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Middle Jurassic Plant Diversity and Climate in the Ordos Basin, China

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Abstract—The Ordos Basin is one of the largest continental sedimentary basins and it represents one major and famous production area of coal, oil and gas resources in China. The Jurassic non-marine deposits are well developed and cropped out in the basin. The Middle Jurassic Yan'an Formation is rich in coal and contains diverse plant remains. We recognize 40 species in 25 genera belonging to mosses, horsetails, ferns, cycadophytes, ginkgoaleans, czekanowskialeans and conifers. This flora is attributed to the early Middle Jurassic Epoch, possibly the Aalenian-Bajocian. The climate of the Ordos Basin during the Middle Jurassic was warm and humid with seasonal temperature and precipitation fluctuations. The result tends to support the palaeophytogeographic/palaeoclimatic setting of the Ordos Basin in the North Floristic Province, or the North Chinese Province in the warm temperate zone during the Middle Jurassic.

Keywords: Middle Jurassic, Yan'an Formation, Plant diversity, Palaeophytogeography, Palaeoclimate, Ordos Basin, China

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INTRODUCTION

The Ordos Basin, bounded by the Yinshan and Daqingshan on the north, the Qinling on the south, the Helanshan and Liupanshan on the west, and the Luliangshan and Taihangshan on the east, is one of the largest continental sedimentary basins (Ritts et al., 2009; Zhao et al., 2012). It consists of a thick, undeformed stratigraphic succession over a wide region, representing a major and famous coal, oil and natural gas producing area in China. The Jurassic non-marine deposits are well developed and mainly exposed in northeastern and central Ordos Basin, and the Middle Jurassic is represented by the Yan'an, the Zhiluo and the Anding formations in ascending order (*Bureau of Geology and Mineral Resources*..., 1991; *Bureau of Geology and Mineral Resources*..., 1996; Wang et al., 2000). The Yan'an Formation is rich in coal resources and contains diverse plant remains.

The fossil plants of the Ordos Basin have been successively studied since the 1930s. Pan (1936) is the first to record the Late Triassic plants of the Ordos Basin. Subsequently, Sze (1956a) described 62 species from the Late Triassic Yanchang Formation of northern Shaanxi and established the Mesozoic floristic succession and continental strata classification scheme in China. The most important publication on the stratigraphy and palaeobotany of the Ordos Basin is probably the monograph by Huang and Zhou (1980). Another important paper describing the Middle Jurassic flora of the southern Ordos Basin was later published by Duan et al. (1986). A series of brief studies on the fossil plants from the Yan'an Formation at Gaotouyao in the northern Ordos Basin were published at the beginning of the 21th century (Ge et al., 2004, 2006, 2007). Additionally, Sun et al. (2011) and Zhao et al. (2011) described the fossil plants from the Yan'an Formation from the Dongsheng Coal Field and attributed the flora of the Yan'an Formation to the Early–Middle Jurassic in age.

However, all the aforementioned palaeobotanical studies were based on material without cuticle. With the discovery of new material with well-preserved

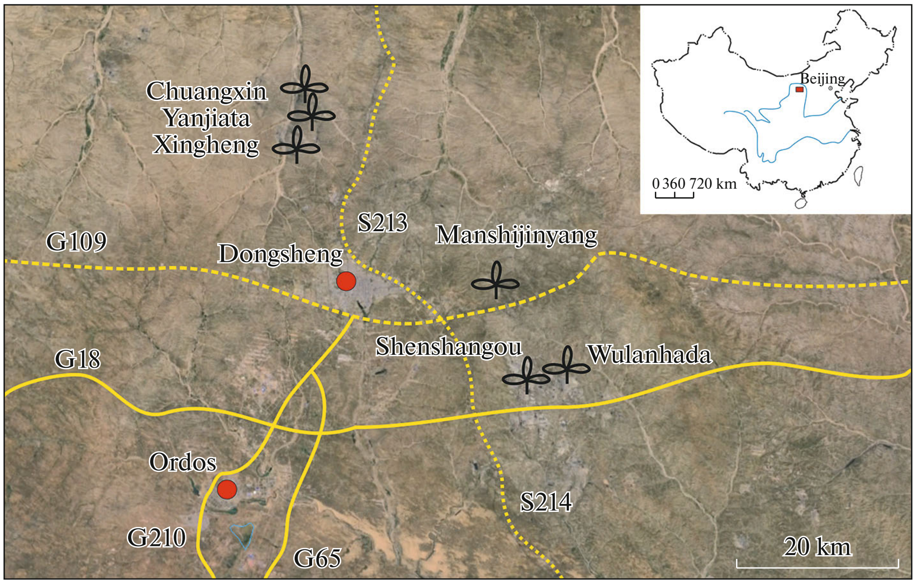

Fig. 1. Geographic map showing the fossil localities in the northeastern area of the Ordos Basin, China.

cuticle from the Ordos Basin, it is now possible to carry out detailed study on the cuticular anatomy of these plant fossils and provide important information in resolving their systematic positions. In addition to studying the Middle Jurassic plant diversity pattern and palaeoclimate of the Ordos Basin, it is also possible to assess the floristic assemblages and to apply this information in biostratigraphic correlations. Recently, with the ongoing conversion of the coal mining operations from underground to the surface, more and more coal seams and plant-bearing beds have been exposed, providing good opportunities to collect and study the fossil plants in a sequential order in this area. During the 2012 and 2015 field seasons, we visited six opencast coal mines in the northeastern area of the Ordos Basin and collected numerous beautiful and well-preserved plant megafossils from the Middle Jurassic Yan'an Formation. Preliminarily investigations show that the flora of the Middle Jurassic Yan'an Formation is very diverse, consisting of mosses, horsetails, ferns, cycadophytes, ginkgoaleans, czekanowskialeans and conifers (Li et al., 2015a, b; Sun et al., 2015a). Among these collections, a number of taxa have well-preserved cuticle (i.e., cycadophytes, ginkgoaleans, czekanowskialeans and conifers). The leaf morphology, cuticular characters and diversity pattern of the Czekanowskiales from the Middle Jurassic sediments of the northern part of the Ordos Basin have been studied and published (Li et al., 2014, 2015a; Sun et al., 2015a, Sun et al., 2015b). A new species of the genus *Eretmophyllum* (Ginkgoales), *E. neimengguensis* Li et Sun, was reported by Li et al. (2018) from the same area.

The purpose of this paper is to present a brief review of the plant biodiversity of the Middle Jurassic Yan'an Flora, and to discuss the biostratigraphic, palaeophytogeographic and palaeoclimatic implications based on our examinations on the plant fossil materials collected from the Ordos Basin. In this paper, plant fossil taxa are mentioned mostly at the generic level. Detailed palaeobotanical studies on the leaf cuticular structure and their systematics will be published separately. This study will provide helpful information for the stratigraphic correlation of the Early Mesozoic coal bearing strata in the Ordos Basin, and will widen our knowledge on the Middle Jurassic plant diversity and palaeoclimate of northern China.

GEOLOGICAL SETTINGS, MATERIAL, AND METHOD

The plant remains studied here were collected from the Middle Jurassic coal-bearing Yan'an Formation from six opencast coal mines in the northeastern area of the Ordos Basin, Inner Mongolia, China, including Chuangxin Coal Mine (40°0′37.67″ N, 109°54′50.58″E), Yanjiata Coal Mine (39°59′46.00″ N, 109°55′52.00″ E), Xingheng Coal Mine (39°57′58.37″ N, 109°54′20.00″ E), Manshijinyang Coal Mine (39°47'52.62" N, 110°10′39.13″ E), Shenshangou Coal Mine (39°42′10.90″ N, 110°13′44.00″ E) and Wulanhada Coal Mine (39°42′19.56″ N, 110°16′14.67″ E) (Fig. 1).

Tectonically, the Ordos Basin is located in the western part of North China Block (Hu et al., 2013; Ritts et al., 2009; Zhao et al., 2015). A relatively continuous continental sedimentary strata was formed in the Triassic to the Early Cretaceous and had remained undeformed (He, 2003; Ritts et al., 2009). The Mesozoic strata include the Triassic, Jurassic and Creta-

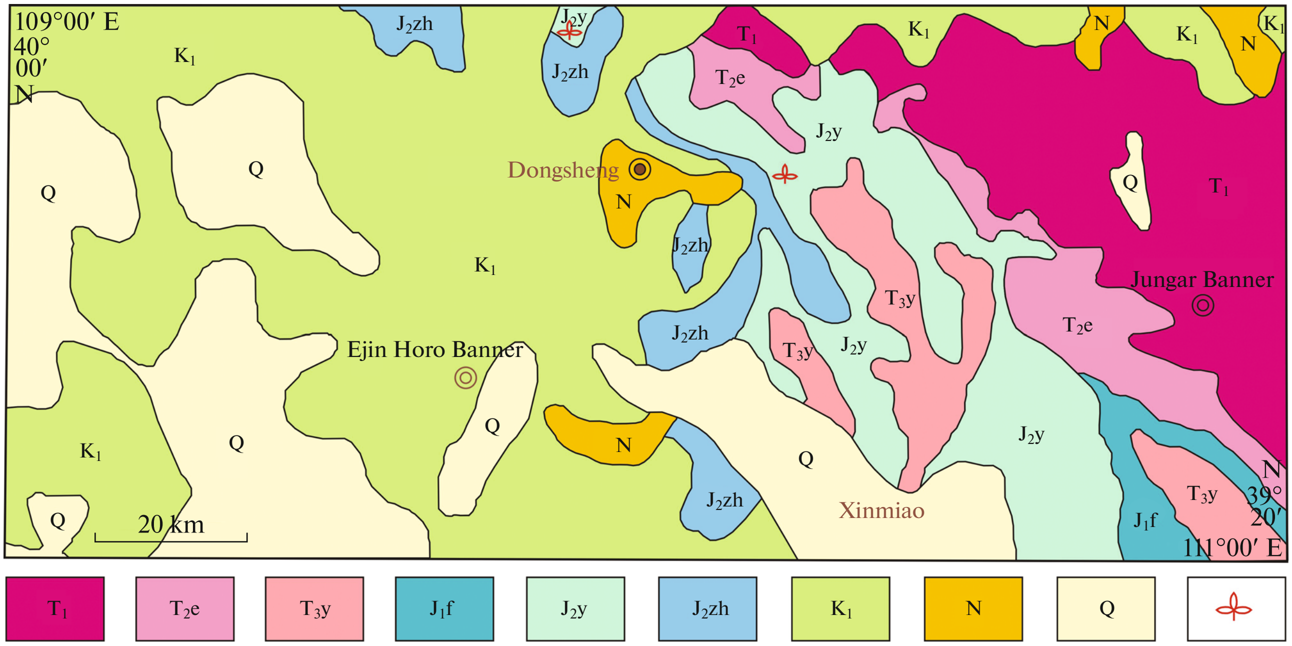

Fig. 2. Geological map of the northeastern area of the Ordos Basin, China (modified after Geological Survey Institute of Inner Mongolia, 2010). T_1, Lower Triassic; T_2e, Middle Triassic Ermaying Formation; T_3y, Upper Triassic Yanchang Formation; J_1f, Lower Jurassic Fuxian Formation; J_2y, Middle Jurassic Yan'an Formation; J_2zh, Middle Jurassic Zhiluo Formation; K_1, Lower Cretaceous; N, Neogene; Q, Quaternary; Trifoliate leaf symbols indicate fossil sites.

ceous continental deposits. The Jurassic deposits were divided into four formations, in ascending order, the Lower Jurassic Fuxian Formation, the Middle Jurassic Yan'an, Zhiluo and Anding formations (Huang and Zhou, 1980; He et al., 2004; Sun et al., 2015a).

In the northeastern area of the Ordos Basin, the well-developed Yan'an Formation unconformably overlies the Upper Triassic Yanchang Formation and is conformably overlain by the Middle Jurassic Zhiluo Formation (Fig. 2). The Yan'an Formation consists of two members. The lower member is the main coal-bearing deposits and comprises sandstone, siltstone, mudstone and coal seams, representing fluvial, lacustrine and swamp environments. The upper member is characterized by lacustrine deposits. In recent years, we have collected abundant fossil plants and a few bivalves from the lower part of the lower member (Fig. 3).

We examined over 1000 specimens collected from the siltstone, mudstone and fine-grained sandstone beds in the lower part of the lower member of the Yan'an Formation. Plant remains are represented by thalluses, leaves, leafy shoots, stems, and male and female fructifications preserved as compressions. The majority of the plant remains are represented by leaves. Fine details of leaf morphology and comparatively complete leafy shoots provide evidence of short distance transportation to burial. Cuticle of some taxa (i.e., cycadophytes, ginkgoaleans, czekanowskialeans and conifers) is usually well preserved, allowing details of the cuticle to be studied. Hand specimens were examined using a stereomicroscope (Olympus SZX10). The photographs were taken using a Canon digital camera (Canon 5D Mark II) and Keyence digital microscope with a camera attachment (Keyence VHX-1000). Plates and figures were made using Adobe Photoshop CS5, CorelDraw X7 sp2, MapGIS67 and DGSInfo 1.0. All specimens and preparations are stored at the Research Center of Palaeontology and Stratigraphy of Jilin University, Changchun, China. Hand specimens are numbered using prefix capital letters, which denote the fossil localities. For example, MSJY denotes the locality in the Manshijinyang Coal Mine.

PLANT DIVERSITY

Field investigation and specimen collections suggest that plants are diverse during the Middle Jurassic time in the Ordos Basin. Based on examination of specimens, we recognized 40 species of 25 genera, belonging to mosses, horsetails, ferns, cycadophytes, ginkgoaleans, czekanowskialeans and conifers (Table 1). The species diversity of each group is shown in Fig. 4. All taxa listed below are illustrated in Figs. 5–11.

Ferns show a relatively high diversity in the flora (Figs. 4, 7, 8), contributing 25% of the species diversity. Recognized taxa are allied to Osmundaceae and Dicksoniaceae. They are assigned to ten species belonging to four genera: *Coniopteris*, *Cladophlebis*,

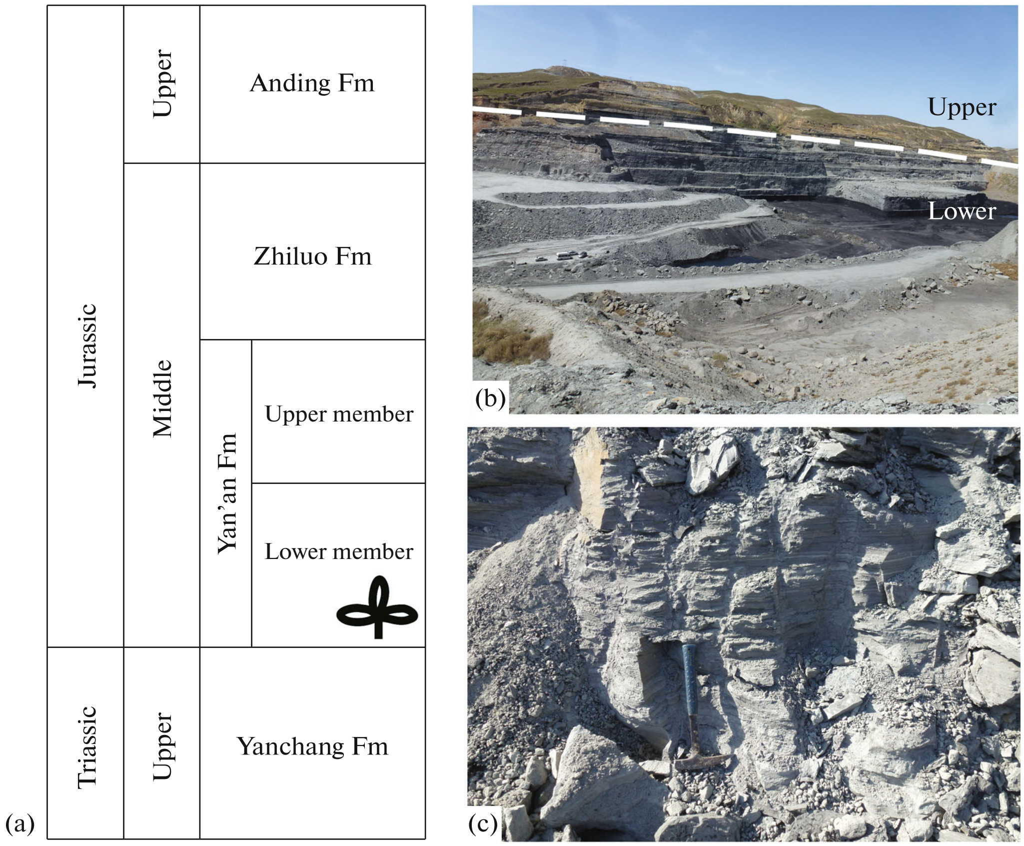

Fig. 3. (a) Generalized stratigraphic column of the Triassic and Jurassic strata in the Ordos Basin, China. Plant fossils were collected from the lower member of the Yan'an Formation; (b) part of section of the Middle Jurassic Yan'an Formation showing the upper and lower members; (c) field images of the lower member showing siltstones and fine-grained sand stones of the plant-bearing beds.

Todites and *Eboracia* (only sterile leaves were found). *Coniopteris* (3 species) and *Cladophlebis* (5 species) are the most diverse. Representatives of *Todites* and *Eboracia* show rather low species diversity, each with one single species. Fine details of venation and leaf morphology of fern elements are illustrated to corroborate their specific determinations (Fig. 5).

Following ferns are the ginkgoaleans (20%) and czekanowskialeans (20%). Ginkgoaleans (Figs. 9, 10) are represented by *Ginkgo*, *Baiera*, *Sphenobaiera,* and *Eretmophyllum*. *Ginkgo* is the most common and species rich (3 species). Their well-preserved cuticular features corroborate their generic determinations. *Baiera* and *Sphenobaiera* are of low species diversity, with two species and one species respectively. Significantly, oar-like ginkgoalean leaves were described as a new species of the genus *Eretmophyllum* (*E. neimengguensis*) based upon the gross leaf morphology and cuticular structure. It is the first record of the genus *Eretmophyllum* with cuticular structure in China (Li et al., 2017). Possibly closed to male strobili of Ginkgoales, *Stenorachis bellus* Mi et al. have also been recognized from this flora. Czekanowskialeans (Fig. 10) are represented by leaves and leafy short shoots belonging to *Czekanowskia* and *Phoenicopsis*, male fructifications of *Ixostrobus* and female fructifications attributable to *Leptostrobus*. *Czekanowskia* (subg. *Harrisella*) *ordosensis* C.-L. Sun, H.-S. Wang, D. L. Dilcher, T. Li, Y.-F. Li, Y.-L. Na is recognizable by its cuticular characteristics (Sun et al., 2015b). Among czekanowskialeans, *Phoenicopsis* is the most species diverse. Three species of three subgenera were recognized by their cuticular features: *Ph.* (subg. *Culgoweria*) *ordo-*

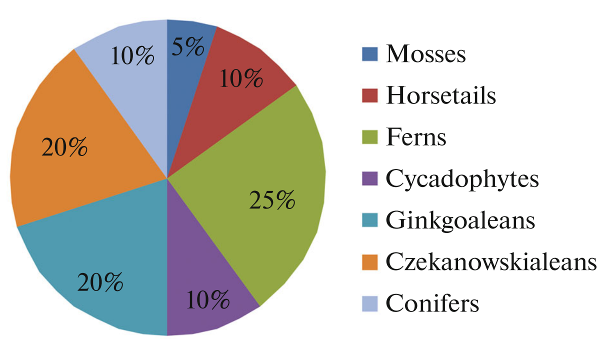

Fig. 4. Floristic composition of the Yan'an Flora.

Table 1. Floristic components of the Ordos flora and their occurrences at the different localities in the northeastern area of the Ordos Basin

Taxa	Locality					
	Chuang-xin	Yan-jiata	Xing-heng	Manshi-jinyang	Shenshan-gou	Wulan-hada
Mosses						
Hepaticites arcuatus (L.et H.) Harris			+			
Thallites sp.				+		
Horsetails						
Equisetites laterale (Phillips) Phillips				+		
Equisetostachys sp.		+				
Neocalamiteshoerensis (Schimper) Halle			+	+		
Annulariopsis bunkeiensis (Kobatake) Kimura			+			
Ferns						
Todites williamsoni (Brongniart) Seward		+				
Cladophlebis asiatica Chow et Yeh						+
Cladophlebis haiburnensis (L. et H.) Brongniart			+			
Cladophlebis hirta Moeller		+			+	
Cladophlebis nebbensis (Brongniart) Nathorst						+
Cladophlebis tsaidamensis Sze			+			
Coniopteris burejensis (Zalessky) Seward	+		+	+	+	
Coniopteris hymenophylloides (Brongniart) Seward				+		+
Coniopteris simplex (L. et H.) Harris	+					
Eboracia lobifolia (Phillips) Thomas				+		
Cycadophytes						
Pterophyllum irregulare Nathorst		+				
Pterophyllum sp. 1			+		+	
Pterophyllum sp. 2					+	
Nilssonia tenuicaulis (Phillips) Nathorst		+				
Ginkgoaleans						
Ginkgo sp. 1				+		
Ginkgo sp. 2			+			
Ginkgo sp. 3		+			+	
Baiera sp. 1				+		
Baiera sp. 2				+		

Table 1. (Contd.)

Taxa	Locality					
	Chuang-xin	Yan-jiata	Xing-heng	Manshi-jinyang	Shenshan-gou	Wulan-hada
Sphenobaiera sp. 1		+		+		+
Eretmophyllum neimengguensis Li et Sun				+		
Stenorachis bellus Mi et al.			+			
Czekanowskialeans						
Czekanowskia (subg. *Harrisella*) *ordosensis* Sun et al.		+	+	+	+	
Phoenicopsis (subg. *Culgoweria*) *ordosensis* Li et al.		+				
Phoenicopsis (subg. *Phoenicopsis*) *ordosensis* Li and Sun		+		+	+	
Phoenicopsis (subg. *Windwardia*) sp.					+	
Phoenicopsis sp.						+
Ixostrobus lepidus (Heer) Harris	+		+	+		
Ixostrobus cf. *whitbiensis* Harris	+		+			
Leptostrobus cancer Harris					+	
Conifers						
Pityophyllum lindstroemi Nathorst						+
Sewardiodendron laxum (Phillips) Florin		+	+	+		

sensis Y.-F. Li, C.-L. Sun, D. L. Dilcher, H.-S. Wang, T. Li, Y.-L. Na, A.-P. Wang, *Ph.* (subg. *Phoenicopsis*) *ordosensis* Li et Sun, and *Ph.* (subg. *Windwardia*) sp. (Li et al., 2014, 2015a; Sun et al., 2015a). Phoenicopsis-type leaves preserved as impression are assigned to *Phoenicopsis* sp.

Each of the following three groups, i.e., cycadophytes, horsetails and conifers, account for 10% of the species diversity. Cycadophytes (Figs. 4, 8) are of low species diversity. Three species of *Pterophyllum* and one species of *Nilssonia* are recognized. Horsetails (Fig. 6) are represented by impressions of stems and nodal diaphragms referable to *Equisetites laterale* (Phillips) Phillips and *Neocalamites hoerensis* (Schimper) Halle, stems with attached leaf whorls attributed to *Annulariopsis bunkeiensis* (Kobatake) Kimura. Among them, the first predominates. Strobili of *Equisetites* were attributed to *Equisetostachys* sp. Among conifers, *Pityophyllum*, *Sewardiodendron*, *Podozamites* and *Elatocladus* were identified, with one species each. Whereas, seed cones attached leafy shoots attributed to *Sewardiodendron laxum* (Phillips) Florin is most common.

Mosses (Figs. 4, 6) are the lowest diverse (5%). Only *Hepaticites arcuatus* (L.et H.) Harris and *Thallites* sp. are recognized based on a few specimens.

AGE OF THE FLORA

Previous biostratigraphic research suggests the age of the Yan'an Formation as the Middle Jurassic (Huang and Zhou, 1980; Duan et al., 1986; *Bureau of Geology and Mineral Resources...*, 1991, 1996; Zhou, 1995; Wang et al., 2000; He et al., 2004). Our study of the flora from the Yan'an Formation, based on examinations of a much larger collection, allows more precise biostratigraphic correlations of the plant-bearing deposits.

Firstly, *Hepaticites arcuatus* (mosses) has only been found in the Bajocian "Middle Deltaic Series" of Yorkshire, England (Harris, 1961) and the Middle Jurassic Orgilokhbulag Formation of South Mongolia (Kostina and Herman, 2013).

As to horsetails, *Equisetites laterale* was firstly described from the Middle Jurassic flora of Yorkshire, England (Phillips, 1829; Harris, 1961) and is widely distributed in the Early and Middle Jurassic of Eurasia (Chen et al., 1984; Li et al., 1988; Vakhrameev, 1991; Zhou, 1995; Mi et al., 1996; Zhang et al., 1998; Kostina and Herman, 2013; Kostina et al., 2015). It is well known that, during the Late Triassic to the Early Jurassic, the stems of *Equisetites* and *Neocalamites* are relatively strong, while in the Middle Jurassic, these taxa were mostly with slender stems. Vakhrameev (1988, 1991) thought that *Neocalamites* is a typical

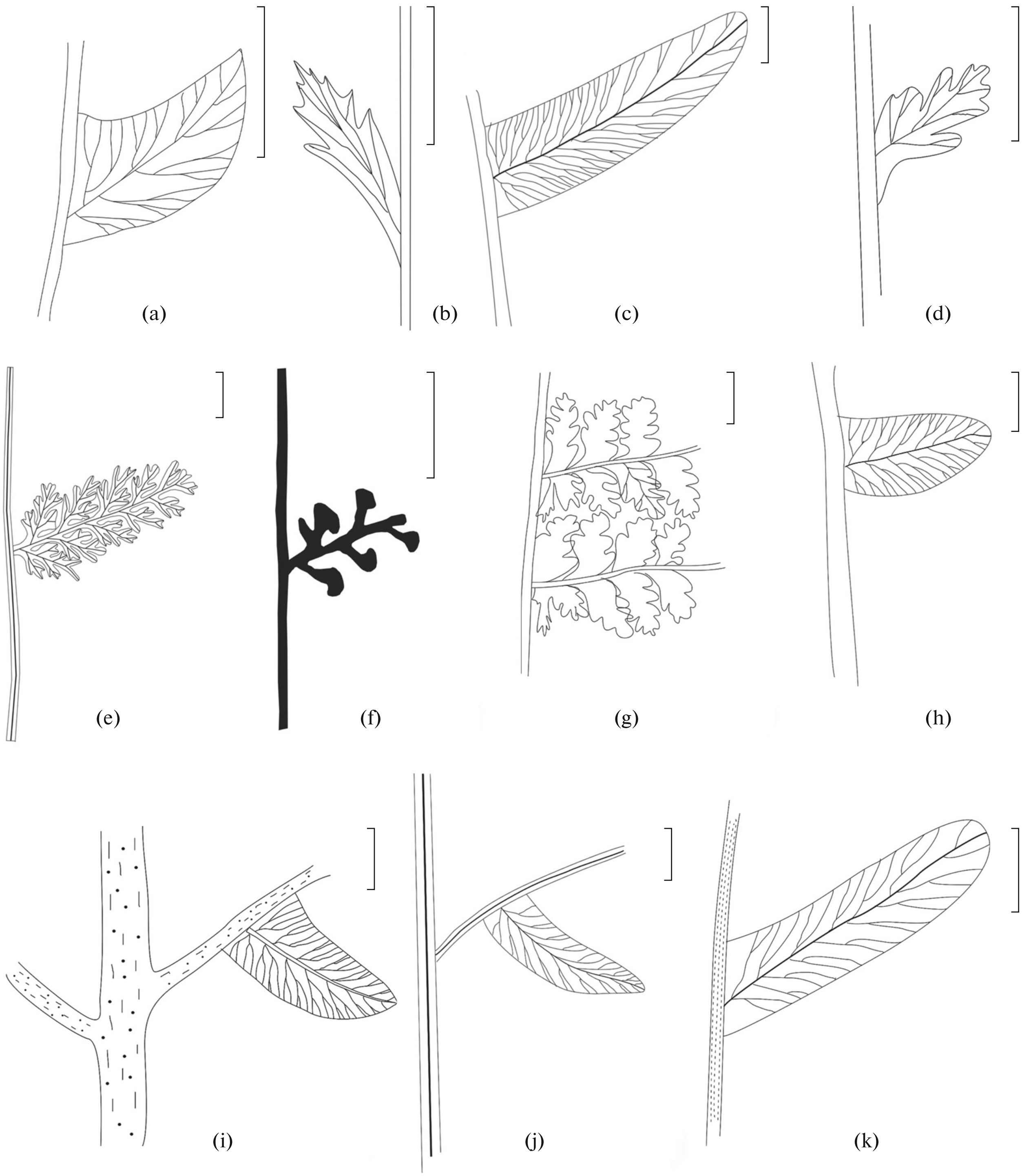

Fig. 5. Line drawing of the fern leaves: (a) *Todites williamsoni* (Brongniart) Seward, YJT075; (b) *Coniopteris burejensis* (Zalessky) Seward, SSG005; (c) *Cladophlebis haiburnensis* (L. et H.) Brongniart, XH018; (d) *Coniopteris hymenophylloides* (Brongniart) Seward, MSJY032; (e) *Coniopteris simplex* (L. et H.) Harris, sterile pinna, CX008; (f) *Coniopteris simplex* (L. et H.) Harris, fertile pinna, CX026; (g) *Eboracia lobifolia* (Phillips) Thomas, MSJY033; (h) *Cladophlebis asiatica* Chow et Yeh, WLHD001; (i) *Cladophlebis hirta* Moeller, YJT080; (j) *Cladophlebis tsaidamensis* Sze, XH001; (k) *Cladophlebis nebbensis* (Brongniart) Nathorst, SSG003. All scale bars = 5 mm.

Early Jurassic taxon. However, it usually occurred in the Middle Jurassic floras of North China which infers that those floras were the early Middle Jurassic in age (Zeng et al., 1995; Zhang et al., 1998). Therefore, the occurrence of *Equisetites laterale* and *Neocalamites hoerensis* with slender stems support that the age of the present flora is the early Middle Jurassic.

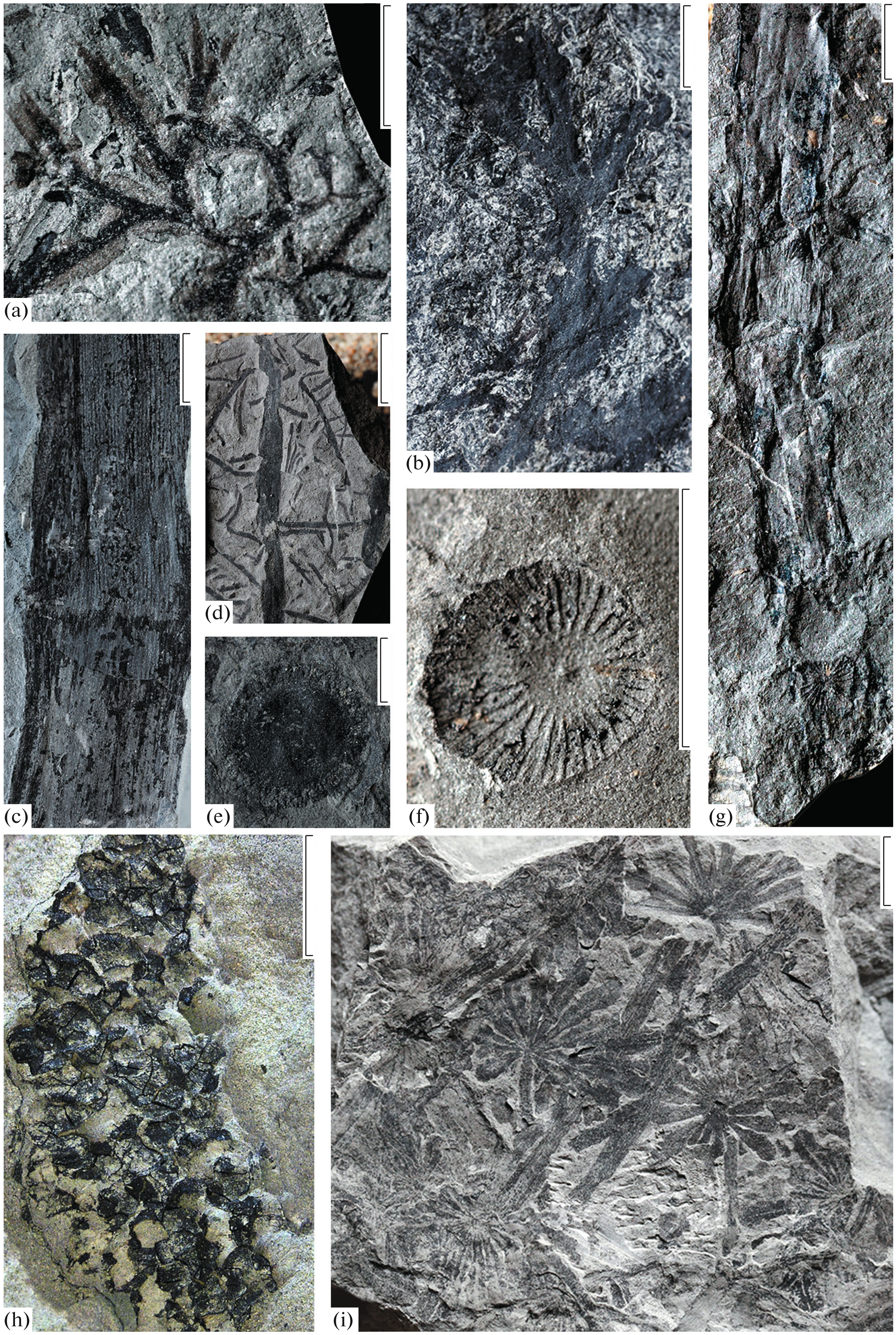

Fig. 6. Mosses and horsetails: (a) *Hepaticites arcuatus* (L.et H.) Harris, XH035; (b) *Thallites* sp., MSJY035; (c) *Neocalamites hoerensis* (Schimper) Halle, stem, XH006; (d) *Neocalamites hoerensis* (Schimper) Halle, branch with leaves, MSJY083; (e) *Neocalamites hoerensis* (Schimper) Halle, nodal diaphragm, MSJY070; (f) *Equisetites laterale* (Phillips), stem and nodal diaphragm, MSJY052; (g) *Equisetites laterale* (Phillips), nodal diaphragm,MSJY084; (h) *Equisetostachys* sp., YJT012; (i) *Annulariopsis bunkeiensis* (Kobatake) Kimura, XH031. All scale bars = 10 mm.

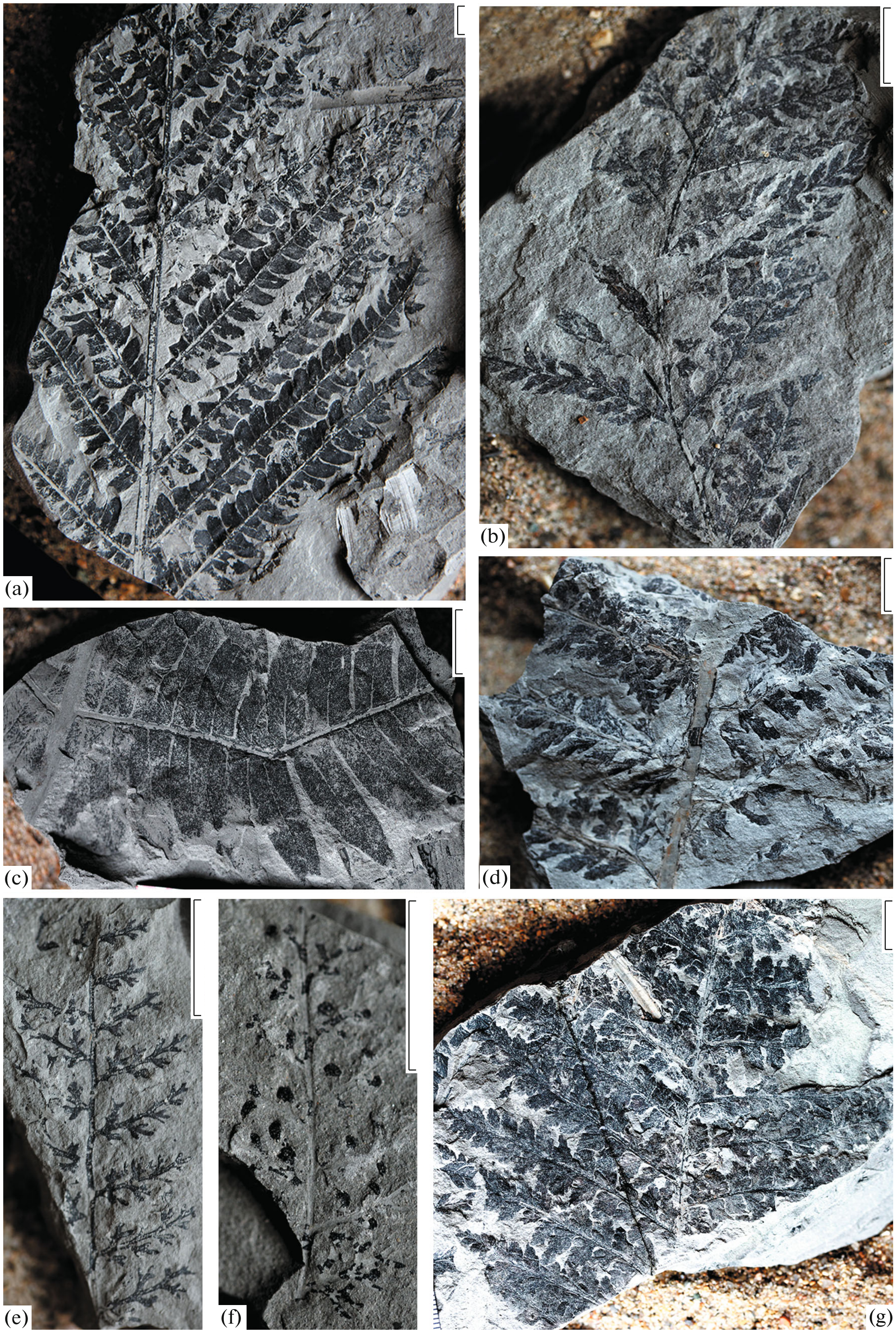

Fig. 7. Ferns: (a) *Todites williamsoni* (Brongniart) Seward, YJT075; (b) *Coniopteris burejensis* (Zalessky) Seward, SSG005; (c) *Cladophlebis haiburnensis* (L. et H.) Brongniart, XH018; (d) *Coniopteris hymenophylloides* (Brongniart) Seward, MSJY032; (e) *Coniopteris simplex* (L. et H.) Harris, sterile pinna, CX002; (f) *Coniopteris simplex* (L. et H.) Harris, fertile pinna, CX026; (g) *Eboracia lobifolia* (Phillips) Thomas, MSJY033. All scale bars = 10 mm.

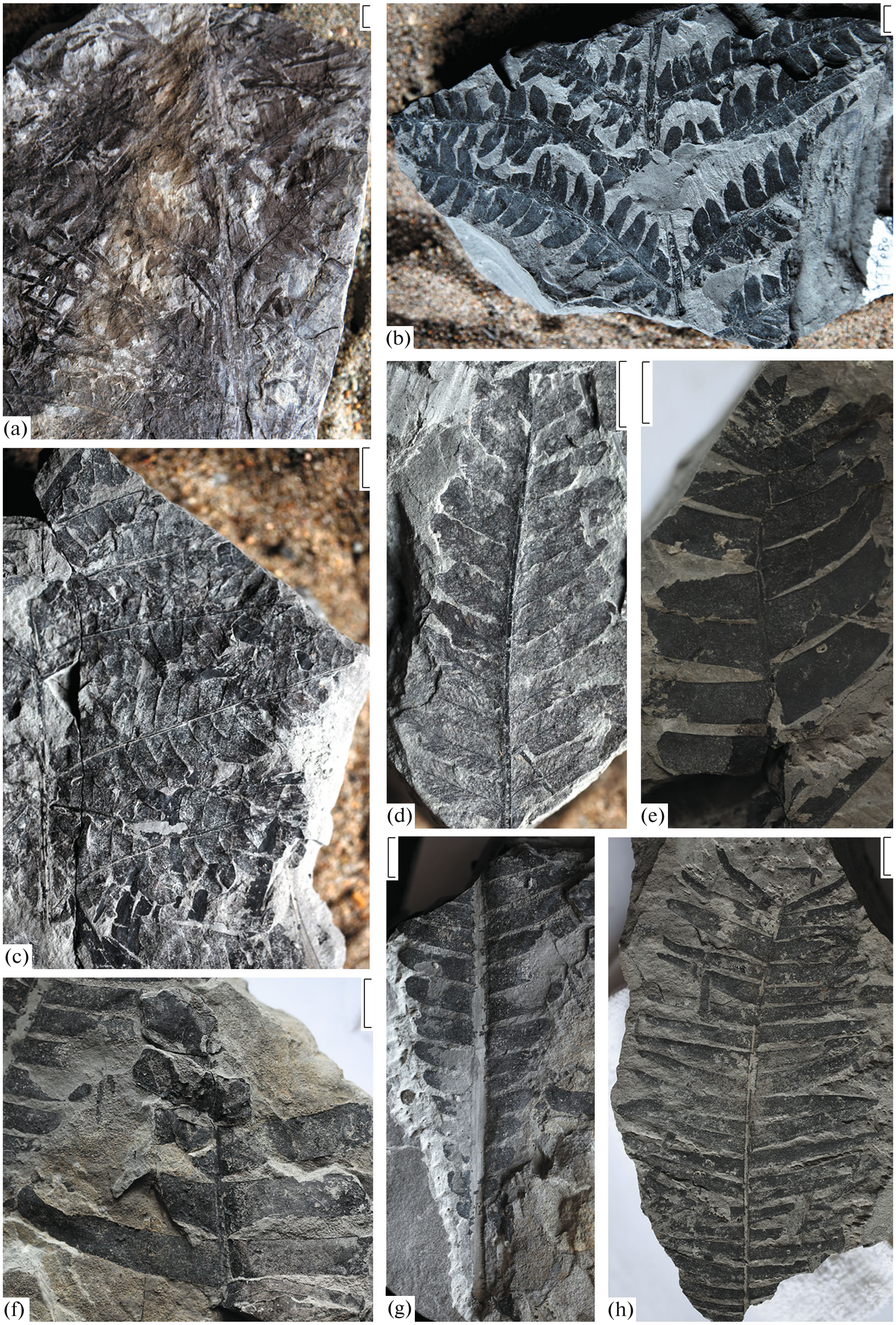

Fig. 8. Ferns and cycadophytes: (a) *Cladophlebis asiatica* Chow et Yeh, WLHD001; (b) *Cladophlebis hirta* Moeller, YJT080; (c) *Cladophlebis tsaidamensis* Sze, XH001; (d) *Cladophlebis nebbensis* (Brongniart) Nathorst, SSG003; (e) *Pterophyllum irregular* Nathorst, YJT055; (f) *Pterophyllum* sp. 1, SSG006; (g) *Pterophyllum* sp. 2, SSG006-1; (h) *Nilssonia tenuicaulis*(Phillips)Nathorst, YJT054. All scale bars = 10 mm.

Fig. 9. Ginkgoaleans:(a) *Ginkgo* sp. 1, MSJY005; (b) *Ginkgo* sp. 2, XH025; (c) *Ginkgo* sp. 3, SSG018; (d) *Baiera* sp. 1, MSJY036; (e) *Baiera* sp. 2, MSJY023; (f) *Eretmophyllum neimengguensis* Li et Sun, MSJY062; (g) *Sphenobaiera* sp. 1, MSJY074. All scale bars = 10 mm.

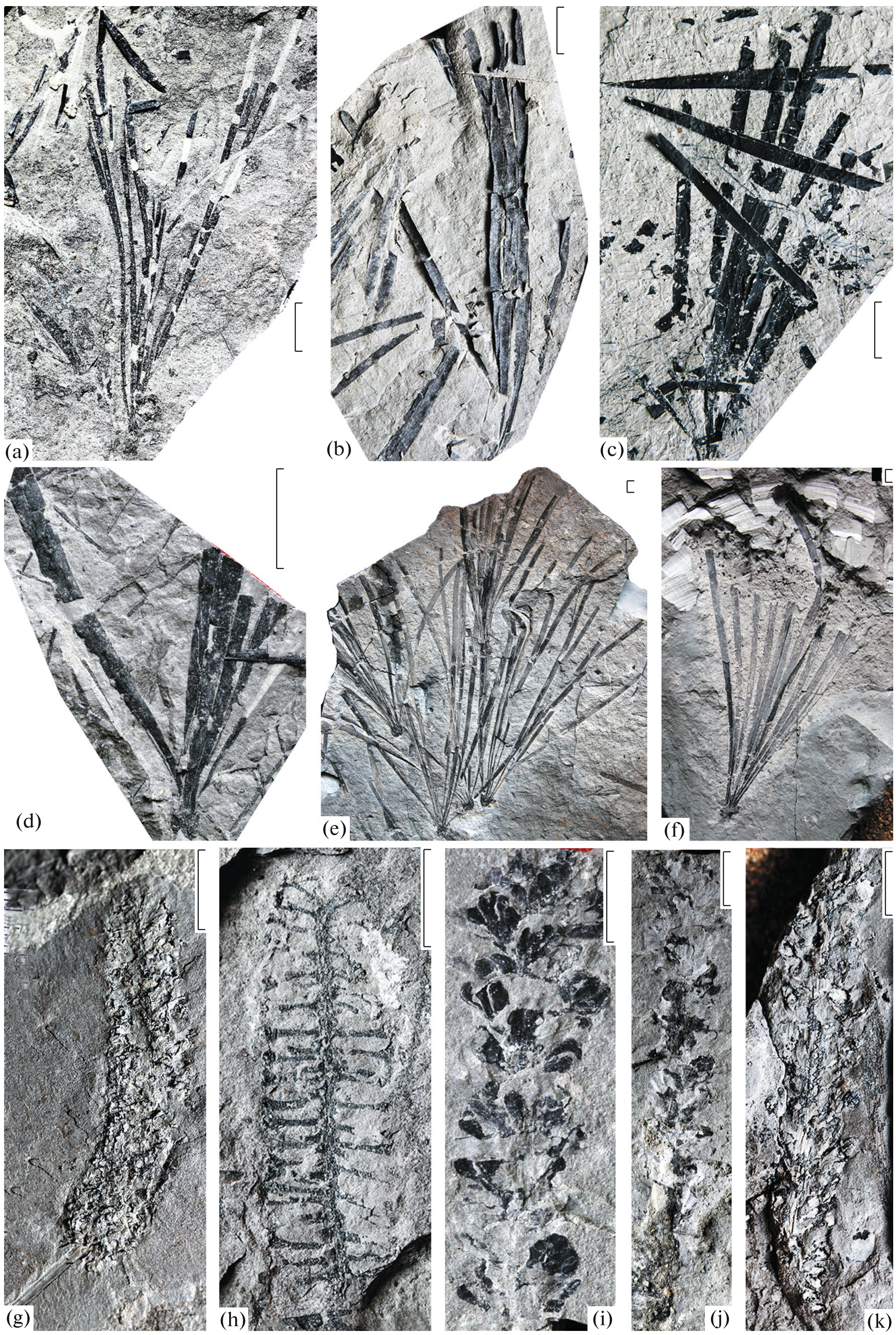

Fig. 10. Czekanowskialeans and ginkgoaleans incertae sedis: (a) *Czekanowskia* (subg. *Harrisella*) *ordosensis* Sun et al., YJT062; (b) *Phoenicopsis* (subg. *Windwardia*) sp., SSG018; (c) *Phoenicopsis* (subg. *Culgoweria*) *ordosensis* Li et al., YJT001; (d) *Phoenicopsis* (subg. *Phoenicopsis*) *ordosensis* Li and Sun, SSG011; (e) *Phoenicopsis* sp., WLHD069; (f) *Phoenicopsis*sp., WLHD064; (g) *Ixostrobus lepidus* (Heer) Harris, MSJY031; (h) *Ixostrobus* cf. *whitbiensis* Harris, XH003; (i) *Leptostrobus cancer* Harris, YJT003-1; (j) *Leptostrobus cancer* Harris, YJT003-2; (k) *Stenorachis bellus* Mi et al., XH024. All scale bars = 10 mm.

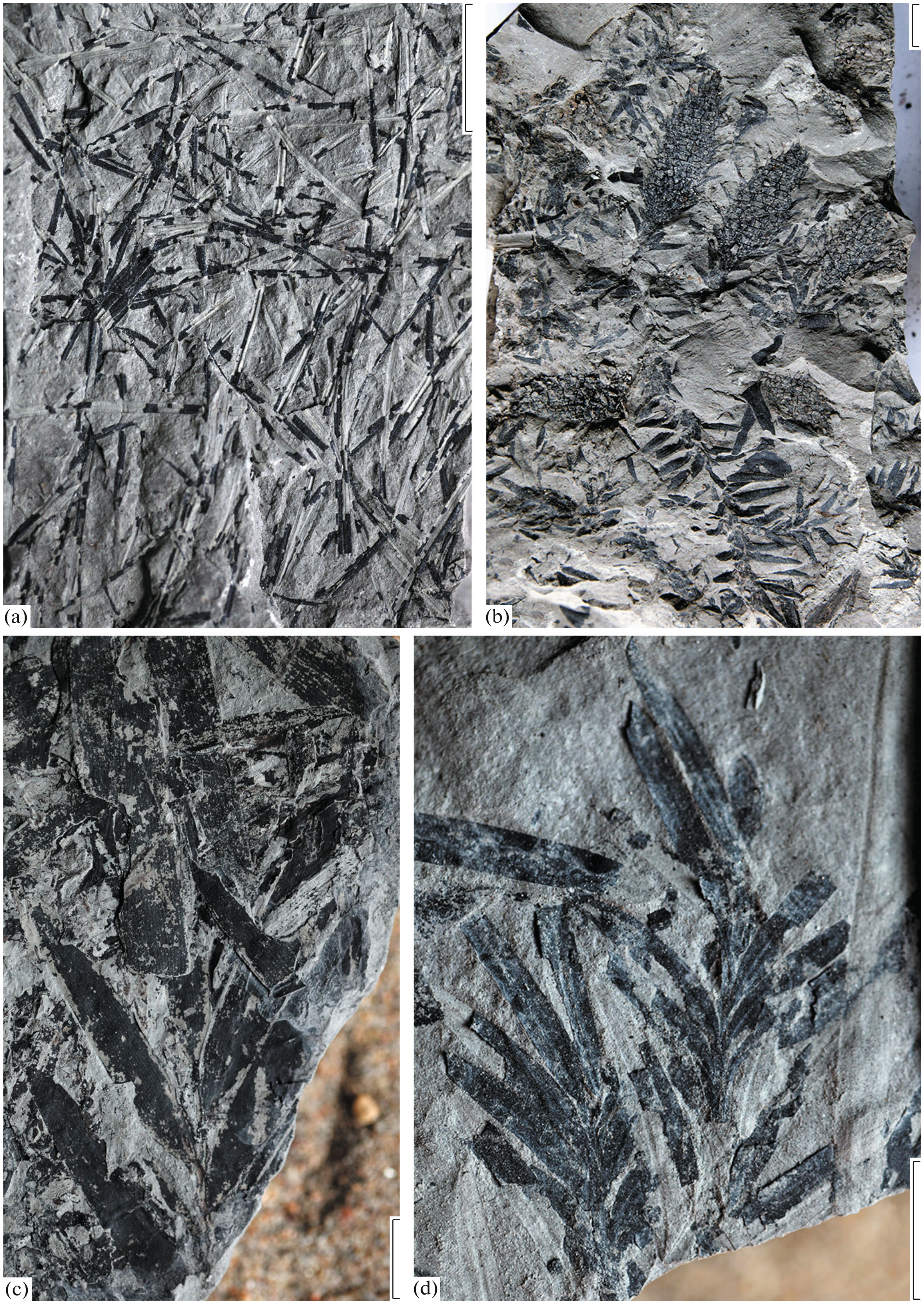

Fig. 11. Conifers: (a) *Pityophyllum lindstroemi* Nathorst, SSG007; (b) *Sewardiodendron laxum* (Phillips) Florin, YJT047; (c, d) *Podozamites distans* (Presl) Braun, (c) XH022; (d) XH010. All scale bars = 10 mm.

The present flora is characterized by the high diversity of the fern genera *Coniopteris* (Dicksoniaceae) and *Cladophlebis*. It is widely accepted that the Dicksoniaceae were flourished with a high species diversity of the genus *Coniopteris*, which is usually represented by several species (four or more) in the Middle Jurassic (especially Bajocian) floras throughout the Northern Hemisphere (Brick, 1953; Harris, 1961; Teslenko, 1970; Vakhrameev, 1974, 1991; Genkina, 1977, 1979; Luchnikov, 1982; Chen et al., 1984; Duan, 1987; Li et al., 1988; Zeng et al., 1995; Mi et al., 1996; Zhang et al., 1998; Shang et al., 1999b; Deng and Lu, 2006; Kiritchkova et al., 2002; Deng et al., 2003; 2017; Kostina and Herman, 2013). *Coniopteris hymenophylloides* (Brongniart) Seward, one of the typical Middle Jurassic species through the Northern Hemisphere, is also present in the Yan'an Flora. *C. burejensis* (Zalessky) Seward and *C. simplex* (L. et H.) Harris are not only the important elements of the Middle Jurassic Yorkshire Flora of England, but also are common in the Middle Jurassic floras of North China and East Asia. Another ferns species, *Eboracia lobifolia* (Phillips) Thomas, is also a characteristic member from Middle Jurassic in Siberian area. Additionally, some common genera of the Late Triassic-Early Jurassic (e.g., *Dictyophyllum* and *Clathropteris*) were not found in the flora.

Cycadophytes are only represented by bennettitalean *Pterophyllum* and cycadalean *Nilssonia* which were common in the Late Triassic and Jurassic floras. *Pterophyllum irregulare* Nathorst was recorded from the Rhaetian-Bajocian (Late Triassic—Middle Jurassic) flora of Scania, southern Sweden (Pott, McLoughlin, 2009). *Nilssonia tenuicaulis* (Phillips) Nathorst has been found in the Middle Jurassic floras of Yorkshire, England (Harris, 1964) and Hebei, China (Sze and Li, 1963; Mi et al., 1996).

Ginkgoaleans and czekanowskialeans were flourished throughout Mesozoic, but they were rather diverse in the Middle Jurassic. Among conifers, *Pityophyllum lindstroemi* Nathorst is widely distributed in the Jurassic deposits of North China. *Sewardiodendron laxum* has only been found in the Bajocian "Lower and Middle Deltaic Series" of Yorkshire, England (Harris, 1979) and in the Middle Jurassic (Bajocian to Bathonian) flora of Yima, Henan (Yao et al., 1989; 1998; Zeng et al., 1995). *Elatocladus* sp. is very similar to *Elatocladus ramosus* (Florin) Harris from the Middle Jurassic flora of Yorkshire, England (Harris, 1979) and *E. qaidamensis* Wu from the Middle Jurassic flora of the Qaidam Basin, Qinghai (Li et al., 1988).

Furthermore, the composition of the Yan'an Flora is very similar to those of the Aalenian-Bajocian from the North China and Mongolia, e.g. the floras of the Dameigou Formation from the Qaidam Basin (Li et al., 1988), the Haifanggou Formation from west Liaoning (Mi et al., 1996), the Shangyaopo Formation from Western Hill of Beijing (Chen et al., 1984) and the Nariin-Sukhait Flora of South Mongolia (Kostina and Herman, 2013), the Tsagan-Ovoo Flora of Central Mongolia (Kostina et al., 2015).

In summary, the age of the Yan'an Flora is attributed to the early Middle Jurassic, possibly the Aalenian-Bajocian, based upon correlation with coeval floras. This conclusion is also supported by palynological data. The temporal distribution of palynomorph and comparison with similar the early Middle Jurassic palyno-assemblages of Eurasia infer that the palynoflora from the Yan'an Formation should be early Middle Jurassic, possibly the Aalenian-Bajocian (Shang, 1995; Yin and Hou, 1999; Jiang and Wang, 2002; Sun et al., 2017).

PALAEOPHYTOGEOGRAPHIC AND PALAEOCLIMATIC IMPLICATIONS

The Yan'an Flora is of palaeophytogeographic and palaeoclimatic significance. According to Vakhrameev (1964, 1974, 1988), during the Early to Middle Jurassic, Eurasia was divided into two palaeofloristic regions: the Siberian Region with a temperate or warm-temperate climate and the Euro-Sinian Region with a subtropical climate. In China, the northern and the southern floristic regions, usually referred to *Coniopteris-Phoenicopsis* and *Dictyophyllum-Clathropteris* floras, respectively, were proposed based upon the floristic components. The northern floristic region is situated in the Siberian Region, and the southern floristic Region is in the Euro-Sinian Region (Sze, 1956b; Sze and Chow, 1962; Sze and Li, 1963; Zhou, 1995). Our study shows that the Yan'an Flora is mainly composed of ginkgoaleans, czekanowskialeans, conifers, ferns and a few members of cycadophytes. It is characterized by the abundance and high diversity of the fern genera *Coniopteris* and *Cladophlebis*, the absence of thermophilous ferns belonging to the families Dipteridaceae, Marattiaceae and Matoniaceae, the scarcity and low diversity of cycadaleans and bennettitaleans, the abundance and high diversity of ginkgoaleans and czekanowskialeans, the abundance of conifer foliage assignable to *Pityophyllum* and the presence of *Podozamites* and *Elatocladus*, and the absence of thermophilic conifers with adpressed scale-like and rigid hook-like leaves (e.g., *Brachyphyllum* and *Pagiophyllum*). The composition of the Middle Jurassic Yan'an Flora demonstrates that it clearly lies in the Siberian Region or in a typical *Coniopteris-Phoenicopsis* flora, characterized by a temperate or warm temperate climate. Along with more and more knowledge about the floras of the Siberian Region, it is worth noting that some palaeobotanists have noticed that the taxonomic composition of the Early and Middle Jurassic floras from the south part of the Siberian Region was different from the north Siberian Region, characterized by the presence of a small number of thermophilous ferns, cycadaleans and bennettitaleans (Sun, 1992;

Kiritchkova et al., 2005; Sun et al., 2010, 2015a; Kostina and Herman, 2013, Kostina et al., 2015). Based upon the composition, the south part of the Siberian Region can be considered to be a mixed zone (ecotone) between the Euro-Sinian Region and the Siberian Region. In Gordenko's (2008) opinion, *Phoenicopsis*, *Eretmophyllum*, *Czekanowskia,* and *Podozamites*, which are usual indicators of ecotone floras, are usually present in the mixed zone. This mixed zone was referred to the North Floristic Province (Sun, 1992; Sun et al., 2010, 2015a) or the North Chinese Province (Kiritchkova et al., 2005; Kostina and Herman, 2013, Kostina et al., 2015). The floristic components of the Middle Jurassic Yan'an Flora are similar to those of the North Floristic Province or the North Chinese Province, reflecting a warm-temperate climate.

On the other hand, vegetation/climate biome models based on a more comprehensive database (flora and lithological data combined) revealed evidently climatic vertical zonation consistent with latitudes during the Jurassic (Krassilov, 1981; Hallam, 1984, 1985, 1993; Ziegler et al., 1993, 1996; Rees et al., 2000; Scotese, 2001, 2002). Ziegler et al. (1996) thought that the scale of Vakhrameev's (1991) climatic zonation was too warm through and gave the impression that the poles were very warm indeed. They proposed three main climatically related biomes for the Jurassic throughout Eurasia, the dry subtropical in low to middle palaeolatitudes, the warm temperate centering at about 45° palaeolatitude and extending to palaeolatitudes of up to 60° north and cool temperate in middle to high palaeolatitudes, a zonation which was basically the same as proposed by Krassilov (1981) or the same as Hallam's (1984, 1985, 1993) dry, seasonally wet and wet belts. Thereafter, Rees et al. (2000) distinguished five vegetation biomes for the Jurassic based on exploring the foliar morphology and climate relationship using multivariate statistical analysis: (a) cool temperate at high latitudes (>60°) with low species diversity and seasonality; (b) warm temperate (40°–60°) with high species diversity and abundant macrophyllous cycadophytes; (c) winter-wet with microphyllous elements that are typical for seasonal water deficits (narrowband in N-America, India, southern Hemisphere); (d) sub-tropical desert where plants are absent; and (e) summer-wet (tropical) around the equator with microphyllous elements, where cycads, ginkgophytes and some of the conifer families are absent. Scotese's (2001, 2002) biome map illustrated a climatic zonation which is nearly the same as Rees et al. (2000). According to these models, the floras have some marked differences in the abundance and variety of the plant genera and higher taxonomical groups present, depending on their palaeogeographic positions. Continental reconstructions from palaeomagnetic data and globally constrained plate motion patterns suggest that the Ordos Basin of north China was situated at palaeolatitudes of 35°–55°N (Zhang et al., 1995, 1998; Ziegler et al., 1996) in the warm temperate/humid zone during the Middle Jurassic (Krassilov, 1981; Hallam, 1984, 1985, 1993; Ziegler et al., 1993, 1996; Rees et al., 2000; Scotese, 2001, 2002).

The relationship between plants and palaeoclimate in past time is a subject of palaeobotanic interest. Distribution and diversity pattern of fossil flora and the floristic components are often used to infer the palaeoclimate (Behrensmeyer and Hook, 1992; Chinnappa et al., 2015; DiMichele and Gastaldo, 2008). The fossil records and their nearest living relatives can provide informative evidence for general climatic conditions (Wang et al., 2005; 2006). The floristic components and their nearest living relatives' habitat indicate a warm and humid climate in the Ordos Basin during the Middle Jurassic (Table 2). Among the floristic components, mosses, including *Hepaticites* and *Thallites*, favor a humid and warm climate, although they can still endure arid environments (Deng, 2007; Na et al., 2017). Extant mosses are widely spread in lowlands, wetlands and swamps of the tropical, subtropical, temperate and cold climatic zones, but it always indicates a wet habitat (Shaw, Renzaglia, 2004; Stech and Quandt, 2010). Generally, horsetails, including *Equisetites*, *Neocalamites*, *Annulariopsis* and *Equisetostachys*, are usually coexisting, indicating that they share similar ecological habits. Watson (1983), Watson and Betten (1990) and Watson and Alvin (1996) suggested that these plants grown at riverbanks, stream margins or freshwater marshes. Fossil *Equisetites* are usually found in the swamp, flood plain deposits, indicating wet habitats near water bodies (Cúneo et al., 2003; Costamagna et al., 2018). Extant *Equisetum* is very similar to *Equisetites* in gross morphology, growing at riverbanks, stream margins or underside of wet forests of temperate and cold climatic zones of the Northern Hemisphere.

Ferns are much diverse, including *Coniopteris*, *Cladophlebis*, *Todites* and *Eboracia* allied to Osmundaceae and Dicksoniaceae. The ecology of the majority of Mesozoic ferns including the Osmundaceae and Dicksoniaceae confirms the common view that they grew under moist, rather warm conditions either in marshes, along river banks or as understory in forests (Van Konijnenburg-van Cittert, 2002; Barbacka and Bodor, 2008). High abundance and diversity of ferns in the flora that require moisture for reproduction can be generally regarded as good indicators of more or less humid conditions preferably in a warm environment (Chen et al., 1984; Hallam, 1984, 1985, 1993; Vakhrameev, 1991; Frakes et al., 1992; Abbink, 1998; Abbink et al., 2004; Deng, 2007; Deng et al., 2017). Additionally, thermophilous ferns belonging to the families Dipteridaceae, Marattiaceae and Matoniaceae which lived only in tropical or subtropical areas during the geologic past (Zhou, 1995; Van Konijnenburg-van Cittert, 2002; Wang, 2002; Deng, 2007), are absent in the present flora. The majority of extant

Table 2. Floristic components of the Ordos flora and their palaeoclimatic implications

Taxa		Fossil characters and distribution	Nearest living relatives' habitat and distribution	Climate inferred
Mosses	*Hepaticites*	Morphological structure simple, creeping; widely distributed	Usually grows under forests	Humid
	Thallites		Grows inshady and moist places	Humid
Horsetails	*Equisetites* *Equisetostachys* *Neocalamites* *Annulariopsis*	Living *Equisetum* distributes in frigid and temperate belts of North Hemisphere	Generally grows in wet or damp habitats and are particularly common along the banks of streams or irrigation canals	Humid
Ferns: Osmundaceae	*Todites* *Cladophlebis*	Large pinnae and small pinnules	The nearest living genus *Todea*, perennial ferns with short trunk and pinnate fronds, are widely distributed in tropical and south temperate belt	Warm and humid
Ferns: Dicksoniaceae	*Coniopteris* *Eboracia*	These genera may supposed to be tree ferns; widely distributed	The modern Dicksoniaceae, distributed in tropical belt and temperate belt of Southern Hemisphere	Humid, subtropical or temperate
Cycadophytes	*Pterophyllum* *Nilssonia*	Distributed mainly in tropical or subtropical belts	The living cycad plants are only distributed in tropical and subtropical belts	Tropical or temperate
Ginkgoaleans	*Ginkgo* *Baiera* *Sphenobaiera* *Eretmophyllum* *Stenorachis*	Seasonal deciduous	The living *Ginkgo*, with only one species, *Ginkgo biloba,* is seasonal deciduous trees; natural habitat in high altitude (500-1000m) in Tianmu mountain, Zhejiang Province, China. Widely cultivated	Temperate
Czekanowskialeans	*Czekanowskia* *Phoenicopsis* *Ixostrobus* *Leptostrobus*	Seasonal deciduous		Temperate
Conifers	*Pityophyllum* *Sewardiodendron* *Podozamites* *Elatocladus*	Long-broad or needle-lanceolate leaf *Pityophyllum* seasonal deciduous	The living conifers are evergreen or deciduous treesand are distributed in temperate belt	Temperate

ferns prefer to grow in a shady, humid environment in tropical zone, but they can also be common in temperate forests (Abbink, 1998). The modern counterpart of *Eboracia* and *Coniopteris* are represented today by *Dicksonia*, and *Cladophlebis* and *Todites* are represented today by *Todea*. These extant ferns usually occur in tropical and southern temperate zones. The Mesozoic cycadophytes can be subdivided into two groups based on their climatic implications. One indicates hot and dry climate, including *Ptilophyllum*, *Otozamites*, *Zamites*, etc.; the other shows warm but humid climate, such as *Pterophyllum*, *Nilssonia*, *Nilssoniopteris*, *Anomozamites*, etc. (Vakhrameev, 1991; Deng, 2007; Deng et al., 2017). In the Yan'an Flora, the cycadophytes are represented by *Pterophyllum* and *Nilssonia* belonging to the bennettitaleans and cycadaleans. Extant cycads occur in tropical and subtropical zones and many are adapted to withstand drought, being typical tropical and subtropical flora elements (Wang et al., 2005, 2006).

Ginkgoaleans and czekanowskialeans are of most abundance and diversity in the Yan'an Flora. In the Mesozoic times, the ginkgoaleans were a more diverse group that was mainly restricted to temperate regions, but occasionally representatives were found in the subtropical belt (Tralau, 1967, 1968; Wang et al., 2005, 2006). Furthermore, ginkgoaleans and czekanowskialeans are regarded as typical deciduous plants, indicating a warm and humid climate with seasonal variations (Vakhrameev, 1991; Royer et al., 2003; Greb et al., 2006; Sun et al., 2008, 2009; Zhou, 2009; Na et al., 2017). It's worth noting that the genus *Eretmophyllum* which can be considered as an indicator of humid and warm climatic conditions (Li et al., 2017), is present in the flora. *Eretmophyllum* and *Czekanowskia* (Czekanowskiales) are characterized by thin and brittle cuticles suggesting a humid environment similar to extant *Ginkgo* and fossil ginkgophytes (Costamagna et al., 2018). *Ginkgo biloba* L. is the only extant representative of the ginkgoaleans (Hasebe, 1997; He et al., 1997; Zhou, 1997, 2009). It is a deciduous tree that lives in temperate regions and can withstand severe frost (Wang et al., 2005, 2006; Deng, 2007).

Conifers are represented by *Pityophyllum*, *Sewardiodendron*, *Podozamites,* and *Elatocladus* belonging to Pinaceae, Taxodiaceae, and Podocarpaceae. The present of these long-broad or needle-lanceolate conifer leaves and the absence of thermophilic conifers with adpressed scale-like and rigid hook-like leaves (e.g., *Brachyphyllum* and *Pagiophyllum*) indicate a climate in warm or cool areas instead of tropical or subtropical regions (Krassilov, 1978; Vakhrameev, 1991; Yao et al., 1998; Barbacka, 2009, 2011). Living Pinaceae is widely distributed at uplands in temperate regions of the Northern Hemisphere, and many taxa can withstand severe cold (Shang et al., 1999a). Podocarpaceae occur nowadays only in (sub) tropical and southern temperate areas of the Southern Hemisphere. Extant Taxodiaceae are thermophilic conifers living in the subtropical areas, but they prefer humid environments and are associated with wet lowland conditions (Yu, 1995).

In conclusion, the climate of the Ordos Basin during the Middle Jurassic was warm and humid with seasonal temperature and precipitation fluctuations. The floristic composition supports the Ordos Basin was located in North Floristic Province (Sun, 1992; Sun et al., 2010, 2015a), or the North Chinese Province (Kiritchkova et al., 2005; Kostina and Herman, 2013, Kostina et al., 2015) in the warm temperate climate zone (Krassilov, 1981; Hallam, 1984, 1985, 1993; Ziegler et al., 1993, 1996; Rees et al., 2000; Scotese, 2001, 2002) during the Middle Jurassic.

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REFERENCES

Abbink, O.A., *Palynological investigations in the Jurassic of the North Sea region, PhD Theses*, Univ. Utrecht, 1998.

Abbink, O.A., Van Konijnenburg-van Cittert, J.H.A., and Visscher, H.A., Sporomorph ecogroup model of the Northwest European Jurassic–Lower Cretaceous: concepts and framework, *Geologie en Mijnbouw*, 2004, vol. 83, pp. 17–38.

Barbacka, M., Sphenophyta from the Early Jurassic of the Mecsek Mts., Hungary, *Acta Palaeobot.*, 2009, vol. 49, no. 2, pp. 221–231.

Barbacka, M., Biodiversity and the reconstruction of Early Jurassic flora from the Mecsek Mountains (southern Hungary), *Acta Palaeobot.*, 2011, vol. 51, no. 2, pp. 127–179.

Barbacka, M. and Bodor, E., Systematic and palaeoenvironmental investigations of fossil ferns *Cladophlebis* and *Todites* from the Liassic of Hungary, *Acta Palaeobot.*, 2008, vol. 48, no. 2, pp. 133–149.

Behrensmeyer, A.K. and Hook, R.W., Paleoenvironmental contexts and taphonomic modes in the terrestrial fossil record, in *Terrestrial Ecosystems through Time: Evolutionary Paleoecology of Terrestrial Plants and Animals*, Behrensmeyer, A.K., Damuth, J.D., DiMichele, W.A., Potts, R., Sues, H.-D., and Wing, S.L., Eds., Chicago: Univ. Chicago Press, 1992, pp. 15–138.

Brick, M.I., *Mezozoiskaya flora Vostochno-Ferganskogo kamennougol'nogo basseina* (The Mesozoic Flora of Eastern Fergana Coal Basin), Moscow: Gosgeolizdat, 1953.

Bureau of Geology and Mineral Resources of Inner Mongolia Autonomous Region, Regional geology of Inner Mongolia Autonomous Region, Beijing: Geol. Publ. House, 1991.

Bureau of Geology and Mineral Resources of Inner Mongolia Autonomous Region, Stratigraphy (Lithostratic) of Inner Mongolia Autonomous Region, Wuhan: China Univ. Geosci. Press, 1996.

Chen, F., Dou, Y.W., and Huang, Q.S., *The Jurassic Flora of West Hills Beijing (Peking)*, Beijing: Geol. Publ. House, 1984.

Chinnappa, C., Rajanikanth, A., and Rao, Y.V., Early Cretaceous plant diversity and ecology in the Krishna–Godavari Basin, East Coast, *J. Palaeontol. Soc. India*, 2015, vol. 60, no. 1, pp. 73–96.

Costamagna, L.G., Kustatscher, E., Scanu, G.G., Rio, M.D., Pittau, P., and Van Konijnenburg-van Cittert, J.H.A., A palaeoenvironmental reconstruction of the Middle Jurassic of Sardinia (Italy) based on integrated palaeobotanical, palynological and lithofacies data assessment, *Palaeobio. Palaeoenv.*, 2018, vol. 98, pp. 111–138.

Cúneo, N.R., Taylor, E.L., Taylor, T.N., and Kring, M., In situ fossil forest from the upper Fremouw Formation (Triassic) of Antarctica: paleoenvironmental setting and paleoclimate analysis, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2003, vol. 197, pp. 239–261.

Deng, S.H., Palaeoclimatic implications of main fossil plants of the Mesozoic, *J. Palaeogeogr.*, 2007, vol. 9, no. 6, pp. 259–274.

Deng, S.H. and Lu, Y.Z., The Mesozoic dicksoniaceous ferns: characteristics, distribution and origin and evolutionary trends, *Glob. Plant Lett.*, 2006, vol. 1, no. 1, pp. 9–29.

Deng, S.H., Yao, Y.M., Ye, D.Q., Chen, P.J., Jin, F., Zhang, Y.J., Xu, K., Zhao, Y.C., Yuan, X.Q., and Zhang, S.B., *Jurassic System in the North of China*, vol. 1: *Stratum Introduction*, Beijing: Petroleum Industry Press, 2003.

Deng, S.H., Zhao, Y., Lu, Y.Z., Shang, P., Fan, R., Li, X., Dong, S.X., and Liu, L., Plant fossils from the Lower Jurassic coal-bearing formation of central Inner Mongolia of China and their implications for palaeoclimate, *Palaeoworld*, 2017, vol. 26, pp 279–316.

DiMichele, W.A. and Gastaldo, R.A., Plant Paleoecology in deep Time, *Ann. Mo. Bot. Gard.*, 2008, vol. 95, no. 1, pp. 144–198.

Duan Shu-ying, *The Jurassic Flora of Zhaitang, West Hills of Beijing*, Stockholm: Akademitryck Edsbruk, 1987.

Duan, S.Y., Chen, Y., and Niu, M.L., Middle Jurassic flora from southern margin of the Ordos Basin, *Acta Bot. Sin.*, 1986, vol. 28, no. 5, pp. 549–554.

Frakes, L.A., Francis, J.E., and Syktus, J., *Climate Modes of the Phanerozoic: The History of the Earth's Climate over the Past 600 Million Years*, Cambridge: Cambridge Univ. Press, 1992.

Ge, Y.H., Sun, C.L., and Liu, M.X., Discovery of Middle Jurassic flora from Gaotouyao area in the Northeastern Margin of the Ordos Basin, *World Geol.*, 2004, vol. 23, no. 2, pp. 107–117.

Ge, Y.H., Sun, C.L., and Liu, M.X., The flora from the Middle Jurassic Yan'an Formation in the Northeastern Margin of the Ordos Basin and discussion on the palaeoclimate, *J. Jilin Univ.*, 2006, vol. 36, no. 2, pp. 164–168.

Ge, Y.H., Sun, C.L., and Liu, M.X., Stratigraphic division and correlation of the Yan'an Formation in the Northeastern Margin of the Ordos Basin, China, *J. Stratigr.*, 2007, vol. 31, no. 2, pp. 151–157.

Genkina, R.Z., Stratigraphy of Jurassic continental deposits of Fergana Ridge and paleontological rationale for their age, *Sov. Geol.*, 1977, no. 9, pp. 63–79.

Genkina, R.Z., Division of continental deposits of Upper Triassic and Jurassic in east of Middle Asia, *Sov. Geol.*, 1979, no. 4, pp. 27–39.

Gordenko, N.V., Middle Jurassic flora of the Peski locality (Moscow Region): Systematics, Paleoecology, and Phytogeography, *Paleontol. J.*, 2008, vol. 42, no. 12, pp. 1285–1382.

Greb, S.F., DiMichele, W.A., and Gastaldo, R.A., Evolution of wetland types and the importance of wetlands in earth history, in *Wetlands through Time*, DiMichele, W.A. and Greb, S.F., Eds., Geol. Soc. Am. Spec. Pap., vol. 399, Geol. Soc. Am., 2006, pp. 1–40.

Hallam, A., Continental humid and arid zones during the Jurassic and Cretaceous, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1984, vol. 47, pp. 195–223.

Hallam, A., A review of Mesozoic climates, *J. Geol. Soc.*, 1985, vol. 142, pp. 433–445.

Hallam, A., Jurassic climates as inferred from the sedimentary and fossil record, *Phil. Trans. R. Soc. Lond. B*, 1993, vol. 341, pp. 287–296.

Harris, T.M., *The Yorkshire Jurassic Flora. I. Thallophyta-Pteridophyta*, London: Brit. Mus. Nat. Hist., 1961.

Harris, T.M., *The Yorkshire Jurassic Flora, II. Caytoniales, Cycadales and Pteridosperms*, London: Brit. Mus. Nat. Hist., 1964.

Harris, T.M., *The Yorkshire Jurassic Flora, V. Coniferales*, London: Brit. Mus. Nat. Hist., 1979.

Hasebe, M., Molecular phylogeny of *Ginkgo biloba*: close relation between *Ginkgo biloba* and cycads, in *Ginkgo biloba-A Global Treasure from Biology to Medicine*, Tokyo: Springer Verlag, 1997.

He, S.A., Yin, G., and Pang, Z.J., Resources and prospects of *Ginkgo biloba* in China, in *Ginkgo biloba—A Global Treasure from Biology to Medicine*, Tokyo: Springer Verlag, 1997, pp. 373–383.

He, S.A., *Evolution and Formation of Oil and Gas in Ordos Basin*, Beijing: Petroleum Industry Press, 2003.

He, Z.X., Yang, H., and Yuan, X.Q., *Atlas of geology profile in Ordos Basin*, Beijing: Petroleum Industry Press, 2004.

Hu, J.M., Liu, X.S., Li, Z.H., Zhao, Y., Zhang, S.H., Liu, X.C., Qu, H.J., and Chen, H., SHRIMP U-PB zircon dating of the Ordos Basin basement and its tectonic significance, *Chinese Sci. Bull.*, 2013, vol. 58, no. 1, pp. 118–127.

Huang, Z.G. and Zhou, H.Q., Fossil plants, in *Mesozoic Stratigraphy and Paleontology from Shanganning Basin*, Beijing: Geol. Publ. House, 1980, pp. 43–104.

Jiang, D.X. and Wang, Y.D., Middle Jurassic sporo-pollen assemblage from the Yan'an Formation of Dongsheng, Nei Monggol, China, *Acta Bot. Sin.*, 2002, vol. 44, no. 2, pp. 230–238.

Kiritchkova, A.I., Bystritskaya, L.I., and Travina, T.A., Significance of *Coniopteris* and Czekanowskiales for the Jurassic stratigraphy of West Siberian continental deposits, *Stratigr. Geol. Correl.*, 2002, vol. 10, no. 3, pp. 239–256.

Kiritchkova, A.I., Kostina, E.I., and Bystritskaya, L.I., *Fitostratigrafiya i flora yurskikh otlozhenii Zapadnoi Sibiri* (Jurassic Phytostratigraphy and Flora of the West Siberia), St. Petersburg: Nedra, 2005.

Kostina, E.I. and Herman, A.B., The Middle Jurassic Flora of South Mongolia: Composition, age and phytogeographic position, *Rev. Palaeobot. Palynol.*, 2013, vol. 193, pp. 82–89.

Kostina, E.I., Herman, A.B., and Kodrul, T.M., Early Middle Jurassic (possibly Aalenian) Tsagan-Ovoo Flora of Central Mongolia, *Rev. Palaeobot. Palynol.*, 2015, vol. 220, pp. 44–68.

Krassilov, V.A., Araucariaceae as indicators of climate and paleolatitudes, *Rev. Palaeobot. Palynol.*, 1978, vol. 26, nos. 1–4, pp. 113–124.

Krassilov, V.A., Changes of Mesozoic vegetation and the extinction of dinosaurs, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1981, vol. 34, nos. 3–4, pp. 207–224.

Li, P.J., He, Y.L., Wu, X.W., and Li, B.Y., *Early and Middle Jurassic Strata and Their Floras from Northeastern Border of Qaidam Basin, Qinghai*, Nanjing: Nanjing Univ. Press, 1988.

Li, T., Li, Y.F., Na, Y.L., Huang, W., and Sun, C.L., Discovery of subgenus *Phoenicopsis* (*Culgoweria*) from Middle Jurassic of Ordos Basin, Inner Mongolia, *Glob. Geol.*, 2014, vol. 33, no. 3, pp. 524–534.

Li, T., Li, Y.F., Na, Y.L., Huang, W., Tan, X., and Sun, C.L., First report of subgenus *Phoenicopsis* (Czekanowskiales) from Middle Jurassic of Ordos, China and its paleoclimatic implications, *Glob. Geol.*, 2015a, vol. 18, no. 3, pp. 145–154.

Li, Y.F., Sun, C.L., Li, T., Chen, F., and Na, Y.L., The Middle Jurassic flora from the Ordos Basin of China, in *Abstracts of the 12th Symposium on Mesozoic Terrestrial Ecosystems (MTE-12), August 15–20, 2015*, Shenyang: Paleontol. Mus. Liaoning/Shenyang Normal Univ., China, 2015b.

Li, Y.F., Sun, C.L., Wang, H.S., Dilcher, D.L., Tan, X., Li, T., and Na, Y.L., First record of *Eretmophyllum* (Ginkgoales) with well-preserved cuticle from the Middle Jurassic of the Ordos Basin, Inner Mongolia, China, *Palaeoworld*, 2018, vol. 27, no. 2, pp. 188–201.

Luchnikov, V.S., Stratigraphy of coal-bearing deposits of Jurassic in Central Tadjikistan, *Sov. Geol.*, 1982, no. 3, pp. 66–75.

Mi, J.R., Sun, C.L., Sun, Y.W., Cui, S.S., and Ai, Y.L., *Early–Middle Jurassic Phytoecology and Coal-Accumulating Environments in Northern Hebei and Western Liaoning*, Beijing: Geol. Publ, House, 1996.

Na, Y.L., Sun, C.L., Wang, H.S., Dilcher, D.L., Li, Y.F., and Li, T., A brief introduction to the Middle Jurassic Daohugou Flora from Inner Mongolia, China, *Rev. Palaeobot. Palynol.*, 2017, vol. 247, pp. 53–67.

Pan, C.H., Older Mesozoic plants from North Shensi, *Palaeontol. Sin., Ser. A*, 1936, vol. 4, no. 2, pp. 1–49.

Phillips, J., *Illustration of the Geology of Yorkshire, or a description of the strata and organic remains of the Yorkshire Coast: Accompanied by a Geological Map, Sections, and Plates of the Fossil Plants and Animals*, York: Thomas Wilson and Sons, 1829.

Pott, C. and McLoughlin, S., Bennettitalean foliage in the Rhaetian–Bajocian (latest Triassic–Middle Jurassic) floras of Scania, southern Sweden, *Rev. Palaeobot. Palynol.*, 2009, vol. 158, no. 1, pp. 117–166.

Rees, P.M., Ziegler, A.M., and Valdes, P.J., Jurassic phytogeography and climates: new data and model comparisons, in *Warm Climates in Earth History*, Cambridge: Cambridge Univ. Press, 2000, pp. 297–318.

Ritts, B.D., Weislogel, A., Graham, S.A., and Darby, B.J., Mesozoic tectonics and sedimentation of the giant polyphase nonmarine intraplate Ordos Basin, Western North China Block, *Int. Geol. Rev.*, 2009, vol. 51, no. 2, pp. 95–115.

Royer, D.L., Hickey, L.J., and Wing, S.L., Ecological conservatism in the "living fossil" *Ginkgo, Paleobiology*, 2003, vol. 29, pp. 84–104.

Scotese, C.R., http://www.scotese.com (PALEOMAP website, 2002).

Scotese, C.R., *Atlas of Earth History*, vol. 1: *Paleogeography*, Arlington, TX: PALEOMAP Project, 2001.

Shang, P., Deng, S.H., Sun, K.Q., and Guo, Y.R., Study on the Paleoecology and Paleoclimate of the Flora from Yuanbaoshan Formation, Inner Mongolia, *Acta Geosci. Sin.*, 1999a, vol. 20, pp. 170–174.

Shang, P., Fu, G.B., Hou, Q.Z., and Deng, S.H., Middle Jurassic fossil plants from Turpan-Hami Basin, Xinjiang, Northwest China, *Geoscience*, 1999b, vol. 13, no. 4, pp. 403–407.

Shang, Y.K., Palynology of the Yan'an Formation in the Dongsheng region, Nei Monggol, *Acta Micropalaeontol. Sin.*, 1995, vol. 12, no. 4, pp. 398–420.

Shaw, J. and Renzaglia, K., Phylogeny and diversification of Bryophytes, *Am. J. Bot.*, 2004, vol. 91, no. 10, pp. 1557–1581.

Stech, M. and Quandt, D., 20,000 species and five key markers: The status of molecular bryophyte phylogenetics, *Phytotaxa*, 2010, vol. 9, no 4, pp. 196–228.

Sun, C.L., The division of the Early Jurassic floristic province of the Eurasia continent, in *Changchun University Earth Science Quarterly*, Changchun: Changchun Univ., 1992.

Sun, C.L., Dilcher, D.L., Wang, H.S., Sun, G., and Ge, Y.H., A study of *Ginkgo* leaves from the Middle Jurassic of Inner Mongolia, China, *Int. J. Plant Sci.*, 2008, vol. 169, no. 8, pp. 1128–1139.

Sun, C.L., Dilcher, D.L., Wang, H.S., Sun, G., and Ge, Y.H., *Czekanowskia* from the Jurassic of Inner Mongolia, China, *Int. J. Plant Sci.*, 2009, vol. 170, no. 9, pp. 1183–1194.

Sun, C.L., Li, T., Sun, Y.W., Chen, Y.J., Li, C.T., and Zhao, G.W., Early Jurassic fossil cycads from the Yihe Basin in southern Jilin Province: paleoclimatic significance, *Geol. Resour.*, 2010, vol. 19. pp. 1–8.

Sun, X.J., Wang, S.L., Shang, X.F., and Li, H.F., Analysis on flora of Yan'an Formation of Jurassic system in Dongsheng Coal Field and palaeoclimate, *J. Shandong Univ. Sci. Technol.*, 2011, vol. 30, no. 1, pp. 31–37.

Sun, C.L., Li, Y.F., Dilcher, D.L., Wang, H.S., Li, T., Na, Y.L., and Wang, A.P., An introductory report on the biodiversity of Middle Jurassic Phoenicopsis (Czekanowskiales) from the Ordos Basin, China, *Sci. Bull.*, 2015a, vol. 60, no. 21, pp. 1858–1865.

Sun, C.L., Wang, H.S., Dilcher, D.L., Li, T., Li, Y.F., and Na, Y.L., A new species of Czekanowskia (Czekanowskiales) from the Middle Jurassic of Ordos Basin, China, *Botanica Pacifica*, 2015b, vol. 4, no. 2, pp. 149–155.

Sun, L.X., Zhang, Y., Zhang, T.F., Cheng, Y.H., Li, Y.F., Ma, H.L., Yang, C., Guo, J.C., Lu, C., and Zhou, X.G., Jurassic sporopollen of Yan'an Formation and Zhiluo Formation in the northeastern Ordos Basin, Inner Mongolia, and its paleoclimatic significance, *Earth Sci. Frontiers*, 2017, vol. 24, no. 1, pp. 32–51.

Sze Hsing-chien, Older Mesozoic plants from the Yanchang Formation, Northern Shaanxi, *Palaeontol. Sin., Ser. A*, 1956a, vol. 139, no. 5, pp. 1–217.

Sze Hsing-chien, The fossil flora of the Mesozoic oil-bearing deposits of the Dzungaria Basin, northwestern Sinkiang, *Acta Palaeontol. Sin.*, 1956b, vol. 4, no. 4, pp. 461–476.

Sze Hsing-chien and Chow Tse-yen, *Mesozoic Continental Deposits of China*, Beijing: Sci. Press, 1962.

Sze Hsing-chien and Li Xing-xue, *Mesozoic Plants of China, Fossil Plants of China*, Beijing: Sci. Press, vol. 2, 1963.

Teslenko, Y.V., *Stratigrafiya i flora yurskikh otlozhenii Zapadnoi i Yuzhnoi Sibiri i Tuvy* (Jurassic Stratigraphy and Flora of Western and Southern Siberia and Tuva), Moscow: Nedra, 1970.

Tralau, H., The phytogeographic evolution of the genus *Ginkgo* L., *Botaniska Notiser*, 1967, vol. 120, pp. 409–422.

Tralau, H., Evolutionary trends in the genus *Ginkgo*, *Lethaia*, 1968, vol. 1, pp. 63–101.

Vakhrameev, V.A., *Yurskie i rannemelovye flory Evrazii i paleofloristicheskie provintsii etogo vremeni* (Jurassic and Early Cretaceous Floras of Eurasia and Paleoflorisitc Provinces of This Period), Tr. Geol. Inst. Akad. Nauk SSSR, vol. 102, Moscow: Nauka, 1964.

Vakhrameev, V.A., Boundaries of the Jurassic epochs in continental deposits of the USSR based on palaeobotanical data, in *Voprosy stratigrafii verkhnei yury* (On the Upper Jurassic Stratigraphy), Tr. Geol. Inst. Akad. Nauk SSSR, vol. 430, Moscow: Nedra, 1974, pp. 12–19.

Vakhrameev, V.A., *Yurskie i melovye flory i klimaty zemli* (Jurassic and Cretaceous Floras and Climates of the Earth), Akhmetiev, M.A., Ed., Tr. Geol. Inst. Akad. Nauk SSSR, vol. 430, Moscow: Nauka, 1988.

Vakhrameev, V.A., *Jurassic and Cretaceous Floras and Climates of the Earth*, Cambridge: Cambridge Univ. Press, 1991.

Van Konijnenburg-van Cittert, J.H.A., Ecology of some Late Triassic to Early Cretaceous ferns in Eurasia, *Rev. Palaeobot. Palynol.*, 2002, vol. 119, nos. 1–2, pp. 113–124.

Wang, S.E., Zheng, S.L., Yu, J.S., Liu, G.F., Zhang, W., and Chen, Q.S., *Stratigraphic Lexicon of China: Jurassic*, Beijing: Geol. Publ. House, 2000.

Wang Yong-dong, Fern ecological implications from the Lower Jurassic in Western Hubei, China, *Rev. Palaeobot. Palynol.*, 2002, vol. 119, pp. 125–141.

Wang Yong-dong, Mosbrugger, V., and Zhang Hong, Early to Middle Jurassic vegetation and climatic events in the Qaidam Basin, Northwest China, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2005, vol. 224, nos. 1–3, pp. 200–216.

Wang Yong-dong, Saiki Ken'ichi, Zhang Wu, and Zheng Shao-lin, Biodiversity and palaeoclimate of the Middle Jurassic floras from the Tiaojishan Formation in Western Liaoning, China, *Progr. Nat. Sci.*, 2006, vol. 16, pp. 222–230.

Watson, J., Two Wealden species of Equisetites found in situ, *Acta Palaeontol. Pol.*, 1983, vol. 28, pp. 265–269.

Watson, J. and Alvin, K.L., An English Wealden floral list, with comments on possible environment indicators, *Cret. Res.*, 1996, vol. 17, no. 1, pp. 5–26.

Watson, J. and Betten, D.J., A revision of the English Wealden Flora, II. Equisetales, *Bull. Nat. Hist. Mus. (Geol.)*, 1990, vol. 46, no. 1, pp. 37–60.

Yao Xuan-li, Zhou Zhi-yan, and Zhang Bo-le, On the occurrence of *Sewardiodendron laxum* Florin (Taxodiaceae) in the Middle Jurassic from Yima, Henan, *Chinese Sci. Bul.*, 1989, vol. 34, no. 8, pp. 603–604.

Yao Xuan-li, Zhou Zhi-yan, and Zhang Bo-le, Reconstruction of the Jurassic conifer *Sewardiodendron laxum* (Taxodiaceae), *Am. J. Bot.*, 1998, vol. 85, no. 9, pp. 1289–1300.

Yin, F.J. and Hou, H.W., Middle Jurassic sporopollen assemblage from the Yan'an Formation in Binxian County, Shaanxi Province and its significance, *Acta Bot. Sin.*, 1999, vol. 41, no. 3, pp. 325–329.

Yu Yong-fu, Origin, evolution and distribution of the Taxodiaceae, *Acta Phytotax. Sinica*, 1995, vol. 4, pp. 362–389.

Zeng, Y., Shen, S.Z., and Fan, B.H., *Flora from the Coal-Bearing Strata of Yima Formation in Western Henan*, Nanchang: Jiangxi Sci. Technol. Press, 1995.

Zhang, H., Bai, Q.Z., and Zhao, X.W., *Formation and evolution of the Ordos Coal-forming Basin*, Xi'an: Shaanxi Sci. Techn. Press, 1995.

Zhang, H., Li, H.T., Xiong, C.W., Zhang, H., Wang, Y.D., He, Z.L., Lin, G.M., and Sun, B.N., *Jurassic Coal-bearing Strata and Coal Accumulation in Northwest China*, Beijing: Geol. Publ. House, 1998.

Zhao Xiu-li, Wang Shi-lu, Sun Xi-jie, Sun Hong-xi, and Duan Jian-wei, A Jurassic flora from the Yan'an Formation in Dongsheng coal field, Inner Mongolia, *J. Shandong Univ. Sci. Technol.*, 2011, vol. 30, no. 5, pp. 52–58.

Zhao Zhen-yu, Guo Yan-ru, Wang Yan, and Lin Dong-juan, Study progress in tectonic evolution and paleogeography of Ordos Basin, *Special Oil and Gas Reservoirs*, 2012, vol. 19, no. 5, pp. 15–20.

Zhou Zhi-Yan, Jurassic floras, in *Fossil Floras of China through the Geological Time*, Guangzhou: Guangdong Sci. Technol. Press, 1995, pp. 260–309.

Zhou Zhi-Yan, Mesozoic ginkgoalean megafossils: a systematic review, in *Ginkgo biloba—a Global Treasure from Biology to Medicine*, Tokyo: Springer Verlag, 1997, pp. 183–206.

Zhou Zhi-Yan, An overview of fossil Ginkgoales, *Palaeoworld*, 2009, vol. 18, no. 1, pp. 1–22.

Ziegler, A.M., Parrish, J.M., Yao, J.P., Gyllenhaal, E.D., Rowley, D.B., Parrish, J.T., Nie, S.Y., Bekker, A., and Hulver, M.L., Early Mesozoic phytogeography and climate, *Phil. Trans. R. Soc. Lond., Ser. B: Biol. Sci.*, 1993, vol. 341, no. 1297, pp. 297–305.

Ziegler, A.M., Rees, P.M., Rowley, D.B., Bekker, A., Li, Q., and Hulver, M.L., Mesozoic assembly of Asia: constraints from fossil floras, tectonics, and paleomagnetism, in *The Tectonic Evolution of Asia*, Cambridge: Cambridge Univ. Press, 1996.