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A New Species of *Coniopteris moguqiensis* sp. nov. from the Middle Jurassic Wanbao Formation in Eastern Inner Mongolia, China

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Abstract: In recent years, an increasing number of plant fossil leaves and petrified woods have been discovered from the Middle Jurassic Wanbao Formation in Moguqi Town of Inner Mongolia, NE China. Here, we describe a new species of *Coniopteris moguqiensis* sp. nov. preserved as a fragment with fertile and sterile pinnules. The sterile ultimate pinnules are elongate ovate with sphenopteriod type venation, and fertile pinnules are usually isolated, bipinnate at least with the sorus apical, elliptical, 1 mm in diameter; sporangia are almost globular, 100–150 μm in diameter, and the annulus is vertical. *In situ* spores are rounded-triangular in polar view, 25–30 μm in diameter with sides straight and slightly convex; trilete, laesurae are thin and slightly straight; the exine surface is usually psilate under the light microscope but finely reticuloid sculptured on the proximal view under a scanning electronic microscope. The fern genus *Coniopteris* usually suggests a warm and humid environment, which is consistent with the palaeoclimatic conditions of petrified wood and megafossil plants. The new discovery further supplements the floral composition of the Wanbao Formation, providing new material for understanding the evolutionary trend and classification of *Coniopteris*.

Key words: *Coniopteris*, Wanbao Formation, *in situ* spores, Middle Jurassic, Inner Mongolia

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1 Introduction

Dicksoniaceae includes three extinct genera (*Coniopteris*, *Acanthopteris* and *Gonatosorus*) and one living genus *Dicksonia*, thereinto *Coniopteris* is the most abundant fern group in the Early Cretaceous of the humid-temperate North Phytogeographic Province in China (Deng et al., 2001; 2002). The extinct fern genus *Coniopteris* is widely distributed in the Early Jurassic to Early Cretaceous sediments, playing an important role in strata and flora correlations, which is considered as the earliest known Dicksoniaceous fern (Harris, 1961; Deng, 2002; Cantrill et al., 2005; Xin et al., 2018). To date, more than 60 species of *Coniopteris* have been recognized, including about 40 species distributed in China, additionally, *Coniopteris* usually represents a warm and humid habitat indicating temperate and subtropical climate (Vakhrameev, 1991; Deng Shenghui et al., 2001; Wang Yongdong, et al., 2009; Kostina et al., 2013; Herman et al., 2016; Xin et al., 2018). However, the systematic position of the fern genus *Coniopteris* is still in dispute, due to the wide variation in the morphology of sterile fronds and fertile pinnule features. Understanding the anatomical microstructure of the reproductive organs could further benefit the study of *Coniopteris* in regard to evolutionary trend and classification.

The fertile pinnae, sori, sporangia and *in situ* spores of the present new species of *C. moguqiensis* sp. nov. were well preserved, providing valuable materials and information concerning the paleoenvironment and paleoclimate of the Wanbao Formation and in addition for the evolutionary trend and systematics of *Coniopteris*.

2 Materials and Methods

The present fossil specimens of *C. moguqiensis* sp. nov. described here were collected from the Middle Jurassic Wanbao Formation in Moguqi Town, Zhalantun City, Inner Mongolia, NE China, and the fossil site of Moguqi Town is localized to the northwestern of the Longjiang Country (Fig. 1). Lithologically, the Wanbao Formation is composed of pebbly sandstones, conglomerates, medium-fine sandstones, siltstones and mudstone, representing fluvio-lacustrine clastic sedimentary deposits, additionally, the present fossil specimens were collected from layer 4 of the Wanbao Formation (Fig. 2). Originally, the division and age of the Wanbao Formation at the current fossil-bearing locality have been disputed for

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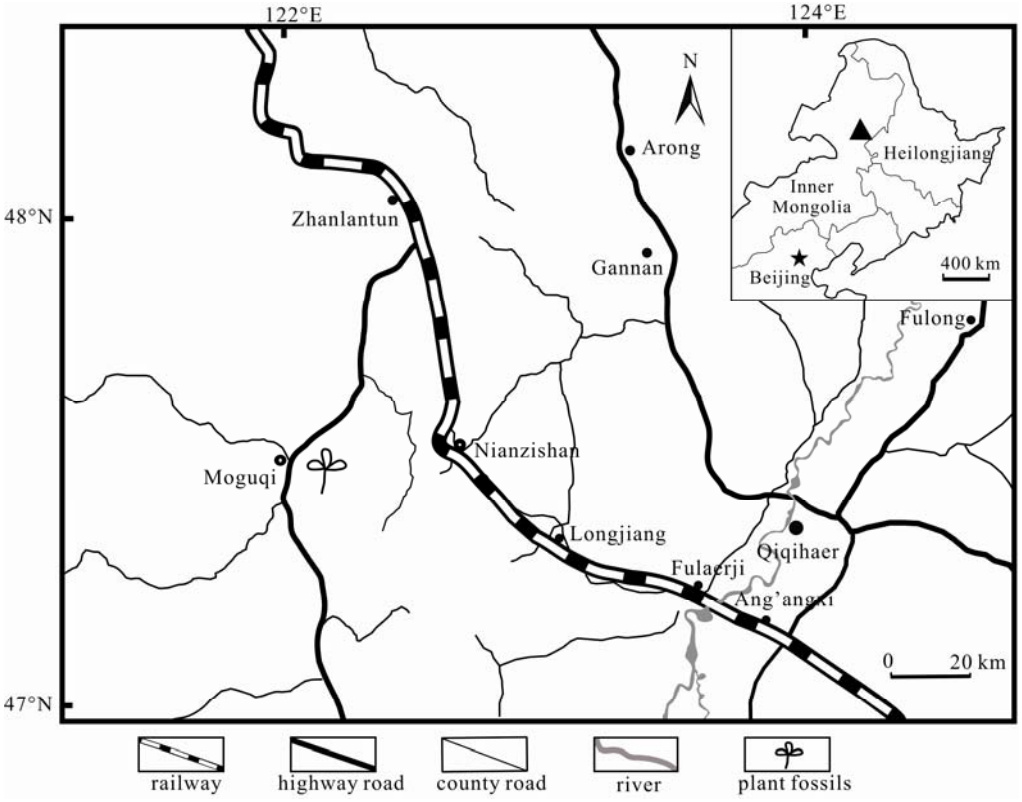

Fig. 1. The locality of the megafossils in Moguqi Town, Inner Mongolia, NE China.

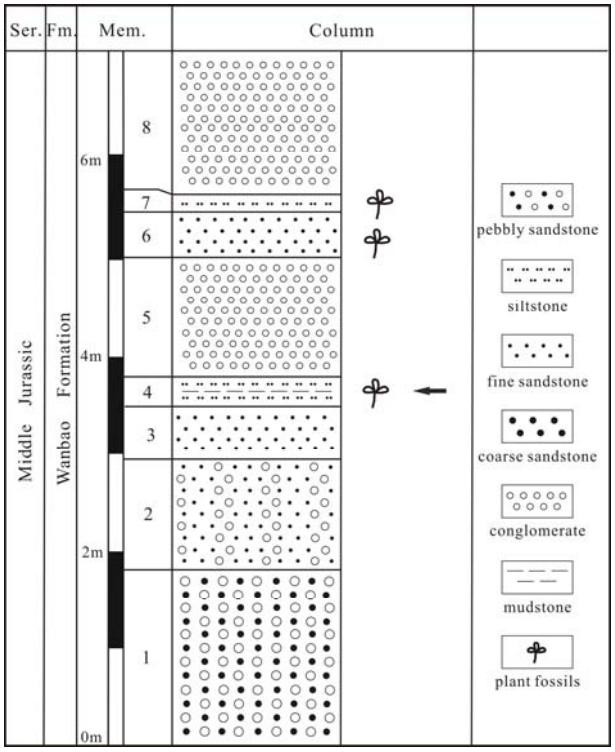

Fig. 2. Stratigraphic column of the Wanbao Formation in Moguqi Town, Inner Mongolia.

a long time, however, recent studies of strata and flora correlations combined with the radioisotope dating data (165.2±1.7 Ma and 162.1±1.6 Ma) indicated that the Wanbao Formation should be assigned to late Middle Jurassic (Ding et al., 2010; Zhang et al., 2018a, b).

The megafossils are preserved as impressions and compressions, and were photographed using 3D super depth microscopy systems (Keyence VHX-5000). The fossil remains of *in situ* spores were detached from the rock surface, and macerated using 30%HCl, then rinsed with distilled water. Afterwards, the sample was treated with 40%HF for more than 24 h and washed to neutral with distilled water, subsequently, macerated with 5% KOH followed by washing in distilled water to neutral. Finally one part of sample was mounted on slides, and observed and photographed using 3D super depth microscopy systems (Keyence VHX-5000), while the other part was used as a standby and was analyzed using a HITACHI S-4800 scanning electron microscope (SEM). The specimens and slides are housed in the Paleontological Museum of Liaoning (PMOL) in Shenyang, China.

3 Systematics

Class Filicopsida
Order Filicales
Family Dicksoniaceae
Genus *Coniopteris* Brongniart, 1849
Species: *Coniopteris moguqiensis* Zhang, Liu et Liang sp. nov.

Holotype: A21.

Paratype: XWHS1.

Type locality: Moguqi Town, Zhalantun City, Inner Mongolia.

Horizon and age: Wanbao Formation, Middle Jurassic.

Etymology: The specific epithet moguqiensis comes from Moguqi Town, where the fossils were collected.

Specific diagnosis: Sterile ultimate pinnule elongate ovate, venation sphenopteriod type, thin and slightly straight, forking once to twice; fertile foliage medium in size, lanceolate, twice pinnate at least, and the fertile pinnule usually isolated. Sorus apical, elliptical or ovate in shape; sporangia globular in outline; annulus vertical, incomplete preserved. Spores rounded triangular in polar view, trilete, laesurae slightly straight, almost reaching the equator. Exine surface smooth and fine-reticuloid sculptured under the SEM.

Description: The present fossil specimen (A21) is preserved as a fragment of fertile pinnules with small debris of a sterile pinnule; the main rachis is about 1 mm

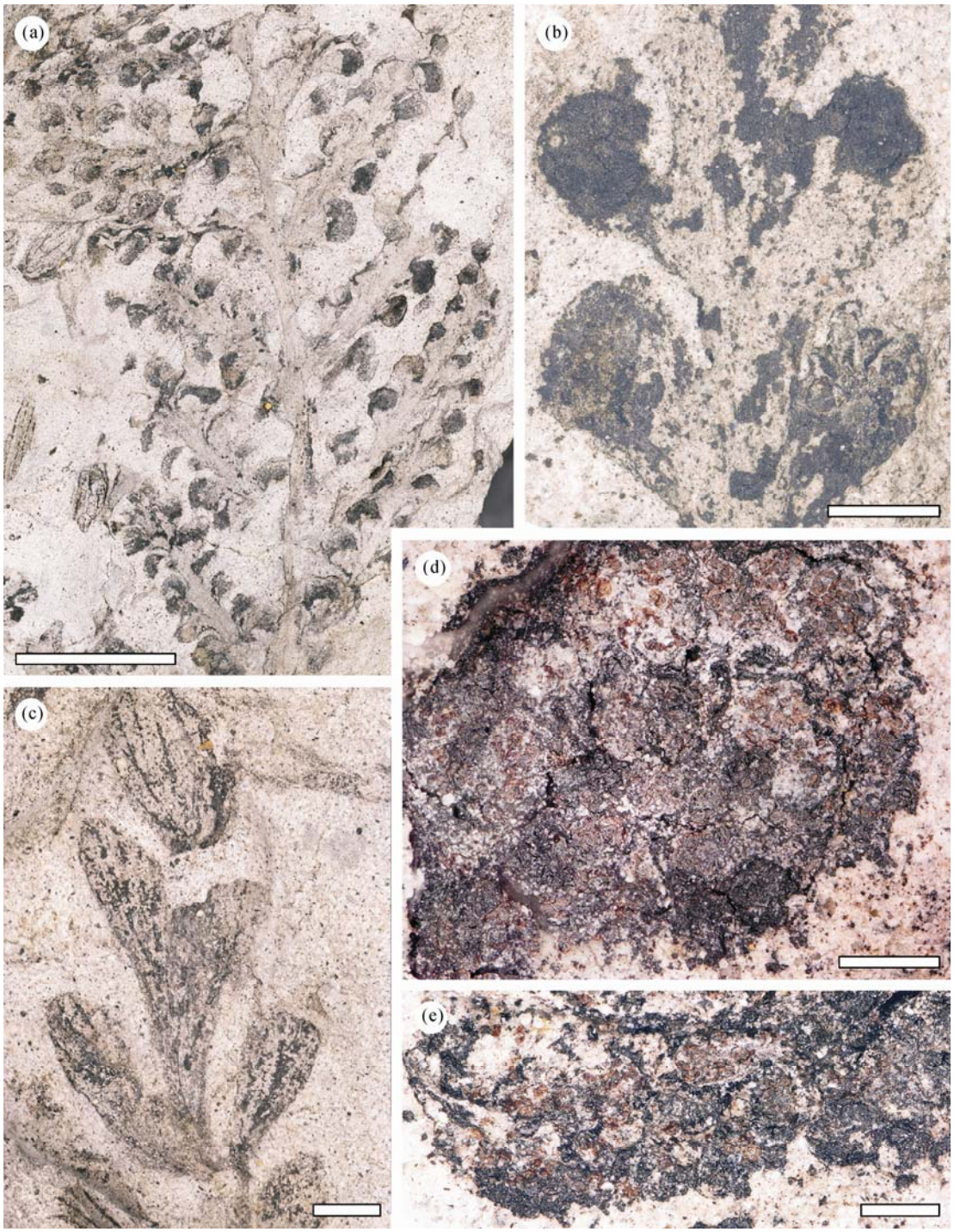

Fig. 3. Fertile and sterile pinnules of *C.moguqiensis* sp. nov..

(a) fertile pinnule, showing the shape and insertion position of the sorus, scale bar=5 mm; (b) sori, showing the position of the sorus, scale bar=500 μm; (c) sterile pinnule, showing the frond shape and venation, scale bar=1 mm. (d-e) sorus, showing the details of the sorus and sporangia, scale bar=100 μm.

in diameter, and the ultimate rachis is 0.5 mm thick, oppositely rising at acute angles (Fig. 3a–c). Sterile fronds are incompletely preserved, and the ultimate pinnule is elongated ovate with an entire margin. In addition, the venation is of sphenopteriod type, forking once to twice to the leaf margin (Fig. 3c). Fertile pinnae are about 45 mm in length, 25 mm in width, usually with 5–6 pairs of lobes, and each lobe has only one apical sorus (Fig. 3a). The sori are elliptical, suborbicular or kidney-like, generally 0.5–1.0 mm in size, each sorus has more than 20 sporangia (Fig. 3a–b, d–e); the sporangia are almost globular, 100–150 μm in diameter with each sporangium bearing more than 32 spores (Fig. 4a–e); the annulus is vertical, incompletely preserved (Fig. 4a–e). The indusia and stalk are unpreserved. Spores are rounded-triangular in polar view, 25–30 μm in size with trilete in the proximal view

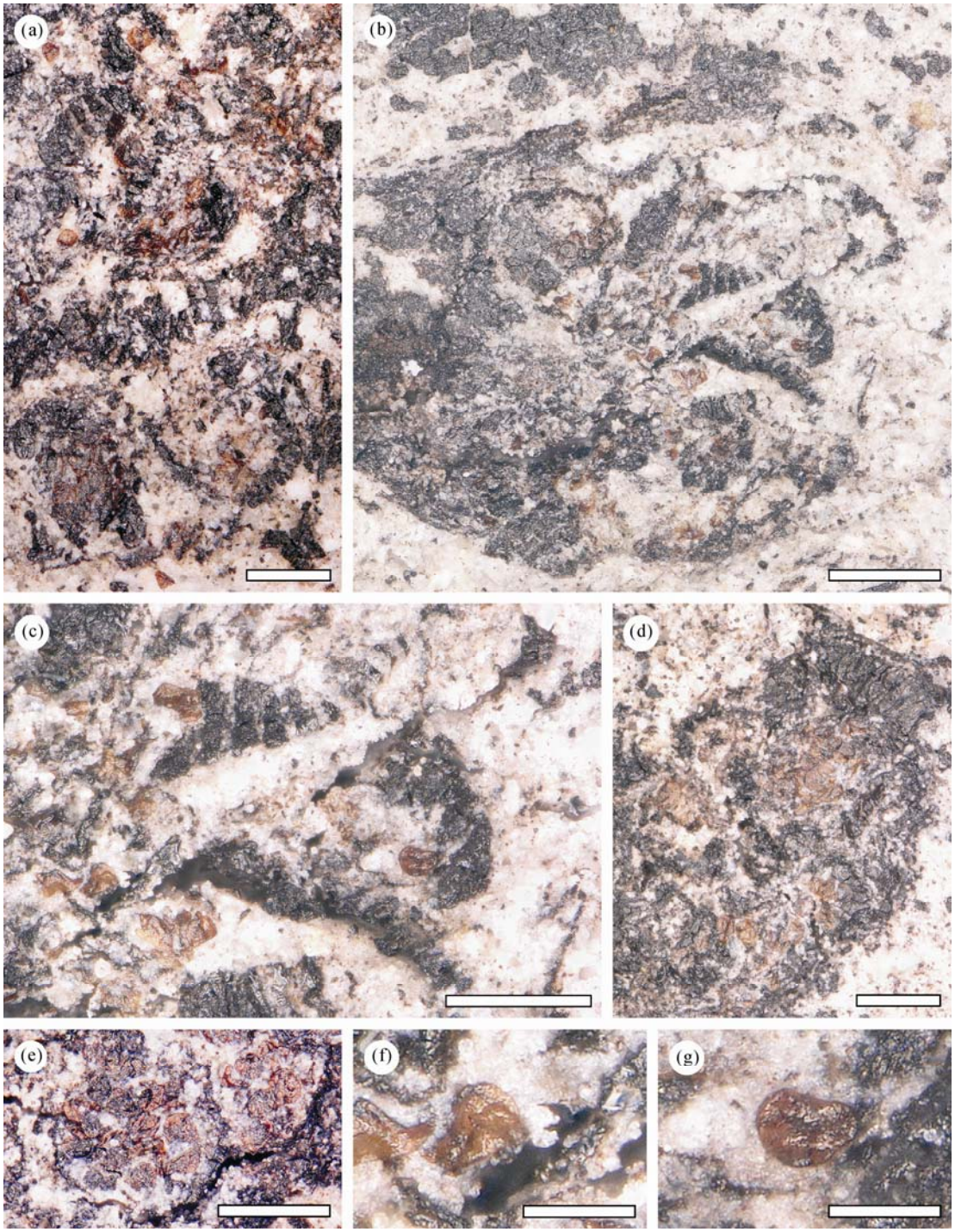

Fig. 4. Sporangia and *in situ* spores of *C. moguqiensis* sp. nov.under the 3D super depth microscope.
(a) sporangia, showing the details of annulus, scale bar=50 μm; (b) sorus, showing the sporangia and annulus, scale bar=100 μm; (c-e) sporangia and annulus, showing the details of the sporangia and some *in situ* spores, scale bar= 50 μm, 25 μm and 50 μm, respectively, and c is the enlargement of b; (f-g) *in situ* spores, showing the details of spores, scale bar=25 μm.

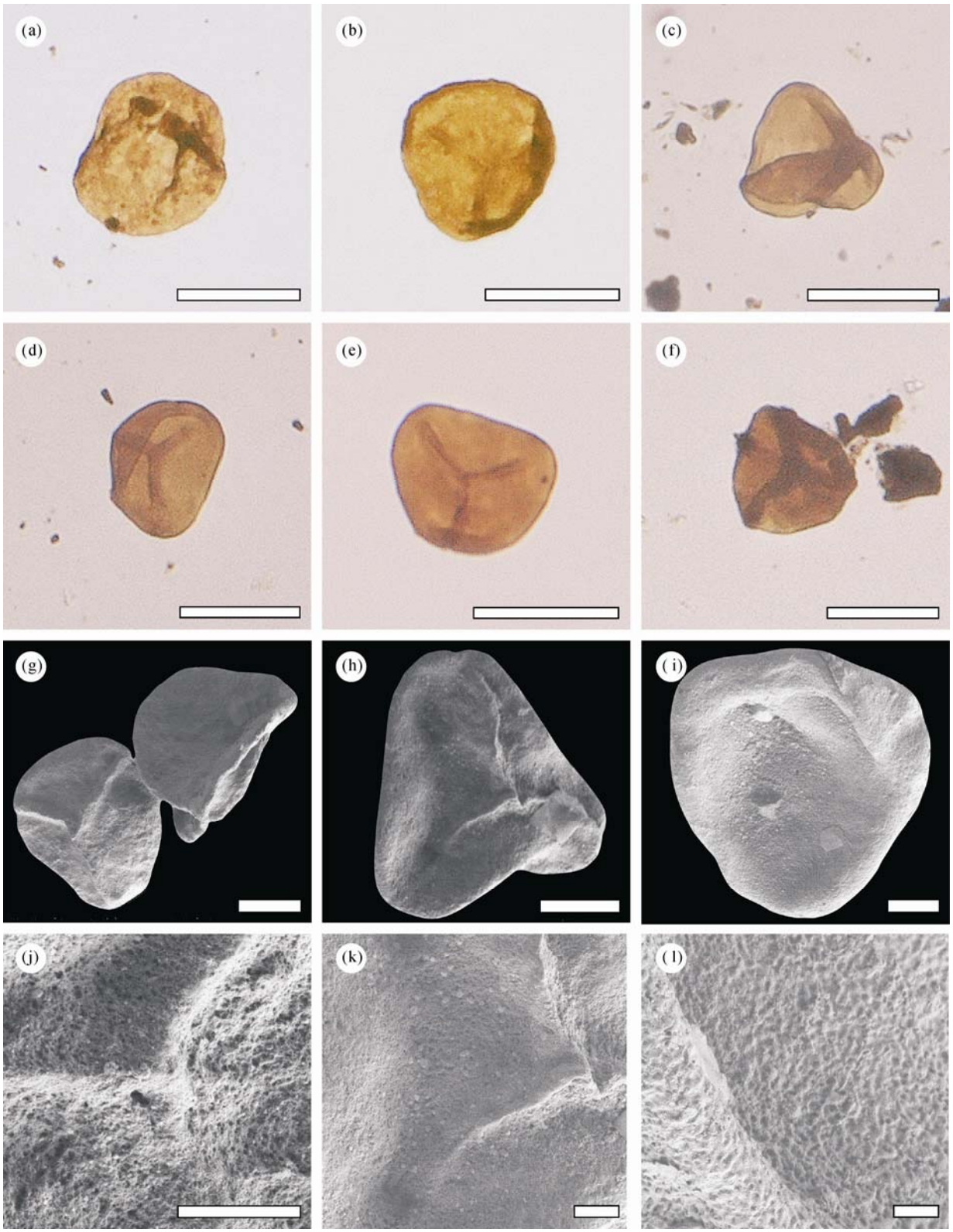

Fig. 5. *In situ* spores of *C. moguqiensis* sp. nov. under the microscope.
(a-f) *In situ* spores under the 3D super depth microscope, showing the proximal, equatorial and distal view of the spores, scale bar=25 μm; (g-l) *In situ* spores under the SEM, g-h showing the trilete in the proximal view,scale bar=10 μm; i showing the distal view of the spores, scale bar=5 μm; j-k showing the finely reticuloid sculptured surface, scale bar=2 μm.

(Fig. 4f–g, Fig. 5a–i); the sides of spores are usually straight and slightly convex, and the laesurae are somewhat thin, straight or slight curved, almost reaching the equator (Fig. 5c–h). The exine surface of spore is

usually psilate under the light microscope (Fig. 5a–f), but finely reticuloid sculptured in the proximal view under the SEM (Fig. 5j–l).

4 Comparisons

The features of sterile fronds and sori in the present specimens are mostly consistent with the fern genus *Coniopteris* Brongniart of the Family Dicksoniaceae (Si Xingjian and Li Xingxue, 1963; Sun Keqin et al., 2010). Compared with three fern species *C. simplex, C. margaretae* and *C. bella* from the Middle Jurassic Yorkshire flora in Britain (Harris, 1961), the shapes of *in situ* spores are quite similar to the present fossils, but the sizes of the spores, sporangia and sori are much larger. Moreover, the exines of spores are usually granularly sculptured, while the present spores appear smooth under the light microscope and finely reticuloid sculptured under the SEM (Table 1). In comparison with three species of the Middle Jurassic in Gansu Province of China, including *C. hymenophylloides* (Xin et al., 2018), *C. lanzhouensis* (Sun, 1986; Xin et al., 2010) and *C. gansuensis* (Cao Zhengyao et al., 1996), the sporangia of the present specimens are much smaller, besides the spore size and laesurae features are different from the former two species (Table 1). Furthermore, compared with some similar *Coniopteris* species from the Early Cretaceous of Northeast China, the fertile pinnule features and the sizes of the sporangia and *in situ* spores are different from those of the present specimens; the detailed comparisons of these species are given in Table 1. Based on the above comparisons, it is reasonable to assign the present

Table 1 Comparisons of the reproductive organs of *C. moguqiensis* with some similar species

Species	Fertile pinnule	Sorus	Sporangia	Spore				Reference
				Shape	Laesurae	Surface	Size	
C. moguqiensis	Isolated, 2 times pinnate at least	Elliptical or ovate, apical 1 mm in diameter	Globular, annulus vertical, 100–150 μm	Rounded triangular, sidesstraight with slightly convex	Almost reaching the equator	Smooth in light microscope, fine reticuloid sculptured under SEM	25–30 μm	Present paper
C. concinna	Contracted, each pinnule with 2–3 apical sorus	Elliptical, apical 1–1.5 mm in diameter	Elliptical or spherical, annulus vertical, 250 μm	Rounded triangular, sides slightly concave	2/3–3/4 of the radius	Smooth	40–60 μm	Chen, 1990
C. ermolaevii	Contracted strongly, together with sterile pinnules.	Elliptical or rounded, apical 1–1.7 mm in diameter	Elliptical, annulus vertical 170–250 μm	Rounded triangular	Reaching the equator	Smooth	35–40 μm	Chen, 1988
C. hymenophylloides	Shrunk to thin-rod shaped	Oval to rounded with a suspensor, 1 mm in diameter	Globate or ellipsoidal, 250–400 μm	Triangular or subcircular, sides slightly concave with round or obtuse apices	4/5 of the radius	Smooth, parts of the exine granulate	27.5–46 μm (37μm on average)	Xin, 2018
C.lanzhouensis	Contracted	Larger with stalk, ovate	Ovate	Rounded triangular, sides slightly concave	3/4 of the radius	Exine smooth	35–50 μm (40 μm on average)	Sun, 1986; Xin, 2010
C. gansuensis	Shrunken with stalk	Oval to rounded	250 μm	Unknown	Unknown	Unknown	Unknown	Cao, 1996
C. venusta	Contracted strongly, each pinnule with 3 sorus	Sorusapical, Trapezoid-like or elliptical, 1–2mm in width	Globular, 200–250 μm	Rounded triangular, trihedral convex, sidesstraight with slightly concave	Almost reaching the equator	Smooth in light microscope, fine granularly under SEM	60–70 μm	Deng, 2001
C. densivenata	Contracted strongly, with 3–5 pairs of lobes	Rounded, 0.6–0.8 mm in diameter	Unknown	Unknown	Unknown	Unknown	Unknown	Deng, 1995
C.longipinnata	Isolated, slightly contracted,	Kidney-like, 0.6–1 mm in width	Globular with stalk, 160–200 μm	Sub-triangle, sidesstraight with slightly concave	Almost reaching the equator	Smooth with wrinkle	30–40 μm	Deng, 1992
C. huolinheensis	Isolated	Elliptical or rounded, 1.5–2.0 mm in diameter	Globular, annulus vertical, 150–250 μm	Triangle or rounded triangular	Almost reaching the equator	Smooth in light microscope, fine granularly under SEM	30–35 μm	Deng, 1991
C. simplex	Shrunken with stalk	1.5–2.0 mm in diameter	With stalk	Triangle to rounded triangular	Unknown	Smooth, perine granular	36–55 μm (45 μm on average)	Harris, 1961
C. margaretae	Shrunken with stalk	Semicircular, 4–5 mm in diameter	250 μm	Rounded triangular	Unknown	Fine granular	62–94 μm (76 μm on average)	Harris, 1961
C. bella	Shrunken	Ovate, apical	Globular with stalk, 200 μm	Rounded triangular, sidesslightly convex	Straight, 3/4 of the radius	Smooth, part of perine granular	46–61 μm (55 μm on average)	Harris,1961

specimens (A21) to a new species, *C. moguqiensis* Zhang, Liu et Liang sp. nov..

5 Discussion

The systematic position of *Coniopteris* was analyzed by Li et al. (2019), who suggested that *Coniopteris* was probably one of stem groups of Polypodiales rather than Dicksoniaceae; however, this required more reliable fossils and plant systematics. Currently, the genus *Coniopteris* was mostly still continue to categorized as Dicksoniaceae (Zheng and Zhang, 1982; Chen et al., 1988; Taylor et al., 1993; Deng, 2002; Kostina et al., 2013; Xin et al., 2018).

The present specimens are well preserved as impressions and compressions, and the fertile and sterile pinnules are isolated preserved in the same fossil. Based on the comparisons and analysis of the features of the sori, sporangia and *in situ* spores, *C. moguqiensis* sp. nov. displays some new characters that should supplement the available data for studies about systematic position and evolutionary trend of *Coniopteris*. Moreover the specimens have provided new material for understanding the terrestrial paleoclimate and paleobiogeography of the Middle Jurassic Wanbao Formation.

So far, petrified wood, megafossil plants and palynological flora have been reported from the Middle Jurassic Wanbao Formation in Inner Mongolia, NE China (Yang and Sun, 1985; Zhang et al., 2018a, b). In general, the Wanbao flora is mainly composed of ferns, ginkgoales and conifers indicating a warm and humid climate with seasonal changes.

6 Conclusion

In summary, combining the comparisons with the analysis of the megafossils described herein, we confirm that the present specimens should be classified as a new species *C. moguqiensis* Zhang, Liu et Liang sp. nov..

Based on the components of megafossil plants, palynological flora and petrified wood, the Middle Jurassic Wanbao flora indicates a warm and humid sub-tropical to temperate climate with seasonal changes.

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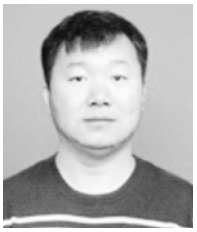

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