Revista Brasileira de Paleontologia, 25(2):135–143, Abril/Junho 2022
A Journal of the Brazilian Society of Paleontology

doi:10.4072/rbp.2022.2.03

TWO NEW SPECIES OF *DICTYOZAMITES* (BENNETTITALES) FROM THE RHAETIC KALARIZ FORMATION, NORTH OF IRAN

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ABSTRACT – *Dictyozamites barnardi* sp. nov. and *Dictyozamites fakhri* sp. nov. are the second and third species of *Dictyozamites* to be described from Iran and the Middle East. They derive from the Rhaetic Kalariz Formation (Shemshak Group) of the Ramsar area, Alborz Mountains, North of Iran. *Dictyozamites barnardi* sp. nov. is distinguished especially by the short and curved to strongly falcate pinnae and clearly auriculate bases and *Dictyozamites fakhri* sp. nov. is distinguished particularly by its long, slightly falcate and very elongated triangular pinnae, opposite to sub opposite pinnae position and clearly auriculate.

Keywords: *Dictyozamites*, Rhaetian, Kalariz Formation, Iran.

RESUMO – *Dictyozamites barnardi* sp. nov. e *Dictyozamites fakhri* sp. nov. são a segunda e terceira espécies de *Dictyozamites* a serem descritas para o Irã e o Oriente Médio. Elas derivam da Formação Kalariz (Grupo Shemshak, Rético) da área de Ramsar, Alborz Mountains, Norte do Irã. *Dictyozamites barnardi* sp. nov. distingue-se especialmente pelas pinas curtas e curvas a fortemente falcadas e bases claramente auriculadas e *Dictyozamites fakhri* sp. nov. distingue-se particularmente pelas suas pinas triangulares longas, ligeiramente falcadas e muito alongadas, opostas à posição das pinas subpostas e claramente auriculadas.

Palavras-chave: *Dictyozamites*, Rético, Formação Kalariz, Irã.

INTRODUCTION

The Bennettitales are a large group of extinct plants well known from the fossil record. Representatives range from the late Permian (Blomenkemper *et al*., 2021) to the Oligocene? (McLoughlin & Pott, 2011) and are widely distributed in both Northern and Southern Hemispheres (Taylor & Taylor, 1993). But they have been often recorded from the Mesozoic Era. One of the rare genera of this class is *Dictyozamites*, which was erected by Oldham (in Oldham & Morris, 1863, p. 40) based on two specimens described by Morris (in Oldham & Morris, 1863, p. 38, pl. 24, figs. 1, 2) as *Dictyopteris falcata* and *Dictyopteris falcata* var. *obtusifolia*. This genus was previously represented by only one very rare species in Iran and the Middle East: *Dictyozamites asseretoi,* of Rhaetian age. So far, several studies have been conducted on plant macrofossils in Ramsar coal-bearing basin, and all of them confirm a Norian–Rhaetian age for sedimentary beds (Sadovnikov 1976, 1989, 1991; Moienosadat & Zadehkabir, 1992; Schweitzer & Kirchner, 1998; Saadatnejad 2006, 2017).

Dictyozamites has been documented from Iran by six authors in seven papers or reports, namely Barnard (1965), Assereto *et al*. (1968), Sadovnikov (1976, 1983), Vassiliev (1984), Vaez-Javadi (2012), and Saadatnejad (2017).

Barnard (1965) established *Dictyozamites asseretoi* as a new species and reported it from the Doroud area, upper Djadjerud valley, central Alborz Mountains and from the lower carbonaceous series, which is the second lithological unit of the Shemshak Formation. He argued that the age of this unit and the underlying "lower sandstone" are Early Jurassic (Barnard, 1965, p. 1125–1128). Assereto *et al*. (1968) mentioned *D. asseretoi* in a list (tab. 1b) indicating its occurrence at Doroud as reported by Barnard (1965). Sadovnikov (1976) cited the species *D. asseretoi*, *Dictyozamites* sp. A and *Dictyozamites* sp. B in a list without figures, locality, stratigraphy position, or age. Sadovnikov (1983) reported *Dictyozamites asseretoi* from the Kalariz series (Tazareh Formation, Shemshak Group) of the Schachduck area (Alborz Mountains). The age of this series is Rhaetian. Vassiliev (1984) reported *Dictyozamites asseretoi* from the Parvadeh coal mine (Tabas coal-bearing Basin) of central Iran in the Ghadir Member (Rhaetian) of the Nayband Formation (Carnian–Rhaetian). Vaez-Javadi (2012) also reported this species from the Parvadeh coal mine, citing Vassiliev (1984). The last report of the change to the *Dictyozamites* genus was by Saadatnejad (2017) as *D. asseretoi* and *Dictyozamites* sp. from the Kalariz Formation (Rhaetian), Shemshak Group (Late Carnian–Early Bajocian) of Kenar-Rud coal mine (Ramsar coal-bearing basin) of northern Iran.

Thus, the only formally defined species of this genus reported from Iran is *Dictyozamites asseretoi.* In this study, two new species from Iran are established. So far, confident records of *Dictyozamites* have been reported only from Rhaetic deposits in Iran.

MATERIAL AND METHODS

The material described in this work (prefixed **SRKJ** and **SRKR**) is held in the Laboratory of Paleontology, Faculty of Geology, University of Tehran, Tehran, Iran. Specimens were photographed with a Nikon SMZ 1000 microscope and Samsung J5Pro mobile phone, then photos enhanced in quality by Illustrator CS5.

The studied fossil sites are located north of Salmal village, 50°30' E; 36°51' N, 14 km southwest of Ramsar, and 1.5 km southwest of Ramsar, 50°37' E; 36°54' N, both of them are west of Mazandaran Province, northern Iran. These sites are located in the Alborz Mountains in western Alborz, Figure 1.

GEOLOGY SETTING AND STRATIGRAPHY

Fürsich *et al*. (2009) divided the Shemshak Group into nine formations: Ekrasar (upper Carnian–Norian), Lalehband (upper Norian), Kalariz (Rhaetian), Shahmirzad (Norian–Rhaetian), Alasht (Hettangian–Toarcian), Shirindasht (Hettangian–Aalenian), Fillzamin (Aalenian–lower Bajocian?), Dansirit (lower Bajocian) and Javaherdeh (Hettangian–lower Bajocian). The Kalariz Formation in the study area consists of gray argillaceous to silty and fine–medium-grained sandstones, gray to dark gray argillaceous siltstone and dark gray to black shale with coal seams. In the study area, the Kalariz Formation lies conformably on the Lalehband Formation and the upper contact is with the Javaherdeh Formation, Figure 2.

SYSTEMATIC PALEONTOLOGY

Systematic Paleontology is based on the scheme of Schweitzer & Kirchner (2003).

Division CYCADOPHYTA
Order BENNETTITALES

Dictyozamites Oldham & Morris, 1863

Dictyozamites barnardi sp. nov.

(Figures 3A, B; 4A–E; 5A–F)

Diagnosis. Leaf pinnate (length unknown), Rachis 1–1.5 mm broad, marked with numerous, fine longitudinal ribs, pinnae attached on upper surface of rachis, arising at an angle of 75°–90°, but angle reduced to 50° near apex, pinnae alternate, crowded, slightly overlapping, short, curved to strongly falcate specially towards leaf and pinnae apex, auriculate, sessile, pinnae 7 mm wide and up to 20 mm long, width to length ratio 1:2.5–3, pinnae attached by a small area on basiscopic side of pinnae (at the middle of the base), base of pinnae asymmetric,

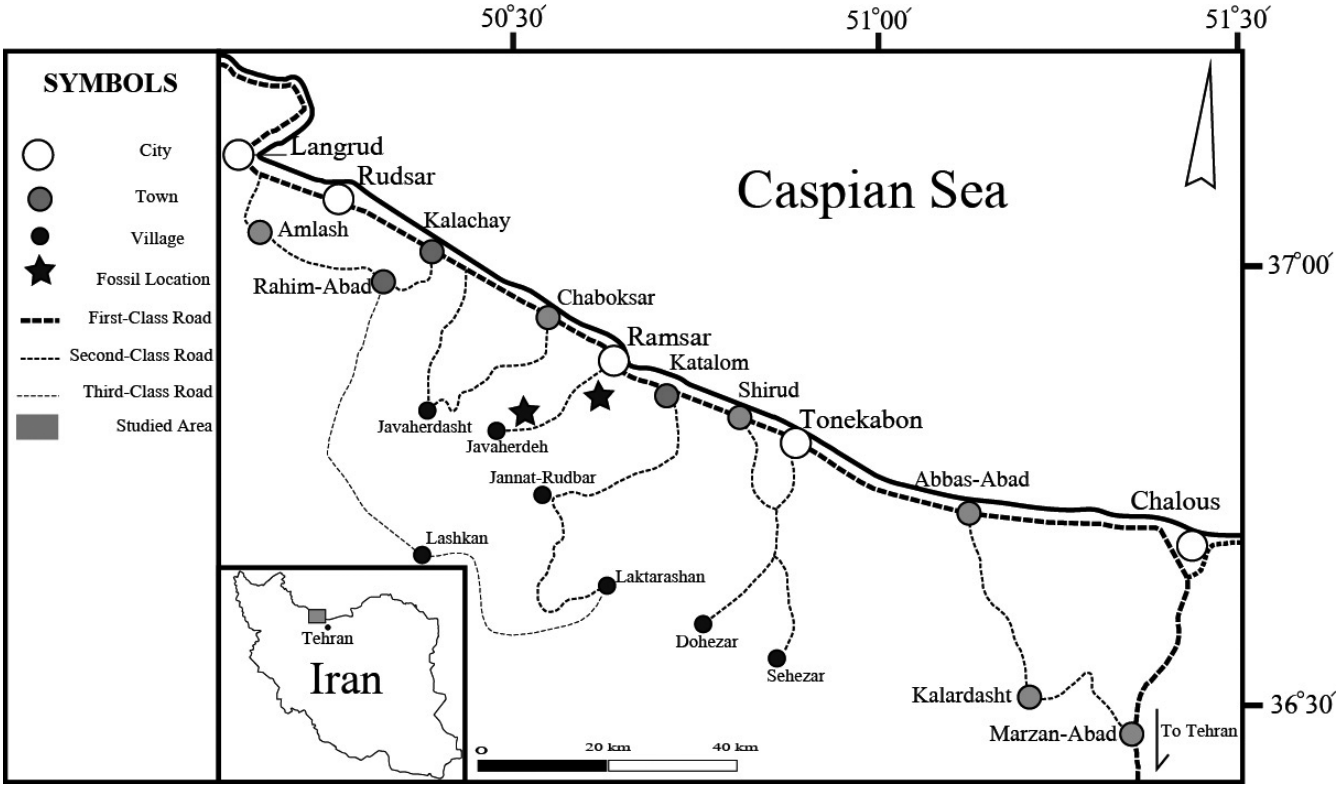

Figure 1. Location map of the studied area.

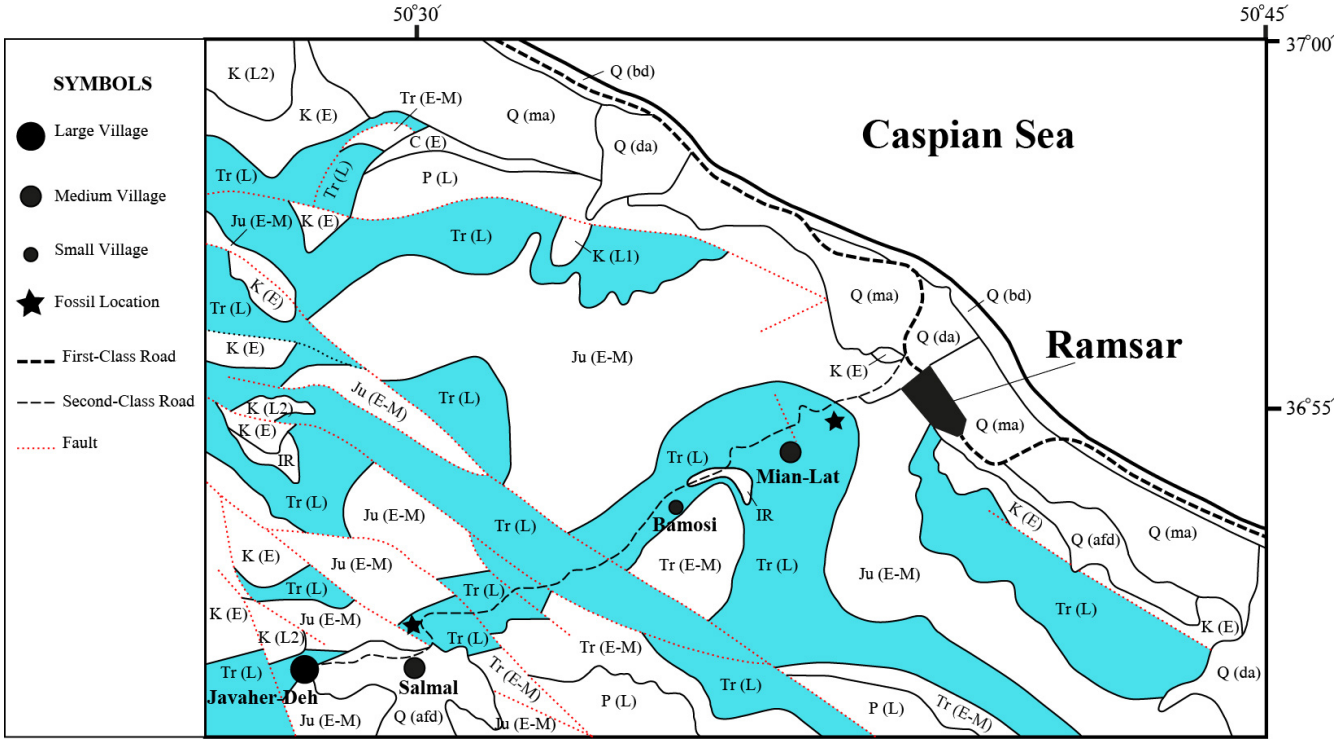

Figure 2. Geological map of the studied area. **Abbreviations: C (E)**, Early Carboniferous (Mobarak Fm.); **P (L)**, Late Permian (Ruteh Fm.); **Tr (E–M)**, Early–Middle Triassic (Elika Fm.); ***Tr (L)**, Late Triassic (Ekrassar, Lalehband & Kalariz Fms.) (colored); **Ju (E–M)**, Early–Middle Jurassic (Javaherdeh Fm.); **K (E)**, Early Cretaceous (Tiz-Kuh Fm.); **K (L1)**, Late Cretaceous Limestone beds; **K (L2)**, Late Cretaceous basic volcanic; **Q (ma)**, marine alluvium; **Q (bd)**, beach deposits; **Q (da)**, undivided deltaic alluvium; **Q (afd)**, alluvium and flood-plain deposits.

acroscopic basal angle expanded and auriculate (not very prominent), basiscopic basal angle apparently rounded, apex rounded, margin entire, distal and proximal margins generally parallel for basal one third of pinna length, but some pinna not parallel, proximal margin curving forward to the distal in the apical region. Venation reticulate, 10–12 delicate veins arising from point of attachment, veins of near apex unclear, radiating from base and curving towards margin, sub- parallel to one another in middle of pinna, intersections the proximal and distal margins at about 10°, meshes of middle region of pinnae elongated polygonal and narrow, length up to 20 times breadth, marginal meshes shorter, length 6–10 times the breadth. Vein density measured transversely in middle of pinnae 30–38 per/cm.

Description. The holotype consists of an impression of the proximal part of leaf, cuticles are absent, basiscopic basal angle concealed by imprint of acroscopic (auriculate) basal angle of proximately adjacent pinnae. About 8.5 cm of leaf length is preserved in the holotype, leaf is 4 cm in wide in its distal part, the largest pinna is 2 cm long and 7 mm wide at one third of the length from the base. Meshes are elongate and commonly 0.3 mm wide across all the pinnae.

Apart from the holotype, two other specimens were found southwest of Ramsar at the same location of *Dictyozamites barnardi fakhri* sp. nov. Both specimens are incomplete, but have the same pinna shape, size, venation and other characters as the holotype.

Derivation of name. In honor of Dr. P.D.W. Barnard who established the first species of *Dictyozamites* from Iran and the Middle East.

Holotype. Sample no. SRKJ-4; Figures 3A, B and 4A–E.

Type locality. North of Salmal village, 14 km southwest of Ramsar, west of Mazandaran province, northern Iran (50°30' E; 36°51' N). The location is in the Alborz Mountains (west of Alborz).

Stratigraphic position. Kalariz Formation, Shemshak Group.

Age. Rhaetian.

Repository. Laboratory of Paleontology, Faculty of Geology, University of Tehran, Tehran, Iran. Sample Number SRKJ-4.

Dictyozamites fakhri sp. nov.

(Figures 6A–C; 7A, B; 8A–D)

Diagnosis. Leaf pinnate (length unknown), Rachis 2–2.5mm broad, marked with numerous, fine longitudinal striae, pinnae attached on upper surface of rachis, arising at an angle of about 70°–75°, pinnae generally opposite but sub-opposite towards base of leaf, not closely set, commonly not overlapping, rarely overlapping slightly, but on both sides of rachis always slightly overlapping near the rachis in basal pinnae. Pinnae long, very elongate triangular, slightly falcate or slightly curved distally but more curved towards leaf tip, auriculate, sessile. Pinnae 6 mm wide and up to 40 mm long, width to

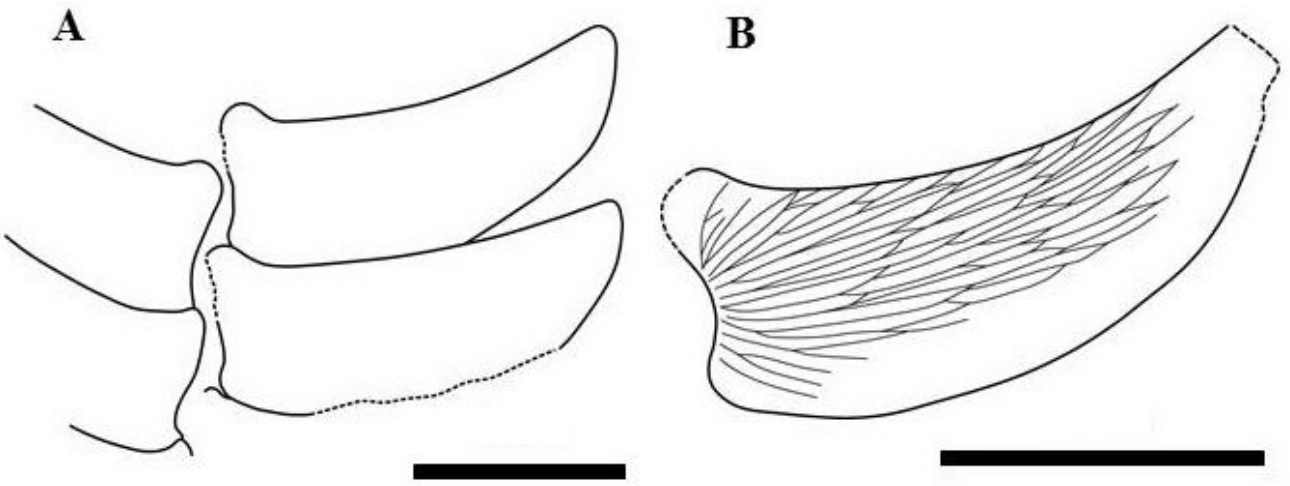

Figure 3. *Dictyozamites barnardi* sp. nov. (SRKJ-4; Holotype sample); **A**, pinnae arrangement; **B**, venation. Scale bars = 10 mm.

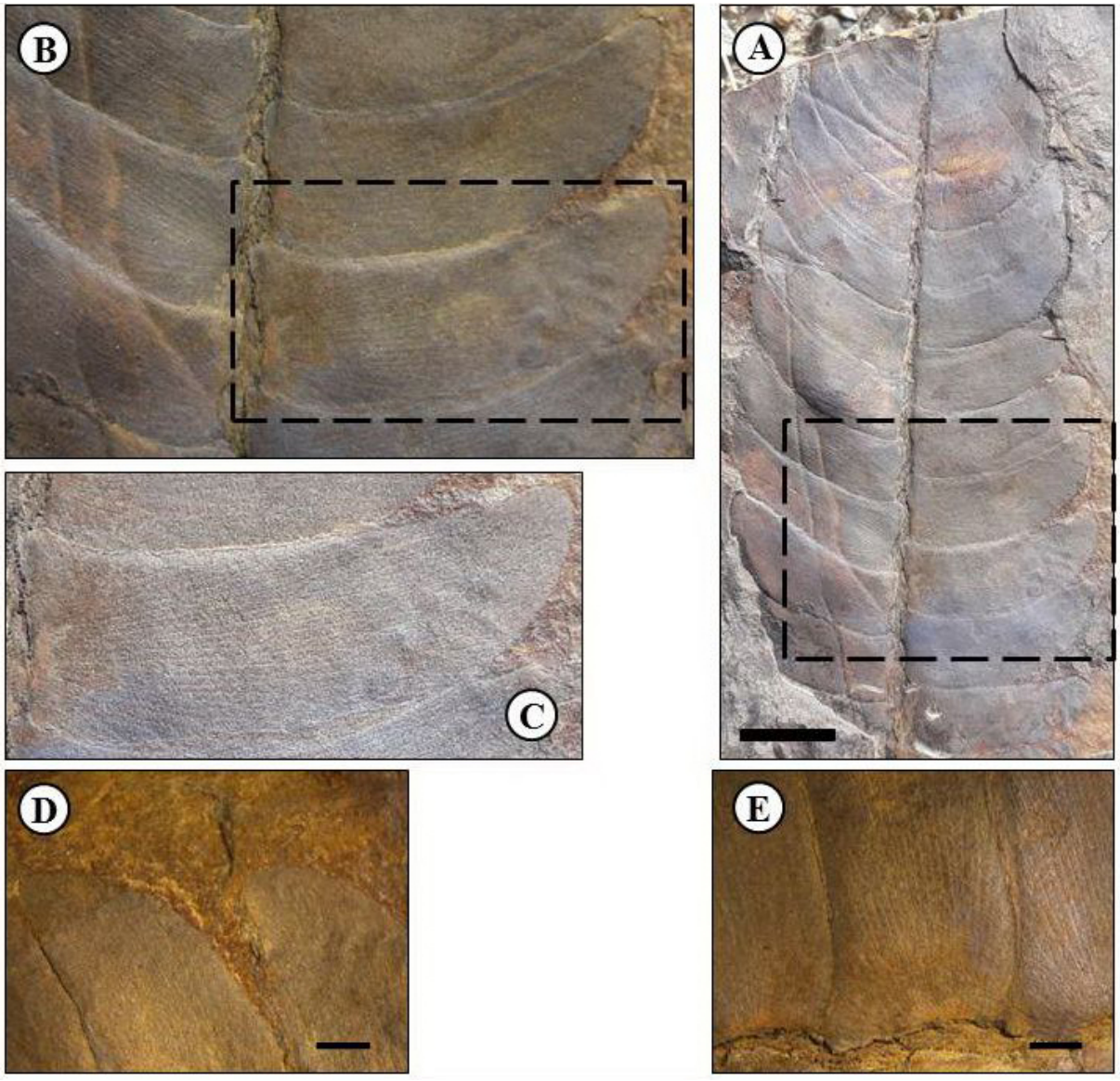

Figure 4. *Dictyozamites barnardi* sp. nov. **A**, holotype sample (leaf); **B**, pinnae arrangement; **C**, pinnae form; **D**, apex of pinnae; **E**, base of pinnae (all images related to sample number SRKJ-4). Scale bars: A = 10 mm; B = A × 2; C = B × 1.3; D–E = 2 mm.

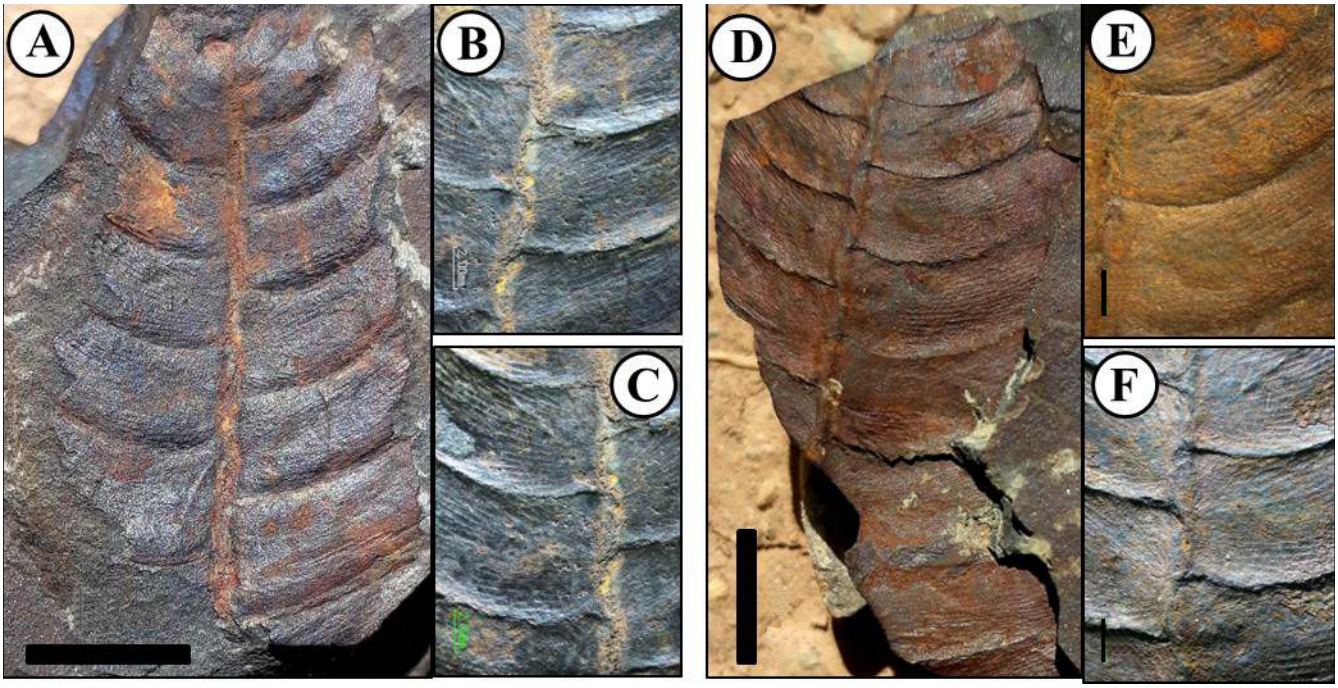

Figure 5. *Dictyozamites barnardi* sp. nov. **A**, SRKR-12 (leaf); **B**–**C**, pinnae arrangement of A; **D**, SRKR-13 (leaf); **E**, pinnae shape (strongly falcate); **F**, pinnae arrangement of D. Scale bars: A, D = 10 mm cm; B, C, E, F = 2 mm.

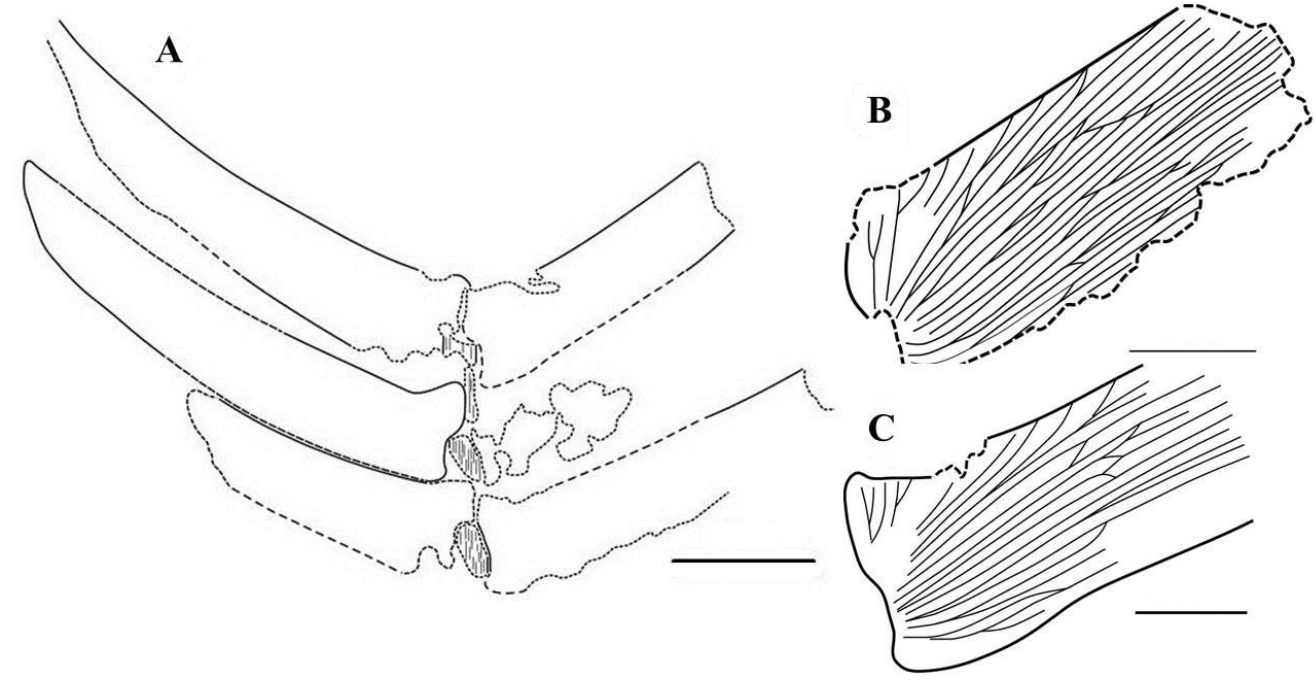

Figure 6. *Dictyozamites fakhri* sp. nov. (SRKR-20; holotype sample); **A**, pinnae arrangement; **B**–**C**, venation. Scale bars: A = 10 mm; B–C = 4 mm.

length ratio 1:6.5; attached by a small area on basiscopic side of pinnae near basal angle; base of pinna asymmetrical, acroscopic basal angle expanded and slightly auriculate, basiscopic basal angle rounded, apex obtuse, margin entire, distal and proximal margins not parallel but margins converse very gradually, pinnae becoming more prominently falcate distally. Venation reticulate, 9–12 prominent veins arising from point of attachment, veins radiating from base and curving gently towards margin, veins sub-parallel to one another and margins in middle of pinna, diverging to meet the proximal margin at about 20° and distal margin at about 10°. Meshes of middle region of pinnae elongate, narrow and rectangular to polygonal, length typically 25–35 times breadth, in some cases less than 20 times breadth, central

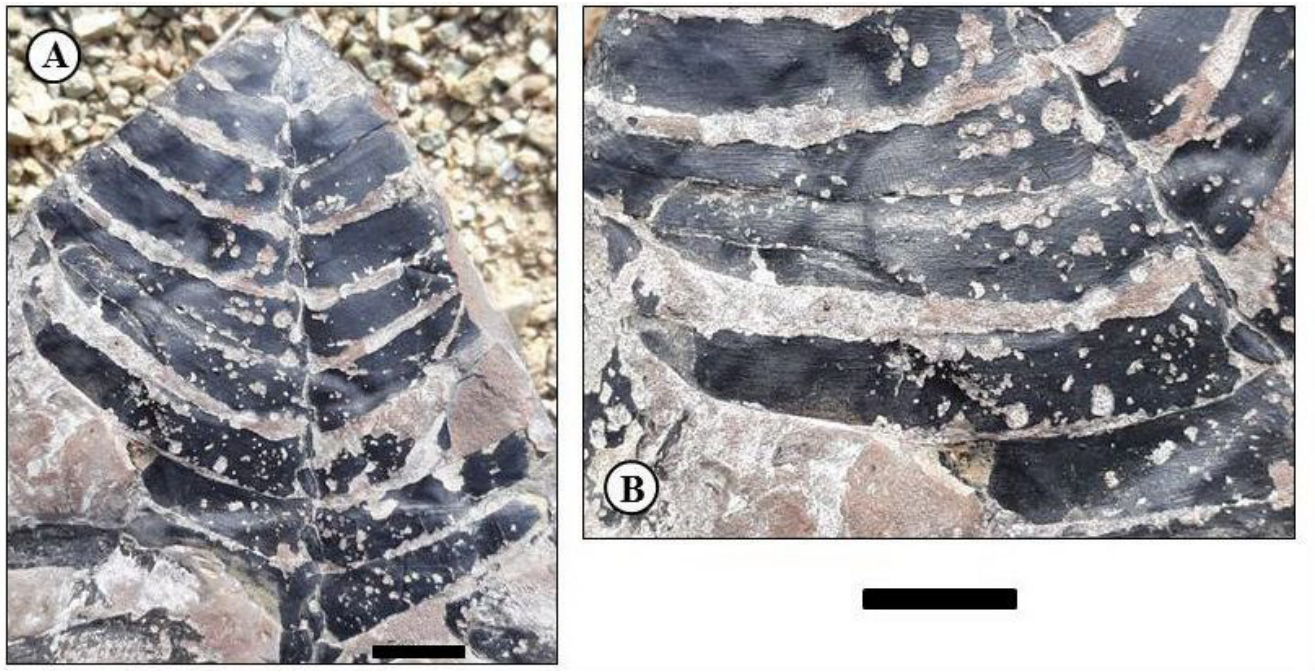

Figure 7. *Dictyozamites fakhri* sp. nov. (SRKR-20). **A**, holotype sample (leaf); **B**, detail of 7A. Scale bars = 10 mm.

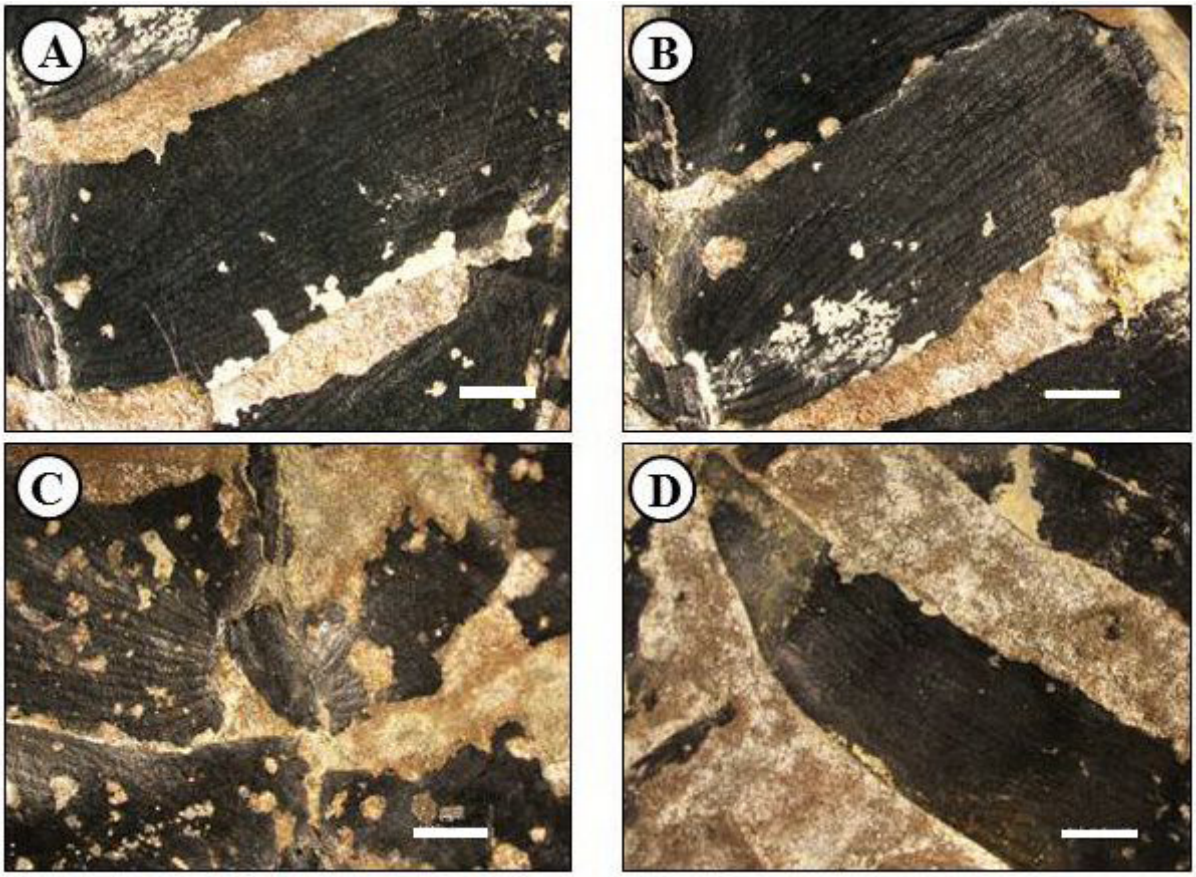

Figure 8. *Dictyozamites fakhri* sp. nov. (SRKR-20). **A**–**B**, pinnae venation; **C**, base of pinnae; **D**, apex of pinnae. (all images related to sample number SRKR-20). Scale bars = 2.0 mm.

meshes, except near apex, approximately similar in size and shape, marginal and apical region meshes shorter, length 5–15 times the breadth near proximal margin and apical region, and 15–20 times the breadth near distal margin; marginal meshes are rectangular or triangular, but all are elongate; width of meshes in middle region of pinnae and along both margins about similar, veins in proximal part of pinna prominent, but towards apex becoming fine, veins density measured across middle of pinnae 26–30 per/cm.

Description. The holotype consists of the proximal portion of a leaf compression exposing the adaxial surface, but the cuticles were not appropriate for study because they were very brittle and compressed. The acroscopic basal angles appear to be preserved above the rachis in figs. 8B, C. Pinnae are opposite to sub-opposite, but only one complete pinna is preserved in the specimen, the complete pinna is 4 cm long and 7 mm wide near the base (beyond the auricle), 5.5 mm wide in the center and 4 mm wide distally based on the complete pinna, the leaf is 64 mm wide. In the auricle 4–5 fine veins arise from the point of attachment and fork once to three time to form elongated meshes that are 0.4 mm wide in the middle part of pinnae and 0.3 mm wide near the margins. The angle of meshes is acute in all part of the pinnae.

Derivation of name. In honor of Dr. M.S. Fakhr who is the founder of paleobotany in Iran.

Holotype. Sample no. SRKR-20; Figures 6A–C; 7A, B; 8A–D.

Type locality. 1.5 km southwest of Ramsar, west of Mazandaran Province, northern Iran (50°37' E; 36°54' N) within the Alborz Mountains (west of Alborz).

Stratigraphic position. Kalariz Formation, Shemshak Group.

Age. Rhaetian.

Repository. Laboratory of Paleontology, Faculty of Geology, University of Tehran, Tehran, Iran. Sample Number SRKR-20.

COMPARISONS

Barnard (1965, p. 1152) compared the *Dictyozamites asseretoi* to *Dictyozamites hawelli* Seward, 1903. He noted that these species are very similar in the form of their pinnae, but *D. hawelli*, like most species of this genus, in lacking on auricle. The two new species (*D. barnardi* sp. nov. and *D. fakhri* sp. nov.) are notable in having auricles *D. asseretoi*-like. However, the auricles on the acroscopic basal margin of these new species are smaller than the auricles of *D. asseretoi*. Generally, these two new species have some similar features to *D. asseretoi* (see Table 1) and were compared with other specimens from Iran (mentioned in the Introduction). The new species differ from *D. asseretoi* in the form and shape of the pinnae, pinnae position (*Dictyozamites fakhri* sp. nov.), shape of the pinnae base and venation details, and are similar with various other species (see Table 2).

Pinnae in *Dictyozamites asseretoi* are long and falcate, the acroscopic basal angle is very clear and expanded, the basiscopic basal angle forms almost a right angle and the distal and proximal margins are parallel for the basal two thirds of the pinna length (Barnard, 1965, p. 1150). But, in *D. barnardi* sp. nov. the pinnae are short and strongly falcate,

Table 1. Comparison of macromorphological features of *Dictyozamites asseretoi*, *Dictyozamites barnardi* sp. nov. and *Dictyozamites fakhri* sp. nov.

	***Dictyozamites asseretoi* Barnard, 1965**	***Dictyozamites barnardi* sp. nov.**	***Dictyozamites fakhri* sp. nov.**
form and shape of pinnae	long and falcate	short, curved to strongly falcate	long, slightly falcate and very elongate triangular
pinnae position	alternate	alternate	opposite to sub-opposite
length of the largest pinna	54 mm	20 mm	40 mm
W/L Ratio	1:5.5	1:2.5—3	1:6.5
auriculate	yes (very clear)	yes (clear)	yes (clear)
acroscopic basal margin	expanded (large, very clear)	expanded (small, clear)	expanded (small, clear)
basiscopic basal margin	right angle	rounded	rounded
tip of pinna	rounded	rounded	obtuse
pinna margins	parallel for basal two thirds of pinna length	parallel for basal one third of pinna length	not parallel
central meshes	length 20—30 times breadth	length up to 20 times breadth	often length 25—35 times breadth, in some cases down to 20 times breadth
marginal meshes	length 4—5 times breadth	length 6—10 times breadth	length 5—15 times breadth
apical region meshes	short (similar to marginal meshes)	longer than marginal meshes and shorter than central meshes	longer than marginal meshes and shorter than central meshes
vein density (measured across pinna)	30 per/cm	30—38 per/cm	26—30 per/cm

Table 2. Comparison of macromorphological features of *Dictyozamites hawelli*, *D. falcatus*, *D. sahnii* and *D. feistmantelii*.

	Dictyozamites hawelli **Seward, 1903**	***Dictyozamites falcatus*** **(Morris) Medlicott & Blanford, 1879**	***Dictyozamites sahnii*** **Gupta & Sharma, 1968**	***Dictyozamites feistmantelii*** **Bose & Zeba-Bano, 1978**
form and shape of pinnae	straight or slightly curved forwards	linear–lanceolate, in some cases falcate	falcate, gradually narrowing towards apical region	apical pinnae falcate, upper margin of basal pinnae more or less straight
pinnae position	alternate	alternate	alternate	alternate
length of the largest pinna	30–40 mm	25 mm	40–50 mm	20–60 mm
W/L Ratio	1:3.5–4	1:4–5	1:5	1:6
auriculate	only basiscopic part	yes (weakly)	yes (clear)	yes (clear), with small stalk
acroscopic basal margin	not expanded	slightly expanded	slightly expanded	slightly expanded
basiscopic basal margin	nearly straight	extending beyond point of emergence of pinnae	locally rounded and extending beyond point of emergence	rounded
tip of pinna	obtuse	obtuse	acute	obtuse
pinna margins	parallel except near apex	parallel except near apex	not parallel	not parallel
central meshes	8 mm long	2–4 mm long	5–8 mm long	5–8 mm long
marginal meshes	Less than 1 mm long	Less than 1 mm long	1–2 mm long	Not mention in diagnosis
vein in middle region	25–35 (rarely 45)	10–12 (rarely 14)	14–16	18–24

the distal basal angle is clear, but only slightly expanded, the proximal basal angle is rounded and the distal and proximal margins are parallel for the basal one third of the pinna length. In *D. fakhri* sp. nov. the pinnae are long, slightly falcate and very elongate triangular, the distal basal angle is clear and not very expanded, the proximal basal angle is rounded and the distal and proximal margins are convergent (see Table 1 for more differences).

DISCUSSION

Late Triassic plant macrofossils in Iran have been reported from Alborz (western, central and eastern Alborz), northeastern Iran (Kopeh-Dagh and Binaloud Mountains) and Central Iran (Tabas and Kerman Basin). So far, reliable records of *Dictyozamites* have been reported only from Rhaetic deposits in Iran from the Kalariz Formation (western and central Alborz) and Nayband Formation (Tabas area from central Iran). In this study, *Dictyozamites barnardi* sp. nov. and *Dictyozamites fakhri* sp. nov. are reported from Rhaetic deposits of Kalariz Formation from western Alborz Mountains (Ramsar coal-bearing basin).

Based on the paleogeographic floral zonation in the Late Triassic age (Kustatscher *et al*., 2018), Kalariz and Nayband formations (formations hosting Late Triassic fossiliferous strata of Iran) are located in Late Triassic floras of easternmost Europe and Asia (except China and Eastern Asia) zone and Norian–Rhaetian floras of Asia (except China and Eastern Asia) sub-zone.

Dictyozamites have been reported in most parts of the world from Jurassic deposits but in Iran (Alborz Mountains and Tabas area) and southern coast of Laurasia, such as southeastern Asia, they have been reported from Late Triassic deposits.

CONCLUSIONS

Two new species of *Dictyozamites* (Bennettitales), *Dictyozamites barnardi* sp. nov. and *Dictyozamites fakhri* sp. nov., are established from the Rhaetian Kalariz Formation (Shemshak Group) from Alborz Mountains, northern Iran. They can be distinguished from previously established species based on gross morphology of the pinnae and venation details. All *Dictyozamites* species from Iran are restricted to Rhaetian strata.

ACKNOWLEDGEMENTS

The author wishes to acknowledge to M.-S. Fakhr for his useful comments, S. Rezaie for help and F. Jourbonian for his assistance in the field.

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Received in 05 April, 2021; accepted in 03 February, 2022.