhaitang, Western Hills of Beying. Dep. Geol., Univer. Stockholm, Swed. Mus. Nat. Hist.

Edwards W.N. (1934) - Jurassic plants from New Zealand. *Ann. Mag. Nat. Hist.,* 13 (10): 81-109.

Endo S. (1952) - *Klukia* remains newly found in Japan. *Palaeobotanist,* 1: 165-167.

Fakhr M.S. (1977) - Contribution a l'étude de la flore Rhéto, Liasique de la formation de Shemshak de l'Elbourz (Iran). *Mém. Sec. Sci.,* 5, Paris, 178 pp.

Fürsich F.T., Wilmsen M. & Seyed-Emami K. (2009) - Lithostratigraphy of the Upper Triassic-Middle Jurassic Shemshak Group of northern Iran. In: Brunet M.-F., Wilmsen M. & Granath J. W. (Eds) - South Caspian to Central Iran Basins. Geol. Soc., London, Spec. Pub., 312: 129-160.

Halle T.G. (1908) - Zur Kenntnis der mesozoischen Equisetales Schwedens. *Kung. Svens. Vetensk. Hand.,* 43 : 1-56.

Harris T.M. (1932) - The fossil flora of Scoresby Sound East Greenland, Part 2. Description of seed plants incertae sedis together with a discussion of certain Cycadophyte cuticle. *Medd. Grön.,* 85(3) : 1-112.

Harris T.M. (1946) - Notes on the Jurassic flora of Yorkshire, 25-27. 25: *Stenopteris nitida* sp. n., 26: *Sphenopteris metzgerioides* sp. n., 27: *Pseudoctenis herriesi* sp. n. *Ann. Mag. Nat. Hist.,* 11(12): 820-835.

Harris T.M. (1947) - Notes on the Jurassic flora of Yorkshire, 34 : *Neocalamites nathorsti* Erdtman, 35: *Annulariopsis simpsoni* (Phillips) comb. nov., 36: *Ctenis reedi* sp. nov. *Ann. Mag., Nat., Hist.*, 11 (13): 649-662.

Harris T.M. (1961) - The Yorkshire Jurassic Flora I. Tallophyta-Pteridophyta. Brit. Mus. (Nat. Hist.), London, 212 pp.

Harris T.M. (1964) - The Yorkshire Jurassic flora II. Caytoniales, Cycadales and Pteridosperms. Brit. Mus. (Nat. Hist.), London.

Harris T.M. (1969) - The Yorkshire Jurassic Flora III. Bennettitales. Brit. Mus. (Nat. Hist.), London, 186 pp.

Harris T.M. (1979) - The Yorkshire Jurassic Flora, V. Coniferales. Brit. Mus. (Nat. Hist.), London, 166 pp.

Harris T.M., Millington W. & Miller J. (1974) - The Yorkshire Jurassic Flora IV-1. Ginkgoales, 2. Czekanowskiales. Brit. Mus. (Nat. Hist.), London.

Hirschfeld H.O. (1935) - A connection between correlation and contingency. *Proc. Cambridge Philos. Soc.*, 31: 520-524.

Jacob K. & Shukla B.N. (1955) - Jurassic plants from the Saighan Series of northern Afghanistan and their palaeoclimatological palaeogeographical significance. *Mem. Geol. Surv. India, Palaeont. Indica.,* N. S., 33(2): 1-64.

Kawasaki S. (1926) - Addition to the older Mesozoic plants in Korea. *Bull. Geol. Sur. Chosen (Korea) Keizyo*, 4(2): 1-35.

Khadem-Alhoseini S.R., Razavi B. & Jarahi A. (1989) - Primarily report of the exploration of thermal coals in the North Kouchekali area (unpublished report).

Kilpper K. (1964) - Über eine Rät/Lias-Flora aus dem nördlichen Abfall des Alburs-Gebirges in Nord-Iran. Teil 1: Bryophyta und Pteridophyta. *Palaeontographica B,* 114: 1-78.

Kilpper K. (1968) - Einige Bennettiteen-Blätter aus dem Lias von Karmozd-Zirab. *J. Linn. Soc. (Bot.),* 61: 129-135.

Kilpper K. (1971) - Über eine Rät/Lias-Flora aus dem nördlichen Abfall des Alburs-Gebirges in Nord-Iran. Teil II: Ginkgophyten-Belaubungen. *Palaeontographica B,* 133 (4-6): 89-102.

Lapasha C.A. & Miller C.N. (1985) - Flora of the Early Cretaceous Kootenai Formation in Montana, Bryophytes and Tracheophytes excluding conifers. *Palaeontographica B,* 196 (4-6): 111-145.

Lee H.H. (1955) - On the Age of the Yungkang Series of the Tantung coalfield in North. *Shansi. Act. Palaeont. Sinica,* 3: 25-46.

Mattei M., Giovanni Muttoni G. & Francesca Cifelli F. (2014) - A record of the Jurassic massive plate shift from the Garedu Formation of central Iran. *Geology,* 42: 555-558.

Nathorst A.G. (1878) - Beiträge zur fossilen Flora Schwedens: Über winige fossile Pflanzen von Palsjö. *Sch. E. Schweiz. Verlag. (E. Koch),* 34 pp.

Nathorst A.G. (1886) - Om floran Skanes kolförande Bildningar. I. Floran vid Bjuf. *Sver. Geol. Unders.*, 85: 85- 131.

Ôishi S. (1940) - The Mesozoic flora of Japan. *J. Sci., Hokkaido Imperial University*, 5: 123-480.

Pais J. (1998) - Jurassic plant macroremains from Portugal. *Mem. Acad. Ciên. Lisboa*, 37: 25-47.

Phillips J. (1829) - Illustrations of the geology of Yorkshire, or a description of the strata and organic remains of the Yorkshire Coast. Thomas Wilson and sons, York, 192 pp.

Phillips J. (1875) - Illustrations of the geology of Yorkshire, or a description of the strata and organic remains. Part I. The Yorkshire Coast. 3rd. Edition, Edited by Etheridge, London, 354 pp.

Pole M. (2009) - Vegetation and climate of the New Zealand Jurassic. *GFF,* 131: 105-111.

Popa M.E. (1998) - The Liassic continental flora of Romania. Systematics, Stratigraphy and Paleoecology. *Act. Bot. Hor. Buc.,* 1997-1998, 177-184.

Popa M.E. (2009) - Late Palaeozoic and Early Mesozoic continental formations of the Reşiţa Basin, Bucharest. *Edit. Univ. Bucureşti.*

Popa M.E. & Van Konijnenburg-Van Cittert J.H.A. (2006) - Aspects of Romanian Early-Middle Jurassic palaeobotany and palynology. Part VII. Successions and floras. Progress in Natural Sciences, Special Issue- Marine and non-marine Jurassic- correlation and boundary events, 16: 203-212.

Popa M.E., Javidan M. & Falahatgar M. (2012) - *Klukia exilis* (Phillips, 1829) Raciborski, 1890 emend. Harris 1961 from Ahan Sar, Shemshak Group, Iran. *Act. Palaeon. Romaniae,* 8: 33-41.

Presl K. in Sternburg C. von (1838) - Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt, Part 8, Leipzig and Prague.

Prynada B. (1933) - Jurassic plants from the Tkvarcheli carboniferous Basin in Transcaucasia. *Trans. Geol. Pros. Serv. U.S.S.R.,* Moscow [in Russian].

Prynada B. (1938) - Jurassic Flora of the Emba Region. *Prob. Palaeont.,* 4: 363-404 [in Russian].

Raciborski M. (1890) - Über die Osmundaceen und Schizeaceen der Juraformation. *Bot. Jahrb.,* 13: 1-9.

Raciborski M. (1894) - Flora Kopalna ogniotrwalych Glinek Krakowskich. *Pamiet. Akad. Umiej.,* 18: 143-243.

Rees P. Mc A., Ziegler A.M. & Valdes P.J. (2000) - Jurassic phytogeography and climate: new data and model comparison. In: Huber B.T., Macleod K.G. & Wing S.L. (Eds) - Warm Climates in Earth History: 297-318. Cambridge University Press, Cambridge.

Saadatnejad J., Ghaderi A. & Naeemi-Ghasbian N. (2010) - Study and presentation of Toarcian-Bajocian plant macrofossils of Gorakhk- Shandiz region, NE of Iran. *Sedim. Facies,* 2(2): 173-203 [in Persian].

Sadovnikov G.N. (1976) - The Mesozoic flora of Alborz and central Iran and its stratigraphic importance. National Iran Steel Company of Iran, Tehran.

Sadovnikov G.N. (1984) - Die Flora der Kohleformation des Elburs. III. Gheshlagh-Flora, Atlas. *Akad. Nauk SSSR, Inst. Geol.*, N 839-840 (In Russian).

Sadovnikov G.N. (1991)- On some gymnosperms from the late Triassic of North Iran. *Paleont. J.,* 4: 95-106 [in Russian].

Saporta G. (1872-1873) - Paléontologie française ou description de fossils de la France, Plantes Jurassiques. I. Algues, equisetacées, characées, fougères.

Saporta G. (1886-1891) - Paléontologie française ou description de fossils de la France, Plantes Jurassiques. III.

Scanu G.G., Kustatscher E. & Pittau P. (2012) - The Jurassic plant fossils of the Lovisato Collection. Preliminary notes. *Boll. Soc. Paleontol. It.*, 51: 71-84.

Scanu G.G., Kustatsher E. & Pittau P. (2013) - Jurassic Plants of Sardinia: an overview with new data. In: Baldanza A. & Monaco P. (Eds) - Giornate di Paleontologia XIII edizione-Perugia 23-25 Maggio. Volume dei Riassunti: 116-117.

Scanu G.G., Kustatscher E. & Pittau P. (2015) - The Jurassic flora of Sardinia - A new piece in the palaeobiogeographic puzzle of the Middle Jurassic. *Rev. Palaeob. Palyn.,* 218: 80-105.

Schweitzer H.J. & Kirchner M. (1995) - Die rhäto-jurassischen Floren des Iran und Afghanistans. 8. Ginkgophyta. *Palaeontographica B,* 237 (1-3): 1-58.

Schweitzer H.J. & Kirchner M. (1996) - Die rhäto-jurassischen Floren des Iran und Afghanistans 9. Coniferophyta. *Palaeontographica B*, 238(4-6): 77-139.

Schweitzer H.J. & Kirchner M. (1998) - Die rhäto-jurassischen Floren des Iran und Afghanistans. 11. Pteridospermophyta und Cycadophyta I. Cycadales. *Palaeontographica B,* 248 (1-3): 1-85.

Schweitzer H.J. & Kirchner M. (2003) - Die rhäto-jurassischen Floren des Iran und Afghanistans 13. Cycadophyta. III. Bennettitales. *Palaeontographica B,* 264 (1-6): 1-166.

Schweitzer H.J., Van Konijnenburg-Van Cittert J.H.A. & Van Der Burg J. (1997) - The Rhaeto-Jurassic flora of Iran and Afghanistan 10. Bryophyta, Lycophyta, Sphenophyta, Pterophyta-Eusporangiate and Protoleptosporangiate. *Palaeontographica B,* 243: 103-192.

Schweitzer H.J., Kirchner M. & Van Konijnenburg-Van Cittert J.H.A. (2000) - The Rhaeto-Jurassic flora of Iran and Afghanistan 12. Cycadophyta II. Nilssoniales. *Palaeontographica B,* 279 (1-6): 1-108.

Schweitzer H.J., Schweitzer U., Kirchner M., Van Konijnenburg-Van Cittert J.H.A. & Van Der Burg J. & Ashraf R.A. (2009) - The Rhaeto-Jurassic flora of Iran and Afghanistan 14. Pterophyta, Leptosporangiatae. *Palaeontographica B,* 279(1-6): 1-108.

Sengör A.M.C. (1979) - Mid-Mesozoic closure of Permo-Triassic Tethys and its implications. *Nature,* 279: 590-593.

Sengör A.M.C. (1990) - A new model for the late Paleozoic-Mesozoic tectonic evolution of Iran and implications for Oman. In: Robertson A.H.F., Searle M.P. & Ries A.C. (Eds) - The geology and tectonics of the Oman region. Geol. Soc. London, Special Publ., 49: 797-831.

Seward A.C. (1898) - Fossil plants for students of Botany and Geology, vol. 1. Cambridge University Press, 452 pp.

Seward A.C. (1900) - The Jurassic flora I. The Yorkshire Coast. Catalogue of the Mesozoic plants in the Department of Geology, vol. 3. Brit. Mus. (Nat. Hist.), London, 341 pp.

Seward A.C. (1912) - Mesozoic plants from Afghanistan and Afghan-Turkistan: Memoirs of the Geological survey of India, *Palaeontol. Indica, n. s.*, 4(4): 1-57.

Seyed-Emami K., Fúrsich F. T. & Wilmsen M. (2001) - Documentation and Significance of Tectonic events in the northern Tabas Block (East-Central Iran) during the Middle and Late Jurassic. *Riv. It. Paleontol. Strat.,* 110(1): 163-171.

Shahabpour J. (1998) - Liesegang blocks from sandstone beds of the Hojedk Formation, Kerman, Iran. *Geomorphology,* 22: 93-106.

Sitholey R.V. (1940) - Jurassic plants from Afghan-Turkistan. *Palaeontol. Indica, n. s.,* 29(1): 1-25.

Soffel H., Davoudzadeh M. Rolf C. & Schmidt S. (1996) - New palaeomagnetic data from Central Iran and a Triassic palaeoreconstruction. *Geolog. Runds.*, 85: 293-302.

Sørensen T. (1957) - A method of establishing groups of equal amplitude in plant society based on similarity of species and its application to analyses of the vegetation on Danish commons. *Biol. Skr./ Kong. Dan. Videns. Sels.,* 5 (4): 1-34.

Stanislavski F.A. (1957) - Jurassic Flora of the Don Basin and Dnieper-Donetz region. *Kiev. Acad. Sci. Ukraine.*

Sze H.C. (1933) - Mesozoic plants from Kansu. *Mem. Nat. Res., Inst. Geol.,* 13: 65-76.

Sze H.C. (1949) - Die mesozoischen Flora aus der Hsiangchi Kohlen Serie in West Hupeh. *Palaeontol. Sinica (n. s., A),* 2: 1-71.

Sze H.C. (1952) - Pflanzenreste aus dem Jura der Inneren Mongolei. *Sci. Rec.,* 5: 183-190.

Takin M. (1972) - Iranian geology and continental drift in the Middle East. *Nature*, 235: 147-150.

Thomas H.H. (1911) - The Jurassic flora of Kamenka in the Distrcit of Isium. *Mém. Com. Géol., n. s.,* 71: 1-95.

Thomas H.H. (1912) - *Stachypteris Hallei*, a new Jurassic Fern. *Proc. Cambridge Phil. Soc.,* 16: 610-614.

Tipper G.H. (1921) - The geology and mineral resources of eastern Persia. *Rec. Geol. Sur. India,* 53(1): 51-80.

Vaez-Javadi F. (2008) - Plant macrofossils of Iran. Tehran. Dep. Envir. Press, Tehran, 236 pp. [in Persian].

Vaez-Javadi F. (2011) - Middle Jurassic flora from the Dansirit Formation of the Shemshak Group, Alborz, north Iran. *Alcheringa,* 35(1): 77-102.

Vaez-Javadi F. (2012) - Plant macrofossils from Tiar area, South Amol, dating and correlation with the other florizones of Iran. *Geosciences,* 21(83): 229-237 [in Persian].

Vaez-Javadi F. (2014) - Triassic and Jurassic Floras and Climate of Central-East Iran. Geological Survey of Iran, Rahi publication, Tehran, 254 pp.

Vaez-Javadi F. (2015) - Plant macrofossils and Biostratigraphy of the Calshaneh section, NW Tabas and its palaeoclimate analysis. *J. Strat. Sed. Res., Esfahan*, 61(4): 105-123 [in Persian].

Vaez-Javadi F. & Pour-Latifi A. (2004) - Study of Golmakan's plant macrofossils, North-East of Iran. *Geosciences,* 51/52: 98-107 [in Persian].

Vaez-Javadi F. & Mirzaei-Ataabadi M. (2006) - Jurassic plant macrofossils from the Hojedk Formation, Kerman area, east-central Iran. *Alcheringa,* 30: 63-96.

Vaez-Javadi F. & Abbasi N. (2012) - Plant macrofossils from the Baladeh area (Central Alborz), dating and biostratigraphy. *J. Strat. Sed. Res., Esfahan*, 48(3): 37-64 [in Persian].

Vaez-Javadi F. & Abbasi N. (2018) - Middle Jurassic biostratigraphy of plant macro and microfossils in Soltanieh Mountains, south of Zanjan, NW Iran. *Geosciences,* 106: 91-102.

Vaez-Javadi F. & Allameh M. (2015) - Biostratigraphy of the Bazehowz Formation at its Type section, SW Mashhad based on plant macrofossils. *Geopersia*, 5(1): 27-44.

Vaez-Javadi F. & Namjoo S. (2016) - Plant Macrofossils and Biostratigraphy of the Hojedk Formation at the North Kouchekali, West Tabas and its Climate analysis. *Paleont. Univ. Ferdowsi, Mashhad,* 3(2): 220-243 [in Persian].

Vakhrameev V.A. (1964) - Jurassic and Early Cretaceous floras of Eurasia and contemporary Palaeofloristic provinces. *Nauka, Moskow* [in Russian].

Vakhrameev V.A. (1991) - Jurassic and Cretaceous floras and climates of the Earth. Cambridge University Press, Cambridge, 318 pp.

Van Konijnenburg-van Cittert J.H.A. (2008) - The Jurassic fossil plant record of the UK area. *Proc. Geol. Assoc.*, 119: 59-72.

Van Konijnenburg-van Cittert J.H.A. & Morgans H.S. (1999) - A guide to the Yorkshire Jurassic flora. Palaeont. Assoc. Field Guides to Foss., 8.

Vozenin-Serra C. & Franceschi de D. (1999) - Flore du Trias supérieur du Viêtnam (bassins houillers du Quang-Nam et de Hongay. *Palaeontographica B,* 249(1-6): 1-62.

Walkom A.B. (1921) - Mesozoic Floras of New South Wales. Part 1- Fossil plants from Cockabutta Mountain and Talbragar. *Mem. Geol. Sur. New South Wales, Paleont.,* 12: 1-21.

Ward L.F. (1900) - Status of the Mesozoic floras of the United States. First paper. The older Mesozoic. *Rep. Unit. Stat. Geol. Sur.,* 20 (2): 211-430.

White M.E. (1981) - Revision of the Talbragar Fish Bed Flora (Jurassic) of New South Wales. *Rec. Austr. Mus.,* 33 (15): 695-721.

Wilmsen M., Fürsich F.T., Seyed-Emami K. & Majidifard M.R. (2009) - An overview of the stratigraphy and facies development of the Jurassic System on the Tabas Block, east-central Iran. *Geol. Soc. London. Spec. Publ.*, 312: 323-343.

Wu S.Q., Ye M.N. & Li B.X. (1980) - Upper Triassic and Lower and Middle Jurassic plants from the Hsiangchi Group, western Hubei. *Mem. Nanj. Inst. Geol. Paleont., Acad. Sinica.,* 14: 63-131 [in Chinese].

Yokoyama M. (1890) - Jurassic plants from Kaga, Hida and Echizen. *J. Coll. Sci. Imp. Univ. Tokyo,* 3(1): 1-66.

Yokoyama M. (1906) - Mesozoic Plants from China. *J. Coll. Sci. Imp. Univ. Japan,* 21(9): 1-39.

Zanchetta S., Berra F., Zanchi A., Bergomi M., Caridroit M., Nicora M. & Heidarzadeh G. (2013) - The record of the Late Palaeozoic active margin of the Palaeotethys in NE Iran: constraints on the Cimmerian orogeny. *Gondwana Res.,* 24: 1237-1266.

Zanchi A., Malaspina N., Zanchetta S., Berra F., Benciolini L., Bergomi M., Cavallo A., Javadi H.R. & Kouhpeyma M. (2015) - The Cimmerian accretionary wedge of Anarak, Central Iran. *J. Asian Earth Sci.,* 102: 45-72.

Zanchi A., Zanchetta S., Balini M. & Ghassemi M.R. (2016) - Oblique convergence during the Cimmerian collision: evidence from the Triassic Aghdarband Basin, NE Iran. *Gondwana Res.,* 38: 149-170.

Zanchi A., Zanchetta S., Berra F., Mattei M., Garzanti E., Molyneux S., Nawab A. & Sabouri J. (2009a) - The Eo-Cimmerian (Late? Triassic) orogeny in north Iran. In: Brunet M.F., Wilmsen M. & Granath J.W. (Eds) - South Caspian to Central IranBasins. *Geol. Soc. London, Spec. Pub.,* 312: 31-55.

Zanchi A., Zanchetta S., Garzanti E., Balini M., Berra F., Mattei M. & Muttoni G. (2009b) - The Cimmerian evolution of the Nakhlak-Anarak area, central Iran, and its bearing for the reconstruction of the history of the Eurasian margin. In: Brunet M.F., Wilmsen M. & Granath J.W. (Eds) - South Caspian to Central Iran Basins. *Geol. Soc. London, Spec. Pub.,* 312: 261-286.

Ziegler A.M., Parrish J.M., Jiping Y., Gyllenhaal E.D., Rowley D.B., Parrish J.T., Shangyou N., Bekker A. & Hulver M.L. (1993) - Early Mesozoic Phytogeography and Climate. *Philos. Trans. Roy. Soc. London B*, 28, 341: 297-305.

Zigno A. de (1856-1885) - Flora Fossilis Formationis Oolithicae. Le Plante Fossili dell'Oolite. 2 vols. Padova.