KLUKIA EXILIS (PHILIPS 1829) RACIBORSKI 1890 EMEND. HARRIS 1961 FROM AHAN SAR, SHEMSHAK GROUP, IRAN

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Abstract A new occurrence of the Schizaeaceous fern *Klukia exilis* (Philips 1829) Raciborski 1890 emend. Harris 1961 is identified in Ahan Sar, a new fossiliferous locality in the Amol area, Mazandaran Province, in Alborz Mountains, Northern Iran. These fossils were collected from a section close to a coal mine in Ahan Sar, included in the Triassic-Jurassic coal bearing Shemshak Group, indicating the Middle Jurassic age of the local sedimentary sequence, most probably the Dansirit Formation, equivalent of the classical Upper Carbonaceous Series of the Shemshak Formation. The studied material includes both sterile and fertile material, represented by compressed, immature frond fragments of *Klukia exilis*. This paper discusses the morphological variations of this fern species, together with a discussion on its previous paleobotanical descriptions and occurrences, *Klukia exilis* having a wide distribution as it represents an important stratigraphical marker for the Middle Jurassic.

Keywords: *Klukia exilis*, Schizaeaceae, Filicopsida, Ahan Sar, Shemshak Group, Jurassic, Alborz Mountains, Iran.

INTRODUCTION

The Triassic-Jurassic compressive flora of Iran is one of the most important floras of this age in the world, both in terms of diversity and preservation, studied since the XIX-th Century by Göppert (1861), Stur (1886), and Schenk (1887). These early works were continued by a series of contributions provided by Krasser (1891), Zeiller (1905), Boureau et al. (1950), Lorenz (1964), Kilpper (1964, 1968, 1971, 1975), Alavi and Barale (1970), Barnard (1965, 1967, 1968), Barnard and Miller (1976), Cartier (1971), Poliansky et al. (1975), Fakhr (1977), Corsin and Stampfli (1977), Boersma and Van Konijnenburg – van Cittert (1991). During later years, the papers of Schweitzer (1977, 1978a, 1978b), Schweitzer and Kirchner (1995, 1996, 1998, 2003), Schweitzer et al. (1996, 2000, 2009), Sadovnikov (1980, 1991) and of Vaez-Javadi (2002, 2006, 2012a, 2012b), Vaez-Javadi and Ghavidel-Syooki (2002), Vaez-Javadi and Pour-Latifi (2002, 2004), Vaez-Javadi and Mirzaei-Ataabadi (2006), Vaez-Javadi and Abbasi (2012), Mirzaei-Ataabadi et al. (2005) and Saadat-Nejad et al. (2010) contributed to the knowledge of the Triassic-Jurassic flora of Iran.

In northern Iran (Alborz Mountains), this flora is confined to the terrestrial, coal bearing Shemshak Group, defined by Assereto (1966) as having a formation rank (Shemshak Formation), with its stratotype in Ruteh Valley, close to Shemshak, north of the Lar Valley (central Alborz). Towards central and eastern Iran (Kerman region), the flora is confined to various continental, coal bearing formations similar to the Shemshak Group, such as the Hojedk Formation (Vaez-Javadi and Mirzaei-Ataabadi, 2006). Initially, the age of the Shemshak Group was identified as Early and Middle Jurassic (Hettangian – Middle Bajocian) in age. According to Assereto (1966), the Shemshak Formation includes four general series: the lower sandstone series, the lower carbonaceous series, the upper sandstone series and the upper carbonaceous series, with various thicknesses and lateral faces developments, being about 1000 m thick and overlain by the Middle Jurassic Dalichai Formation, unconformably overlaying older formations (Assereto, 1966). Corsin and Stampfli (1977) considered the Shemshak Formation as Late Triassic (Upper Norian? – Rhaetian) to Aalenian – Bajocian? in age, as they studied it in the area of Gheshlagh, south of Gonbad Qabus and Azadshahr and east of Gorgan. The age of the Shemshak Formation, as well as its sedimentology, facies variation and distribution was discussed and re-evaluated by Fürsich et al. (2009), redefining several Late Triassic (Late Carnian) – Middle Jurassic (Middle Bajocian) marine and terrestrial formations and uniting them under the newly defined Shemshak Group. Fürsich et al. (2009) based their results on detailed fieldwork in the Alborz Mountains, using stratigraphical denominations introduced by Bragin et al. (1976), Repin (1987), and Nabavi (1980). According to Fürsich et al. (2009), the Shemshak Group reaches 4000m in thickness, and a hypostratotype was proposed at Tazareh. However, this nomenclature is not always accepted and used in Iranian literature. Schweitzer and Kirchner (1996) and Schweitzer et al. (2009) followed the stratigraphic nomenclature of Bragin et al. (1976), for the Middle Jurassic sediments of Alborz using the denomination of Dansirit Series.

This paper introduces and describes plant material collected from a new fossiliferous locality in Iran, the material being dominated by the Schizaeaceous fern *Klukia exilis* (Philips 1829) Raciborski 1890 emend. Harris 1961. The hand specimens include, besides *Klukia exilis*, rare fragments of *Podozamites* sp. and few badly preserved reproductive structures (cones) with uncertain affinities.

MATERIAL AND METHODS

The fossils described in this paper were collected from a new fossil locality, from a sedimentary sequence occurring next to a former coal mine at about 700m south of Ahan Sar village (Fig. 1), 81km south of Amol, northeast of Damavand Mountain, best accessed from the Amol-Tehran road, central Alborz, in Mazandaran Province. Here, the upper sequence of the Shemshak

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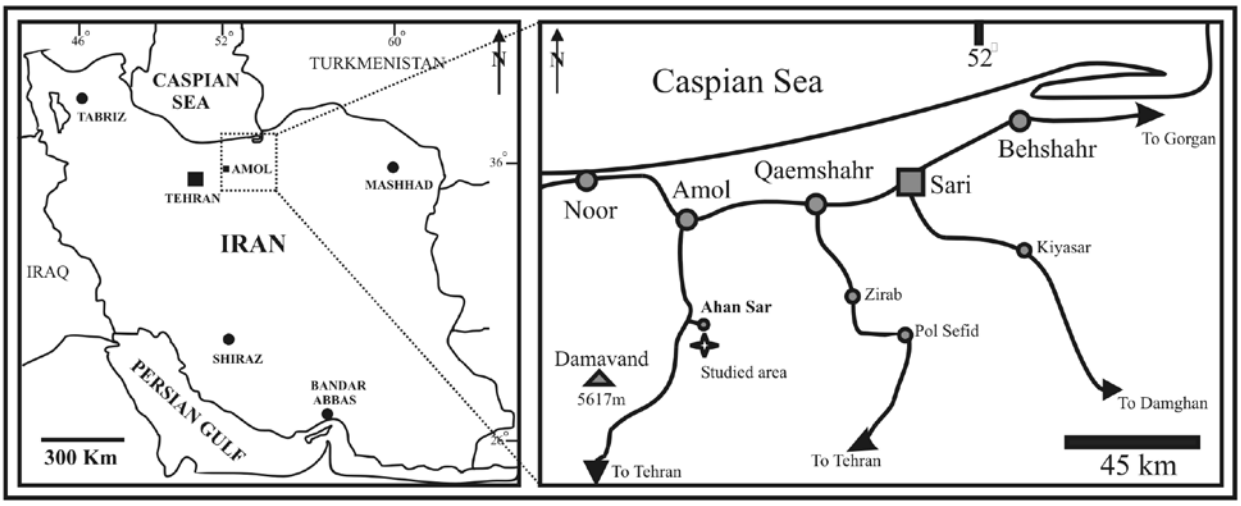

Fig. 1 Occurrence of the new fossiliferous locality Ahan Sar in Mazandaran Province, Alborz Mountains, Northern Iran.

Group outcrops for about 200m thick and starts with dark grey sandstones and shales, followed by conglomerates, microconglomerates, coals and black shales (Fig. 2). The base of the sequence is covered, its relations with older formations are unknown, while the top of the succession records the unconformity between the Shemshak Group and the Upper Jurassic Lar Formation. The fossils were collected from a sequence belonging to the top of the sedimentary succession in Ahan Sar, from fine sandstones occurring stratigraphically under the disconformity between the Shemshak Group and the Upper Jurassic Lar Formation (Fig. 2), geometrically corresponding to the Dansirit Formation of the Shemshak Group.

The material is compressed, it belongs to five hand specimens collected in Ahan Sar and receiving the records nos. LPB0559 to LPB0563. These samples were sent to Bucharest and recorded within the Paleobotany Collections of the Laboratory of Palaeontology under the inventory numbers LPB0559 (with 1 leaf fragment), LPB0560 (with 4 leaf fragments), LPB0561 (which is the counterpart of sample LPB0560, with 3 leaf fragments), LPB0562 (which is the counterpart of sample LPB0563, with 2 leaf fragments) and LPB0563 (with 8 leaf fragments). The best preserved sterile fragments occur on sample LPB0561 (fragments 1-3) and LPB0560. The best preserved fertile fragments occur on sample LPB0562 (fragments 1, 2 as compressions), and LPB0563 (fragments 1, 2 as impressions and counterparts of LPB0562 fragments).

The fossils were degaged with needles and fine chisels (Fairon-Demaret et al., 1999). They were photographed using a Panasonic DMC-L10 digital camera with an Olympus Zuiko 35mm Macro lens, and also using a Carl Zeiss Stemi 2000-C dissecting microscope with a Canon digital camera and Carl Zeiss Axiovision software with a focus enhancement extension (Extended Focus module), as detailed in Popa (2011). Sporangia were degaged under dissecting microscope using needles, the obtained material being attacked with dry Schulze Reagent (Van Konijnenburg-van Cittert, 1981; Kerp, 1990, Kerp and Krings, 1999), washed, neutralized with KOH and mounted in biological slides after repeated centrifugations between each operation.

SYSTEMATICS

Extended discussions and synonymy lists dealing with *Klukia exilis* were published by Harris (1961) and Schweitzer et al. (2009). Therefore we will not detail discussions to such a degree, including in the synonymy list only papers where this species is described, discussed and illustrated in Iran, as we avoid referring in this list papers where only citations of this taxon occur.

Class Filicopsida
Order Filicales
Family Schizaeaceae
Genus *Klukia* Raciborski 1890 emend. Harris 1961
***Klukia exilis* (Philips 1829) Raciborski 1890 emend. Harris 1961**

Fig. 3a-d, Fig. 4a-d

1829 *Pecopteris exilis* Phillips, p. 148, Pl. 8, Fig. 16;
1890 *Klukia exilis* Raciborski, p. 6, Figs. 17-19;
1894 *Klukia exilis* Raciborski, p. 23-25, Pl. 7, Figs. 13, 14, 17, Pl. 8, Fig. 1-3, 7-9b, Pl. 9, Fig. 1-2, Pl. 26, Fig. 6;
1955 *Klukia exilis* Jacob and Shukla, p. 17-18, Pl. III, Fig. 18, Pl. IV, Figs 19-22;
1955 *Klukia westi* Jacob and Shukla, p. 18-19, Pl. IV, Figs. 23, 24;
1961 *Klukia exilis* Harris, p. 128-134, Text-figs. 44-46;
1964 *Klukia exilis* Benda, p. 106, Pl. 6, Fig. 2;
1975 *Klukia westi* Burakova and Smirnova, p. 126-128, Pl. 1, Figs. 1-12;
1977 *Klukia exilis* Harris, p. 7;
1977 *Klukia exilis* Fakhr, p. 54, Pl. 9, Figs. 1-3;
2004 *Klukia westi* Vaez-Javadi and Pour-Latifi, p. 100, Pl. 1, Figs. 1-3, 5, Pl. 2, Fig. 2;
2006 *Klukia exilis* Vaez-Javadi and Mirzaei-Ataabadi, p. 73-75, Figs. 3J-L, 9A, D;
2009 *Klukia exilis* H.-J. Schweitzer, U. Schweitzer, Kirchner, Van Konijnenburg – Van Cittert, Van der Burgh and Ashraf, p. 27-31, Text-fig. 2, Pl. 1, Figs. 1, 2, Pl. 2, Figs. 1-3, Pl. 3, Figs. 1-5;

2010 *Klukia exilis* Saadat-Nejad, Ghaderi, and Naimi-Ghassabian, p. 181-182, Pl. 1, Figs. 5-7;
2012 *Klukia exilis* Vaez-Javadi and Abbasi, p. 43, Pl. 3, Fig. 3.

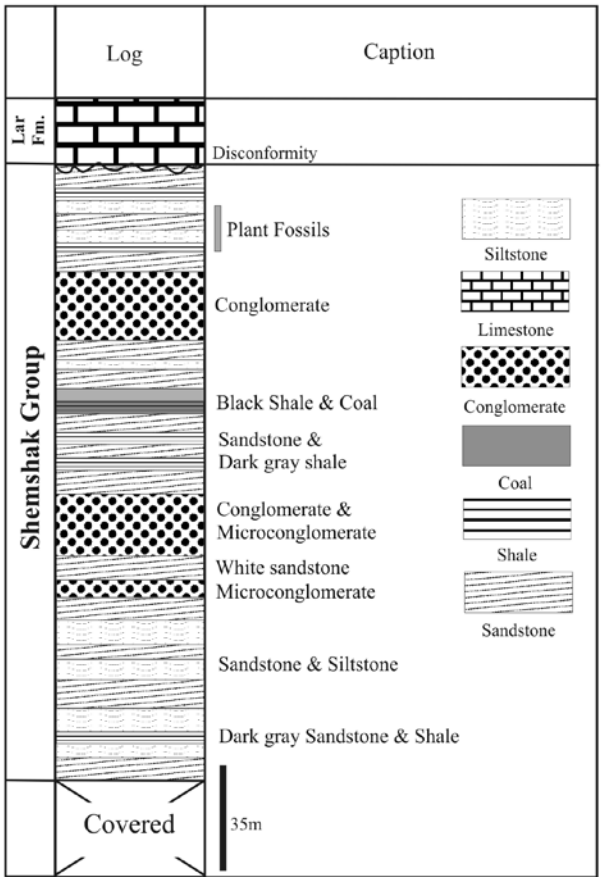

Fig. 2 Lithological log of the Shemshak Group outcroping in the new fossiliferous locality Ahan Sar, section corresponding to the Dansirit Formation, with the occurrence of the fossil plants at the top of the sequence.

DESCRIPTION

The sterile material is represented by frond fragments showing primary and secondary rachises bearing well preserved pinnules (Fig. 3a-c). The primary rachises are straight, smooth, channeled along their adaxial surface, 0.8-1,0 mm wide and 80-120 mm long, in fragmented state. The secondary rachises are also straight, channeled and unornamented, 30-40 mm long, inserted (sub)oppositely to alternately to the primary rachises, at angles between 40°-50° (Fig. 3a-c). The pinnae are 30-40 mm long and 8-12 mm wide at the base, strongly elongated in outline, and imparipinnate. Pinnules are elongated, between 3-8 mm long and 2-3 mm wide, with a decurrent base, entire margin and slightly rounded apex. The pinnule margins are bent abaxially (downwards), especially along the basal and the median parts of the pinnules, without being properly folded. The first acroscopic pinnule is always parallel with the penultimate rachis, it is constantly longer than the other pinnules along the same pinna (Fig. 3b, c). The frond is katadromic, with the basiscopic pinnule being first inserted to the secondary rachis, at about 50°, and it is usually shorter than the other pinnules, while all the basiscopic pinnules have a tendency of being slightly shorter than the acroscopic ones (Fig. 3b). The ultimate pinnule of the pinna is strongly elongated, with an undulate margin and a rounded apex (Fig. 3b). The pinnules of the last quarter of the pinna tend to become triangular as they get closer to the ultimate, terminal pinnule. The midrib is obliquely inserted to the rachis and it reaches the apex before dividing dichotomously once, having a very slight, elongated “S” shape. The secondary veins are inserted at angles between 35°-45° to the midrib, they are straight and undivided, reaching the margin without any dichotomy. Usually the secondary veins are rather elusive due to preservation reasons and for the thickness of the pinnule’s substance. The lamina is slightly depressed between the midrib and the veins.

The fertile material is similar in morphology to the sterile material (Fig. 3d, Fig. 4a-d), except the slightly more accentuated marginal bending of the fertile pinnule (Fig. 4a, b) which makes these pinnules appear slightly narrower than the sterile ones. The usual fertile pinnules show 4-6 sporangia on each side of the midrib (Fig. 3d, Fig. 4a, c-d). The first acroscopic fertile pinnules also show 4-6 sporangia distributed symmetrically along each side of the midrib (Fig. 4c, d). The sporangia are ellipsoidal, with their apex (annulus) striated radially (Fig. 4c, d). They have a median position between the midrib and the pinnule margin, occurring usually under a secondary vein, and generating a lump on the adaxial surface of the pinnule. The sporangial impressions are 0.4-0.6mm in diameter (Fig. 4c, d). No spores could be extracted from the collected sporangia. The compressions show almost no fluorescence reaction under ultraviolet light.

DISCUSSION

The new plant material from Ahan Sar assigned to *Klukia exilis* records the typical characters of this species, both for sterile and fertile material, as these characters have been extensively described and discussed by Raciborski (1890, 1894, Harris, 1977), by Jakob and Shukla (1955) from Afghanistan, Harris (1961) from Yorkshire, by Schweitzer et al. (2009), by Vaez-Javadi and Mirzaei-Ataabadi (2006) and by Saadat-Nejad et al. (2010) from Iran, among many other authors.

As peculiar characters, the Ahan Sar fossils show a marginal bending of the pinnules which is not so sharply incurved or folded inwards as that of the material discussed by Harris (1961) and Schweitzer et al. (2009), this marginal bending occurs mainly in the fertile pinnules (Fig. 4a, b), although it is encountered in sterile pinnules too. Also, spores from sporangia could not be extracted, in spite of attentive collecting and maceration. These two characters can be correlated, and they are pointing to young, immature fronds in the process of becoming fertile, but which could not yet fully develop spores and strong lateral, inward folding of pinnule margins. The lateral folding of the fertile pinnules is considered by Schweitzer et al (2009) as a morphological adaptation for supplementary protection of their large, single, abaxially attached sporangia, as extant Schizaeaceae use these as a pseudo-indusium.

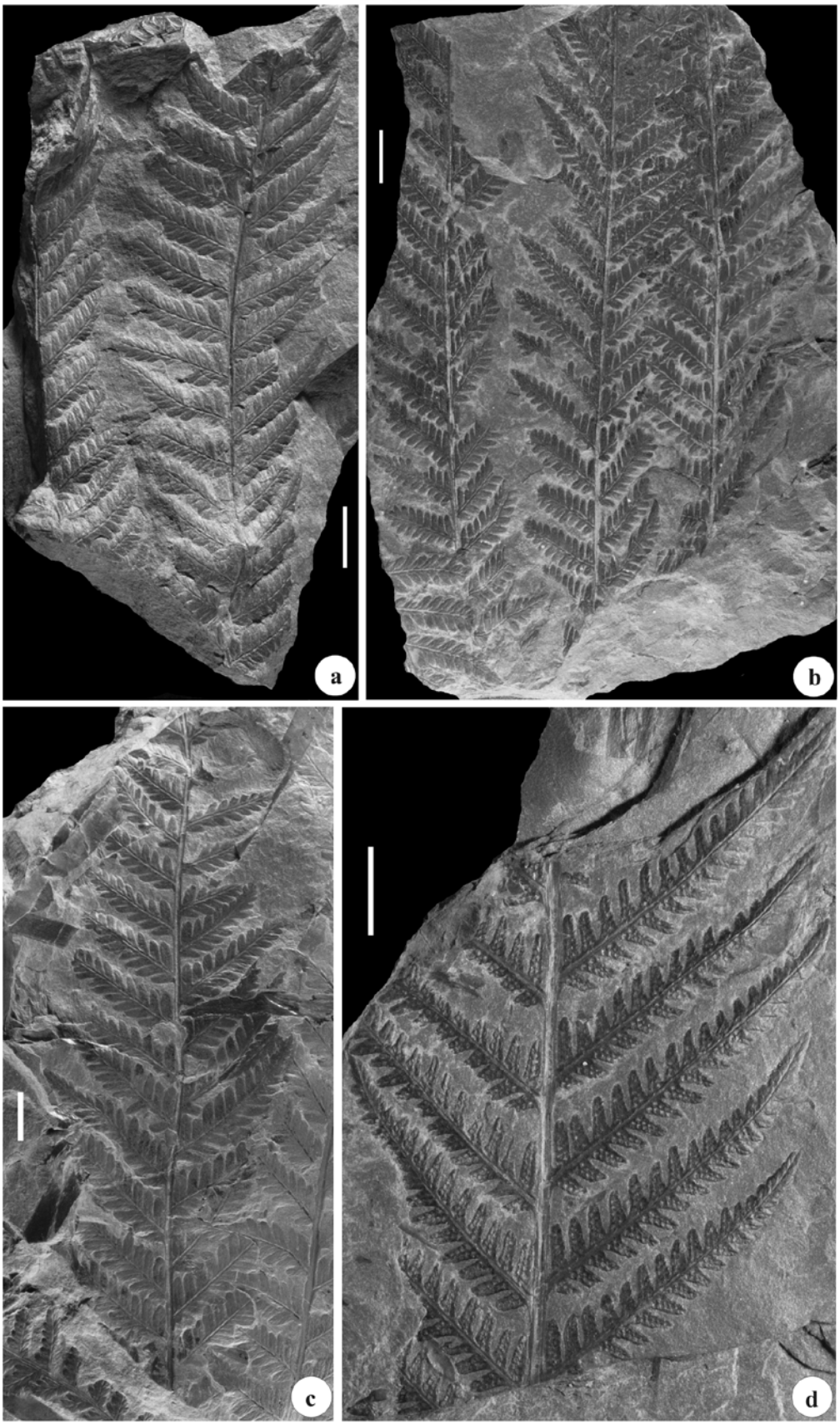

Fig. 3 *Klukia exilis*, sterile and fertile material from Ahan Sar, a new fossiliferous locality of the Mazandaran Province, Iran. **a** *Klukia exilis*, sample LPB0559, frond fragment no. 1, sterile, Ahan Sar, Iran. Scale bar: 10mm; **b** *Klukia exilis*, sample LPB0561, frond fragments nos. 1-3, sterile, Ahan Sar, Iran. Scale bar: 10mm; **c** *Klukia exilis*, sample LPB0563, frond fragment no. 2, sterile, Ahan Sar, Iran. Scale bar: 10mm; **d** *Klukia exilis*, sample LPB0562, frond fragment no. 1, fertile, Ahan Sar, Iran. Scale bar: 10mm.

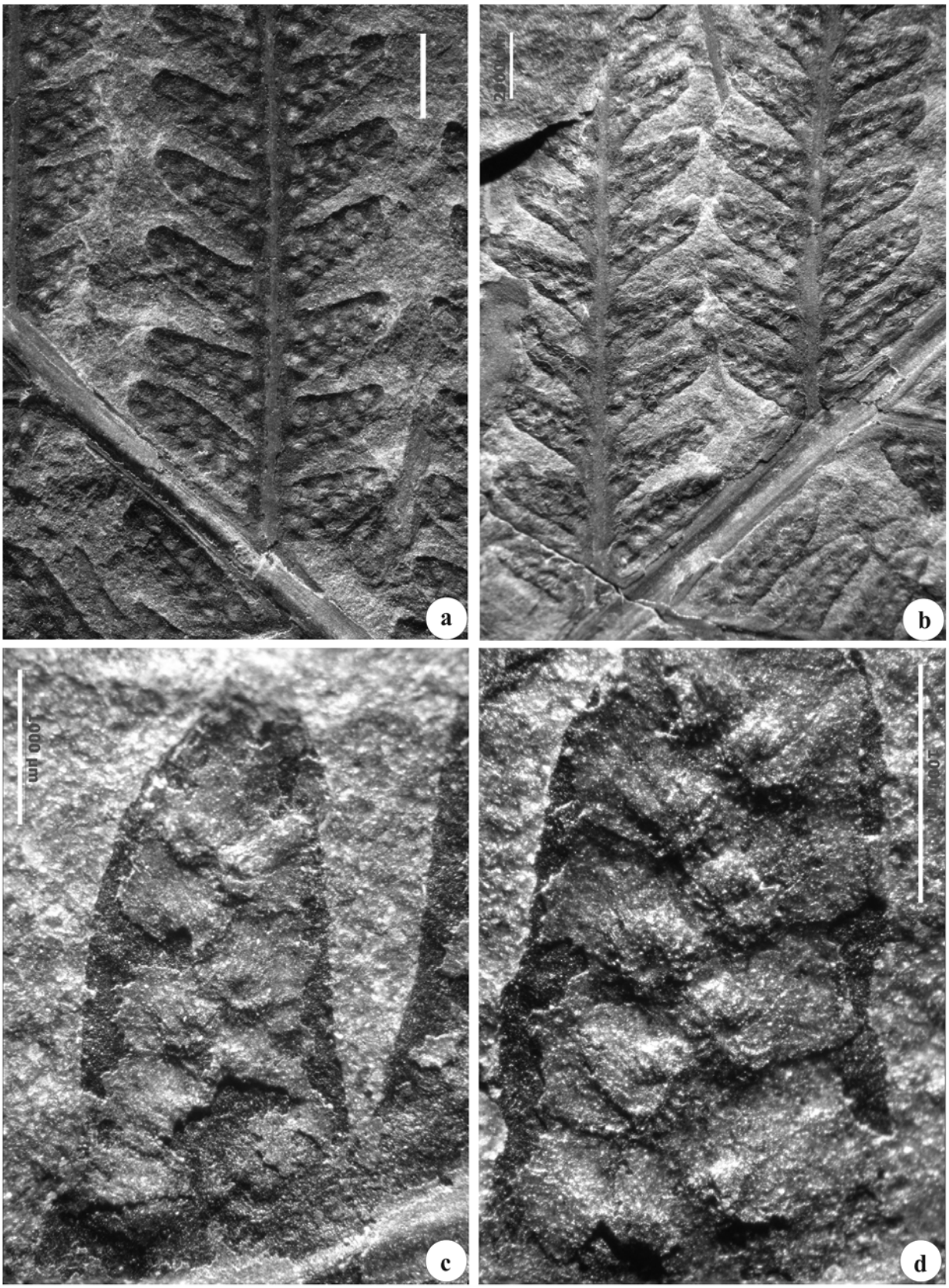

Fig. 4 *Klukia exilis*, fertile material from Ahan Sar, a new fossiliferous locality of the Mazandaran Province, Iran. **a** *Klukia exilis*, sample LPB0562, frond fragment no. 1, detail of fertile pinnules in abaxial view, Ahan Sar, Iran. Scale bar: 2mm; **b** *Klukia exilis*, sample LPB0562, frond fragment no. 1, detail of fertile pinnules in adaxial view, Ahan Sar, Iran. Scale bar: 2mm; **c** *Klukia exilis*, sample LPB0562, frond fragment no. 1, detail of a fertile pinnule in abaxial view with sporangial apices radially ornamented, Ahan Sar, Iran. Scale bar: 1mm; **d** *Klukia exilis*, sample LPB0562, frond fragment no. 1, detail of a fertile pinnule in abaxial with sporangial apices radially striated, Ahan Sar, Iran. Scale bar: 1mm.

The fist acroscopic pinnule is constantly longer in size than other pinnules of the same pinna (Fig. 3d, Fig. 4a, b) a character which was considered by Jakob and Shukla (1955) as one of the characters defining their new species *Klukia westii* from Afghanistan (Ishpushta), along with the narrower pinna shape and the lesser pinnule density along the ultimate rachis, supplementary characters which also occur in the Ahan Sar material (Fig. 3d). From this point of view, the Ahan Sar material is closer to the species *Klukia westii* Jakob et Shukla 1955, than to the typical *K. exilis* discussed by Harris (1961), Benda (1964) and Fakhr (1977). However, Schweitzer et al. (2009) considered that *Klukia exilis* and *K. westii* were conspecific, with *K. westii* a junior synonym, based on the following facts: a. the density of pinnules within various pinnae in the same frond fragment varies, b. the first acroscopic pinnules are also larger in typical *Klukia exilis* fossils described before 1955 elsewhere in the world, and c. the outlines of the pinnae also varies within large limits in *K. exilis*. These characters also vary in the Ahan Sar material, especially the density of pinnules, in the case of fertile versus sterile fragments, due as well as to the lateral shrinking (thinning) of pinnules, when gradually becoming fertile. This is the reason for which the Ahan Sar material is assigned in this paper to *Klukia exilis*.

Klukia exilis has been cited, described and illustrated from Iran by several authors, both from Alborz Mountains and Kerman area, as Schweitzer et al. (2009) gave details with regard to these occurrences. Furon (1941), Hückriede et al. (1962), Assereto and Barnard (1968), Poliansky et al. (1975), Arjang (1975), Barnard and Miller (1976), Schweitzer (1978a), Sadovnikov (1980) and Achilles et al. (1984) cited *Klukia exilis* in their publications. Farshad (1960), Fakhr (1977), Vaez-Javadi and Pour-Latifi (2004), Vaez-Javadi and Mirzaei-Ataabadi (2006), Schweitzer et al. (2009), and Saadat-Nejad et al. (2010) described and illustrated this species in detail, while Vaez-Javadi and Abbasi (2012) illustrated it. The material shows no affinities with other *Klukia* species. Vaez-Javadi and Mirzaei-Ataabadi (2006) defined *Klukia crenata*, a peculiar *Klukia* species of the Hojedk Formation (Kerman area), but the Ahan Sar material shows no crenulation of such amplitude as that of *K. crenata*.

OCCURRENCE AND STRATIGRAPHY

In Iran, *Klukia exilis* has been cited and described from several localities, as Schweitzer et al. (2009) and Vaez-Javadi and Mirzaei-Ataabadi (2006) synthesized: Ferizi (Fakhr, 1977), Mazino mine (Tabas, Vassiliev, 1985), Gorakhk-Shandiz area (Saadat et al., 2010), Baladeh (Central Alborz, in Vaez-Javadi and Abbasi, 2012) and Golmakan (Eastern Alborz Mountains, in Vaez-Javadi and Pour-Latifi, 2004). Schweitzer et al. (2009) cited this species from all Lower Middle Jurassic age localities from Iran (Alborz Mountains and Kerman area). In northern Afghanistan, *Klukia exilis* was reported from Ishpushta and Kohana Qeslaq (from the Saighan Series, in Jacob and Shukla, 1955, Benda, 1964), Doab, Dahana-i-Tor, Chail Valley (Seward, 1912; Schweitzer et al., 2009). The species was reported from Turkmenistan (Seward, 1907), Uzbekistan (South Fergana), Kazakhstan (Emba), Tadjikistan (as *K. westi*, in Burakova and Smirnova, 1975), and from Georgia (Tkibuli, Tkvarcheli, in Prynada, 1933; Delle, 1967).

Klukia exilis was defined (Raciborski, 1890) and detailed (Raciborski, 1894, Harris, 1977) from Grojec, in central Poland, where it is Middle Jurassic in age. Further European occurrences were reported in United Kingdom (Yorkshire, from Gristhorpe, Cloughton and Beast Cliff, in Harris, 1961; Van Konijnenburg-van Cittert, 1981), Sardinia, and Ukraine (Donets Basin, Kamenka, in Thomas, 1911; Stanislavski, 1957), and Russia (Southern Russia, in Thomas, 1911; Stanislavski, 1957). Gordenko (2008) cites *Klukia exilis* occurrences in Middle Jurassic deposits of the Eurosinian Region.

In the rest of Asia, outside of the peri-Caspian region, species of *Klukia* were reported from Israel (Negev), Eastern Russia (Bureja Basin, Amur, in Vakhrameev, 1975, 1991), China (Zhou, 1995, Deng and Shang, 2000), Japan (with several occurrences in both Inner and Outer zones of Japan, in Oishi, 1940; Endo, 1952; Kimura, 1980), and Canada (Bell, 1956).

Barnard (1973) and Vozenin-Serra and Taugourdeau-Lanz (1985) detailed the distribution of *Klukia exilis* in the world, as well as its stratigraphic significance for the Middle Jurassic interval.

Klukia exilis is considered a typical, marker taxon for the lower Middle Jurassic (Aalenian-Bajocian) in Iran and Afghanistan (Schweitzer et al., 2009). Not only its macroscopical remains but also its dispersed spores, *Ischyosporites variegatus* (Couper 1958) Schulz 1967, are very good markers for the Middle Jurassic in Asia (Arjang, 1975; Ashraf, 1977, Schweitzer et al, 1987, 2009).

CONCLUSIONS

Klukia exilis (Philips 1829) Raciborski 1890 emend. Harris 1961 is reported from Ahan Sar, a new fossil plant occurrence in Alborz Mountains, Northern Iran. The fossils are represented by immature, sterile and fertile frond fragments, the fertile fragments showing an abaxial curving of the pinnule margins, without an inward, typical folding, and they lack spores. The material is well preserved in fine sandstones belonging to the Shemshak Group, Dansirit Formation, equivalent of the Upper Carbonaceous Series in the classic definition of the Shemshak Formation by Assereto, 1966, and it is a valuable marker for the lower Middle Jurassic (Aalenian-Bajocian) interval.

ACKNOWLEDGEMENTS

The authors wish to thank to Professor Johanna J. H. A. van Konijnenburg – van Cittert (Leiden and Utrecht Universities), to Dr. Maria Barbacka (Natural History Museum, Budapest), for their valuable and constructive peer-reviews, and to Professor Ioan I. Bucur (Babes-Bolyai University, Cluj-Napoca), for helpful advice regarding the manuscript.

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