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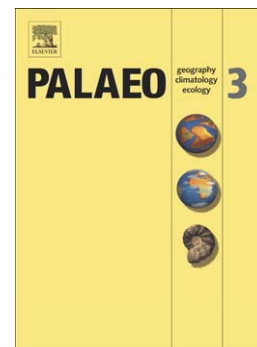
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**Fossil *Equisetum* from the Lower Cretaceous in Jiuquan Basin, Gansu, Northwest China  
and its paleoclimatic significance**

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**Abstract:** Tubers of *Equisetum* are described for the first time from the Lower Cretaceous Zhonggou Formation, Jiuquan Basin, Gansu Province, Northwest China. The fossils are preserved as rows of 2-3 tubers. The tubers are elliptical, ovate and more or less rounded, the most distal one being mucronate, with some ridges on the surface of the tubers. According to the similarity of the morphology and arrangement with extant *Equisetum* subgenus *Equisetum*, the present fossils are assigned to a new species of *Equisetum*. Furthermore, the cellular details of the tubers are clearly revealed for the first time. And the cellular morphology of extant *Equisetum* tubers can be compared to those of the fossil species. The occurrence of *Equisetum* would suggest a wet habitat, and the presence of tubers implies that burial occurred during the late fall or winter. Based on the palynological assemblages and mega-fossil assemblages, it had been thought that in the Early Cretaceous the Jiuquan Basin was arid, but the living habitat of *Equisetum* indicates a wet, riparian environment. Therefore, the occurrence of fossil *Equisetum* associated with fishes and ostracodes in the lower sequence would suggest a locally wet environment, probably a lake-shore in an arid region

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during the late Early Cretaceous in the Jiuquan Basin. The study is of great significance for further interpretation of the paleoclimate and environment in the Early Cretaceous of Northwest China.

**Key words:** fossil plants, *Equisetum*, tubers, the Early Cretaceous, Jiuquan Basin, paleoclimate

## 1. Introduction

*Equisetum* Linn. is one of the oldest living genera of vascular plants and is also the sole living representative of the class Sphenopsida (Mehra and Bir, 1959), which contains 15 species with herbaceous habit. The genus *Equisetum* is divided into two subgenera: *Equisetum* L. and *Hippochaete* Milde (Hauke, 1963, 1974, 1978, 1983; Page, 1972; Gifford and Foster, 1989). The subgenus *Equisetum* comprises eight species that are annual, with superficial stomata, regularly branched stems, and obtuse cones (Zhang et al., 2007, 2008), while subgenus *Hippochaete* consists of seven species that are usually perennial, with sunken stomata, unbranched stems, and apiculate cones (Hauke, 1963, 1974, 1978, 1983, 1993). All the species have a nearly worldwide distribution except for Australia and New Zealand and are commonly associated with wet places (Mehra and Bir, 1959; Hauke, 1993; Kenrick and Crane, 1997; Page, 1997).

*Equisetum*-like remains are common in the sediments of the Northern Hemisphere from the Carboniferous to the Pleistocene (Brown, 1975; McIver and Basinger, 1989). They were generally preserved as stems, leaves, cones, rhizomes and tubers, but most of them were not well preserved (Lesquereux, 1878; Bell, 1949; Becker, 1969; Christophel, 1976; McIver and Basinger, 1989). So it is difficult to determine the morphology and relationship with extant taxa. Fossil *Equisetum* is known to be remarkably similar to the extant subgenera *Equisetum* and *Hippochaete* (Brown, 1975; McIver and Basinger, 1989). The earliest record of the subgenus *Equisetum* is dated as Jurassic with well-preserved stems and leaves (Gould, 1968; Silva-Pineda et al., 2009), while the first conclusive report of subgenus *Hippochaete* was found in the Eocene of Oregon based on silicified stem fragments and numerous small roots

(Brown, 1975). The fossil tuberous rhizomes of *Equisetum* are mainly distributed in North America (Lesquereux, 1878; Bell, 1949; Lamotte, 1952; Becker, 1969; Christophel, 1976; McIver and Basinger, 1989; Skog and Dilcher, 1994), Europe (Watson and Batten, 1990; Denk et al., 2005) and Asia (Kon'no, 1962; Chen et al., 1988; Deng, 1995; Deng et al., 1997; Wu, 1999; Sun et al., 2001; Ablaev et al., 2003; Yang, 2003; Zhou et al., 2003).

Most of the *Equisetum*-like fossils, particularly those from the Mesozoic sediments have been assigned to the genus *Equisetites* previously, and the paleontological records in China are abundant. Finds are known from the Early Cretaceous of the Yixian Formation and Fuxin Formation in Liaoning (Chen et al., 1988; Sun et al., 2001; Zhou et al., 2003), the Muling Formation of Jixi Basin, Heilongjiang (Yang, 2003), Huolinghe Formation, Damoguaihe Formation, and Yinmin Formation in Inner Mongolia (Deng, 1995; Deng et al., 1997); the middle Eocene (Ablaev et al., 2003) Hunchun Formation in Jilin (Guo, 2000); the Miocene Lawula Formation of Markam and Wulong Formation of Nanmulin in Tibet (Geng and Tao, 1982; Tao and Du, 1987), and the Xiaolongtan Formation in Yunnan (Zhang et al., 2007). In the present study, our fossils are described from the Early Cretaceous Zhougou Formation of Jiuquan Basin, Gansu Province, Northwest China.

The Early Cretaceous coal-forming flora of northeastern and eastern China are widely distributed and well studied, but the Lower Cretaceous plant fossils in northwestern China are rare and relatively poorly studied (Deng et al., 2005). Moreover, studies on the fossil plants from the Zhougou Formation are comparatively limited. So far, Deng et al. (2005) reported two species of *Pseudofrenelopsis* collected from the Lower Cretaceous Xiagou Formation and Zhougou Formation. Lately, Deng and Lu (2008) systematically described the plant fossils

from the Jiuquan Basin of Gansu Province. The locality has yielded numerous and diversified plants (including charophytes) and animals (fishes, insects, ostracodes, conchostracans and bird feathers), some of which had been reported in the previous studies (Wang, 1965; Hong, 1982; Ma, 1984; Deng et. al., 2005; Deng and Lu, 2008). In addition, the Early Cretaceous climate of the Jiuquan Basin had been discussed based on the fossil plants (Deng and Lu, 2008). The plant fossils from the Lower Cretaceous of the Jiuquan Basin mainly comprise *Sphenopteris*, *Solenites*, *Athrotaxites*, *Podozamites*, *Cupressinocladus*, *Pityocladus*, *Elatocladus*, *Pagiophyllum*, *Pseudofrenelopsis*, *Brachyphyllum* (Deng and Lu, 2008) and *Equisetum*. In the present paper, the fossil specimens preserved as tubers are assigned to *Equisetum jiuquanense* Sun and Du. The paleoenvironments of the Jiuquan Basin, Gansu Province are interpreted using the combined data of fossil assemblages. Moreover, the distribution and evolution of the genus *Equisetum* are discussed based on the fossil records.

## 2. Locality and Stratigraphy

The Mesozoic strata of the Jiuquan Basin in Gansu Province are extensively developed and well exposed on the margins of the basin (Deng et al., 2005). The Lower Cretaceous strata in the Jiuquan Basin can be divided into three formations, the Chijinbao Formation, Xiagou Formation and Zhonggou Formation (Ye and Zhong, 1990). The Chijinbao Formation is usually correlated with the Jehol Group of Northeast China, because it contains representatives of the Jehol Biota, such as *Ephemeropsis trisetalis* and *Eosesthria* sp. Its age is still a matter of argument, but more and more authors believe it to be Early Cretaceous (Ye and Zhong, 1990; Deng et al., 2003). The Xiagou Formation belongs probably to the Barremian based on micropaleontological and palynological data (Lu et al., 2002; Deng et al.,

2005).

( Figure 1 inserted near here )

The fossils described in this paper were collected from the uppermost part of the Zhonggou Formation of the Hanxian section in the southwest of the Jiuquan Basin, Gansu Province, Northwest China (Fig. 1). The Zhonggou Formation consists of mudstones, argillaceous sandstones and conglomerate in the lower part and mudstones with horizontal stratification in the upper part (Fig. 2). According to the lithological characters, the present plant-bearing horizon can be divided into six sequences (Fig. 2). The fossil plants were collected from the first, second, third, fourth and fifth sequences of the deposit (Fig. 2), being particularly numerous in the third sequence. The present fossil *Equisetum* was collected from the second and third sequences of the deposit associated with numerous ostracodes, fishes and insects. The plants, spores and pollen from the overlying Zhonggou Formation indicate that the age is Aptian-Albian (Lu et al., 2002; Deng et al., 2005; Deng and Lu, 2008).

(Figure.2 inserted near here)

### 3. Material and Methods

The plant fossils described here were collected from the laminated mudstone of the Zhonggou Formation. The fossil tubers of *Equisetum* are preserved as compressions and impressions. Their morphological details were observed and photographed with Leica MZ12.5 stereomicroscope. The outer layer was removed and treated with 30% HCl and then HF in order to dissolve the inorganic matter, then coated with gold and examined under a SEM (JEOL JSM-5600LV) at Lanzhou University, China. The cellular morphology of the extant specimens were prepared with a 1:1 solution of glacial acetic acid and 30% H<sub>2</sub>O<sub>2</sub>,

mounted on stubs, coated with gold and examined under the same SEM.

All specimens and SEM stubs are housed in the Paleontological Laboratory of the School of Earth Sciences, Lanzhou University, Lanzhou, China.

#### 4. Systematic Description

Class—Sphenophytina

Order—Equisetales

Family—Equisetaceae

Genus—*Equisetum* Linnaeus 1753

Subgenus—*Equisetum* 1887

Species—*Equisetum jiuquanense* Sun and Du sp. nov.

Holotype: Hanxiak<sub>195-2-16</sub> (A, B) (Plate I, 1 and 2).

Paratype: Hanxiak<sub>195-2-1</sub> (A, B) (Plate I, 3–4); Hanxiak<sub>195-3-125</sub> (Plate I, 5); Hanxiak<sub>195-3-160</sub> (Plate I, 6); Hanxiak<sub>195-2-163</sub> (Plate I, 7).

Type locality: Laojunmiao County, Jiuquan City, Gansu Province, China (Fig. 1).

Stratigraphy: Zhonggou Formation

Age: Early Cretaceous

Etymology: The specific epithet, *jiuquanense* is derived from the fossil source in Jiuquan City.

Diagnosis: Tubers, elliptical, ovate, or round, single or acervate arranged in rows, with raised longitudinal ridges on the surface. The apex of the terminal tuber is mucronate. Cells are mostly rectangular. The anticlinal walls are straight, the periclinal walls are smooth and flattened, with grains on the surface.

##### 4.1 Description



The fossils are preserved as tubers (Plate I, 1-4), with one to three tubers in rows (Plate I, 1-7), 7-20mm long and 4-8mm wide. The tubers are elliptical, ovate, nearly round (Plate I, 1, 2; Plate II, 1), with two raised longitudinal ridges on the surface (Plate I, 1-4). The apices of the tubers at the tip of the bunch are mucronate (Plate I, 1-4; Plate II, 1). The average size of the tubers is 3-8mm long and 4-7mm wide.

(Plate I inserted near here)

The cellular features can be clearly observed under the stereomicroscope. The cells are longitudinal arranged, rectangular in shape, various in size (Plate II, 2-3). The Anticlinal walls are straight (Plate II, 2), periclinal walls are smooth and flattened, with grains on the surface (Plate II, 4-6).

(Plate II inserted near here)

## **4.2. Comparison**

### **4.2.1. Comparison with extant species**

(Figure 3 inserted near here)

The fossil specimens were preserved as tubers in series. Tubers are common in *Equisetum* subgenus *Equisetum* (Marshall, 1986), such as *E. arvense* L., *E. diffusum* Don, *E. palustre* L., *E. pratense* Ehrhart, *E. sylvaticum* L., and *E. telmateia* Ehrhart, while tubers are absent in all the species of the subgenus *Hippochaete* (Thomé, 1885; Campbell, 1928; Mehra and Bir, 1959; Hauke, 1963, 1978; Page, 1972; Bir, 1978; Watson and Batten, 1990). Furthermore, recent researches show that a single tuber per branch is found in four tuberous species of subgenus *Equisetum* (*E. palustre*, *E. sylvaticum*, *E. arvense* and *E. telmateia*) (Page, 1972; Bir, 1978; Zhang et al., 2007), while two or more tubers per branch are recorded only in

*Equisetum pratense* (Thomé, 1885; Zhang et al., 2007). Although another species, *Equisetum diffusum* is characterized by the presence of 1-3 underground tubers, these tubers generally consist of one long swollen internode (Mehra and Bir, 1959), which cannot be found in the present specimens. The arrangement of tubers on the rhizomes of both extant and fossil species is shown in Fig. 3 (a, b and c). The morphology of the fossil rhizomes with 2-3 tubers in a row is similar to those in *Equisetum*.

The micromorphological structures of extant *Equisetum* display longitudinally arranged and rectangular cells (Plate III, 3-6), while the cellular morphology of fossil tubers show more or less rectangular cells in longitudinal arrangement (Plate II, 2-3). Thus, the present specimens are assigned to *Equisetum* based on the similarity of morphological (Plate III, 2-3) and micromorphological features to extant *Equisetum* (Plate III, 4-6).

(Plate III inserted near here)

(Table. 1 inserted near here)

#### 4.2.2. Comparison with *Equisetum*-like fossil species

*Equisetum*-like fossils include *Equisetum*, *Equisetites* and *Equisetostachys*, which were well represented during the Mesozoic and Cenozoic in the Northern Hemisphere by stems fragments, leaf sheaths, rhizomes or tubers (Becker, 1969). *Equisetites* is a genus of fossil plants with similar gross morphology and anatomy to modern *Equisetum* (De Seoane, 2005; DiMichele et al., 2005), that could not be positively assigned to the living genus because of a lack of morphological details (Dimichele et al., 2005), while *Equisetostachys* is an organ genus lacking morphological structures (Kelber and Van Konijnenburg-van Cittert, 1998). Fossil tubers of *Equisetum* are commonly found in Cretaceous and Paleogene sediments. The

number and arrangement of the tubers on the rhizomes differ among species, thus providing important information for identification.

The present specimens are easily distinguished from *Equisetum haydenii* and *Equisetum perlaevigatum* in having two or three elliptical or ovate tubers in a string-like arrangement, while the latter two have an opposite arrangement of the tubers (Bell, 1949; Lamotte, 1952; Lesquereux, 1878). *Equisetum cf. arcticum* and *Equisetum hunchunense* have whorled tubers on the rhizome (Becker, 1969; Guo, 2000), which are different from the present fossils.

Another specimen, *Equisetum burchardtii* from the Wealden of England seems to have single or opposite tubers clearly borne on the rhizomes (Watson, 1983), while our specimens have chains of tubers on the branch. The Miocene *Equisetum* sp. recorded from the Lawula Formation of Markam, Tibet is reported to have two to five tubers on the branches (Tao and Du, 1987). The tubers are elliptical or round, which resemble *Equisetum cf. pratense* reported from the late Miocene of Lühe, Yunnan Province, southwestern China (Zhang et al., 2007).

Although the Paleocene specimen, *Equisetum fluviatoides* from the Ravenscrag Formation of Saskatchewan, Canada appears to have lanceolate to ovate tubers on the rhizomes, the number and arrangement of the tubers are unknown (McIver and Basinger, 1989). In addition, the fragments of *Equisetum* sp. from the Middle to Upper Miocene localities of Iceland are shown to have three tubers on the branch (Denk et al., 2005), which may also be treated as *Equisetum cf. pratense* based on their morphological features.

(Figure 4 inserted near here)

Some fossil species considered to belong to *Equisetites* have been reported from the Early Cretaceous of northwestern China. The Yixian specimen, *Equisetites longevaginatius* is

shown to have only a single tuber on the branches, which is quite different from the present one to three tubers per branch. *Equisetites burejensis* reported from the Fuxin Formation and the Yimin Formation is characterized by single, opposite or three tubers growing on a node (Chen et al., 1988; Deng, 1995; Deng et al., 1997). *Equisetites exiliformis* and *Equisetites naktongensis* have single or opposite tubers on the rhizomes (Sun et al., 2001; Deng et al., 1997), which are different from the single or acervate arrangement of the present specimen (Table 2). *Equisetites macrovalis* has single and relatively large tubers between lateral branch and main branch of the rhizomes (Deng, 1995; Sun et al., 2001). while the *Equisetites* sp. reported from Hunlinhe Formation of Inner Mongolia has single or opposite tubers on the rhizomes (Deng, 1995).

The morphological features of the tubers of the present specimen are quite similar to those reported by Zhang et al. (2007) for *Equisetum* cf. *pratense* (Fig. 4), although they differ in the numbers, shapes and arrangement of the tubers. While the present specimens have 1-3 tubers per branch, and the tuber is single or acervately arranged, more or less rounded in shape, *Equisetum* cf. *pratense* has 2-4 tubers per branch, and the tubers are acervately arranged, mostly elliptical, but with some that are ovate, sub-rounded, and spindle-shaped. The present specimens are preserved as tubers in series, a character state recorded from the extant genus *Equisetum*, but the morphology and arrangement are distinct from other *Equisetum* and *Equisetites* species. Moreover, the cellular structures of the *Equisetum* tubers are described for the first time, so we assigned these specimens to a new species *Equisetum jiuquanense* Sun and Du.

(Table 2 inserted near here).

## 5. Paleoenvironments and Paleoecology

The Zhonggou Formation in the Jiuquan Basin has yielded many well-preserved fossils. Besides fossil plants, there are also numerous insects, ostracodes and fishes, which probably demonstrate a proximal burial. Moreover, the sedimentary characteristics of the Zhonggou Formation clearly represent a lacustrine depositional environment in the Jiuquan Basin (Deng et al., 2005; Deng and Lu, 2008). A rich gymnospermous flora is found in the present locality, which included specimens of *Sphenopteris* sp., *Pseudofrenelopsis dalatzensis* (Chow et Tsao ) Cao ex Zhou, *Cupressinocladus elegans* (Chow) Chow, *Cupressinocladus* sp., *Pagiophyllum yumenense* Deng et Lu, *Pagiophyllum compressum* Deng et Lu, *Pagiophyllum* sp., *Brachyphyllum ningshiaense* Chow et Tsao, *Brachyphyllum obtusum* Chow et Tsao and *Carpolithus* sp. (Deng and Lu, 2008), many of which are scale-leaf conifers, such as the species of the genera *Pseudofrenelopsis*, *Pagiophyllum* and *Brachyphyllum*, which are characterized by a much reduced leaf surface with rather thick cuticles (Deng et al., 2005; Deng and Lu, 2008). The *Pseudofrenelopsis-Brachyphyllum* assemblages of the Zhonggou Formation probably indicate a semi-arid or arid climate (Watson, 1977; Watson and Fisher, 1984; Deng et al., 2005). Furthermore, the large numbers of *Classopollis* in the Zhonggou Formation also suggest a semi-arid or arid climate (Lu et al., 2002; Deng et al., 2005).

The present fossils were found along with fossil ostracodes in the second sequence and fishes in the third sequence (Fig. 2). This could indicate that the present *Equisetum* species lived near the lake. The extant species of *Equisetum* display a combination of xeromorphic (thick cuticle, sunken or protected stomata, and reduced leaves) and hydromorphic (air chambers and reduced vascular tissue) characters (Hauke, 1978; Channing et al., 2011), which

allows them to colonize habitats with a range of edaphic conditions (Channing et al., 2011). *Equisetum* may grow in diverse habitats but predominantly occurs in wet places such as shallow ponds, marshes, wet meadows, seepage slopes, ditches, stream banks, salt flats, and moist woodlands (Hauke, 1978; Page, 1997). Hence, the occurrence of fossil *Equisetum* indicates humid or locally wet habitats. In the case of *Equisetum jiuquanense*, this would indicate a wet habitat in an arid climatic environment.

In addition, the animal remains, such as ostracodes and fishes, associated with the present species would suggest a mesic, probably lacustrine paleoenvironment, which has been evidenced by lithologic characters (Deng and Lu, 2008; Wang et al., 2008; Peng et al., 2011). While the fishes and ostracodes lived in the lake, the hygrophilous specimen, *Equisetum jiuquanense*, probably grew along the lake margins. While the drought-tolerant species belonging to the genera *Pseudofrenelopsis* and *Brachyphyllum*, which are abundant in the fourth and fifth sequences, no doubt reflect an arid climatic environment (Watson, 1977; Watson and Fisher, 1984; Deng et al., 2005), they would have lived on the hillside or in the hinterland, where the high evaporation rate was not compensated for by groundwater. Furthermore, the present *Equisetum* is absent from the fourth and fifth sequences, which yield many other plant fossils, such as *Pseudofrenelopsis*, *Cupressinocladus*, *Pagiophyllum* and *Brachyphyllum*. Therefore, the sequences one to three in the uppermost part of the Zhonggou Formation probably represent a lakeshore environment, while the sequences four to five would indicate a hot dry environment.

Rhizomes and tubers of *Equisetum* are considered to be the principal means of perennation, reproduction, and dissemination (Marshall, 1986). Researches have shown that

tubers of extant *Equisetum* form lateral buds on the rhizomes, as asexual reproductive organs, which are fully developed in late fall or winter when the aerial stems of *Equisetum* die down (Watson, 1983; Watson and Batten, 1990; Sakamaki and Ino, 2004). This perhaps gives an indication of seasonal variations of the climate (Watson, 1983). Furthermore, tubers have been shown to be produced on rhizomes with a high starch concentration (Sakamaki and Ino, 2004, 2006). So the tubers are also used to store energy with which to produce new shoots in the next growing season. Consequently, tubers mainly have two functions. They can be used both in vegetative reproduction and as storage organs. Therefore, the presence of tubers of *Equisetum jiuquanense* would imply that a significant seasonal variation already existed in the Jiuquan Basin during the late Early Cretaceous. Moreover, the distinct growth rings in the associated wood fossils collected from the Early Cretaceous of the Jiuquan Basin underscores a seasonal climate (Deng et al., 2005).

## 6. Distribution and Evolution

(Figure 5 inserted near here)

At the present day, *Equisetum* is widely distributed throughout the world except for Australia and New Zealand, but historically, it was mainly distributed in North America, Europe and NE Asia (Fig. 5). Although the molecular phylogenies suggest a Cenozoic origin for the crown group of *Equisetum* (Des Marais et al., 2003), the fossil record indicates that species morphologically and anatomically resembling modern taxa appeared in the Mesozoic, which can be proved by the presence of *Equisetum thermale* from the Late Jurassic of Argentina. *Equisetum thermale* exhibits all the morphological and anatomical characteristics of the extant crown group *Equisetum*. It displays a mixture of features present in the two

extant subgenera: Superficial stomata typical of the Subgenus *Equisetum* accompanied by infrequently ramifying stems characteristic of the Subgenus *Hippochaete* (Channing et al., 2011). Another example is *Equisetum bryanii* Gould with well-preserved stems and leaves, reported from the Jurassic of southeastern Queensland, which is regarded as the earliest member of the Subgenus *Equisetum* (Gould 1968). Moreover, the Early Cretaceous specimens, *Equisetum haukeanum*, *Equisetum vancouverense* and *Equisetum* sp. from Canada are anatomically similar to the living species of *Equisetum* (Stanich et al., 2009).

The Early Cretaceous specimens from NE China are all assigned to *Equisetites*, most of which are preserved as stems, leaves or leaf sheaths, but some of them are described as having rhizomes with tubers, such as *E. burejensis*, *E. macrovalis*, *E. nakdongensis*, *E. exiliformis* and *E. longevaginatius* (Chen et al., 1988; Deng et al., 1997; Sun et al., 2001). The present specimen is assigned to the Subgenus *Equisetum* because it possesses tubers. While tubers are common in the Subgenus *Equisetum*, they are never found in Subgenus *Hippochaete* (Thomé, 1885; Campbell, 1928; Mehra and Bir, 1959; Hauke, 1963, 1978; Bir, 1978; Watson and Batten, 1990). Thus, we can infer that the Subgenus *Equisetum* was probably widely distributed in NE China during the Early Cretaceous. The warm and humid climate of NE China during the Early Cretaceous provided a suitable environment for its growth.

The specimens collected from the Cenozoic show remarkable similarity to extant *Equisetum*, such as *Equisetum fluviatoides* from the Paleocene Ravenscrag Formation of Saskatchewan, Canada, which had similar reproductive and vegetative organs to extant *Equisetum fluviatile* (McIver and Basinger, 1989). The Eocene specimen, *Equisetum clarnoi* most closely resembles the extant *Equisetum hyemale* var. *affine*, which clearly showed



affinities with the Subgenus *Hippochaete* (Brown, 1975). The Miocene specimens from China and Iceland resemble *Equisetum pratense* morphologically (Zhang et al., 2007). The specimens from the late Tertiary Ash Hollow Formation of central North America, which are preserved as leaf-sheaths, closely resemble modern *Equisetum laevigatum* on micro-morphology (Thomasson, 1980). All taxonomic characters of the Pliocene specimens collected from central Mexico suggest a close affinity to the modern species *Equisetum myriochaetum* (Silva-Pineda et al., 2009).

All this evidence indicates that the initial evolutionary diversification of *Equisetum* species with modern morphology and anatomy probably dated from the Jurassic. The species of *Equisetum* became widely distributed in the Cretaceous and highly developed in the Cenozoic. Since the oldest widely recognized fossil species of *Equisetum* is *Equisetum laterale* Gould from the Middle Triassic of Australia (Gould, 1968), *Equisetum* would appear to have an ancient, but incompletely documented fossil record (Stanich et al., 2009).

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Figure 1. Locality of fossils in western Gansu Province, NW China

Figure 2. The sedimentary sequence of fossil-bearing strata of the Early Cretaceous Zhonggou Formation in Jiuquan Basin, Gansu, NW China.

Figure 3. Tuberos rhizomes of extant *Equisetum* (a, b) and *Equisetum jiuquanense* (c). (modified from Zhang et al., 1980 and Burrill and Parker, 1994)

Figure 4. The arrangement of fossil tubers in *Equisetum*-like species.

Figure 5. The world distribution of fossil *Equisetum* (Data from: Lesquereux, 1878; Fritel and Viguier, 1909; Harris, 1931, 1945; Bell, 1949; Lamotte, 1952; Harris, 1961; Kon'no, 1962; Hauke, 1963; Gould, 1968; Becker, 1969; Brown, 1975; Christophel, 1976; Geng and Tao, 1982; Tao and Du, 1987; Ash, 1988; Chen et al., 1988; McIver and Basinger, 1989; Watson and Batten, 1990; Deng, 1995; Deng et al., 1997; Sun et al., 2001; Skog and Dilcher, 1994; Wu, 1999; Guo, 2000; Zhou, 2003; Yang, 2003; Ablaeu, 2003; Denk et al., 2005; Zhang et al., 2007; Silva-Pineda et al., 2009; Stanich et al. 2009; Channing et al., 2011.)

Plate I. Fossil tubers of *Equisetum jiuquanense*. (1. Specimen Hanxiak<sub>195-2-16</sub>(A); 2. Specimen Hanxiak<sub>195-2-16</sub>(B); 3. Specimen Hanxiak<sub>195-2-12</sub>(A); 4. Specimen Hanxiak<sub>195-2-12</sub>(B); 5. Specimen Hanxiak<sub>195-3-125</sub>(A); 6. Specimen Hanxiak<sub>195-3-125</sub>(B); 7. Specimen Hanxiak<sub>195-3-160</sub>.) Scale bar = 50 mm

Plate II. Morphological and cellular characters of fossil *Equisetum jiuquanense*. (Figure 1, tuber morphology scale bar =1000 $\mu$ m; Figure 2-3, cellular features under the stereomicroscope, scale bar =100 $\mu$ m; Figure 4-5, cellular features under the SEM, scale bar =10 $\mu$ m, figure 4 and figure 5 show the straight anticlinal walls (arrows); Figure 6, shows the grains on the periclinal walls.)

Plate III. Morphological and micromorphological structures of extant *Equisetum arvense*. (Figure 1, tuber of *Equisetum arvense*, scale bar = 5mm; Figure 2, tuberous rhizomes of *Equisetum arvense*, scale bar = 10mm; Figure 4-6, cellular features of the tubers of *Equisetum arvense*)

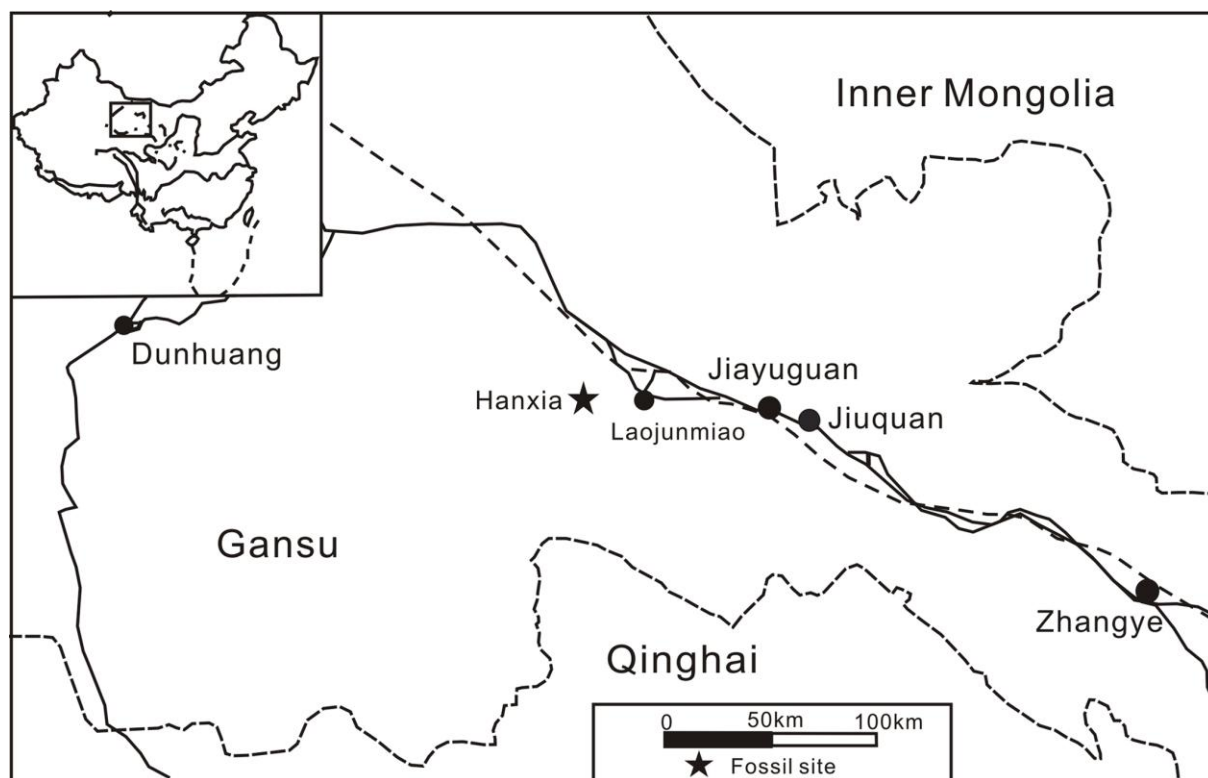


Fig. 1

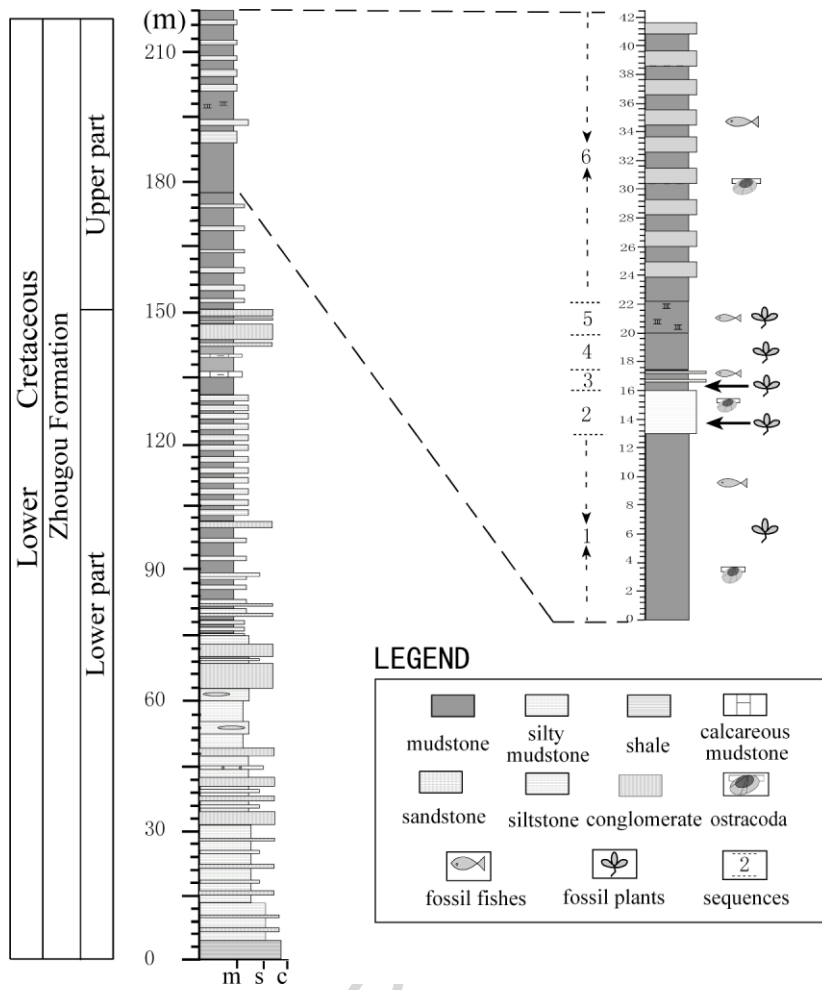


Fig. 2

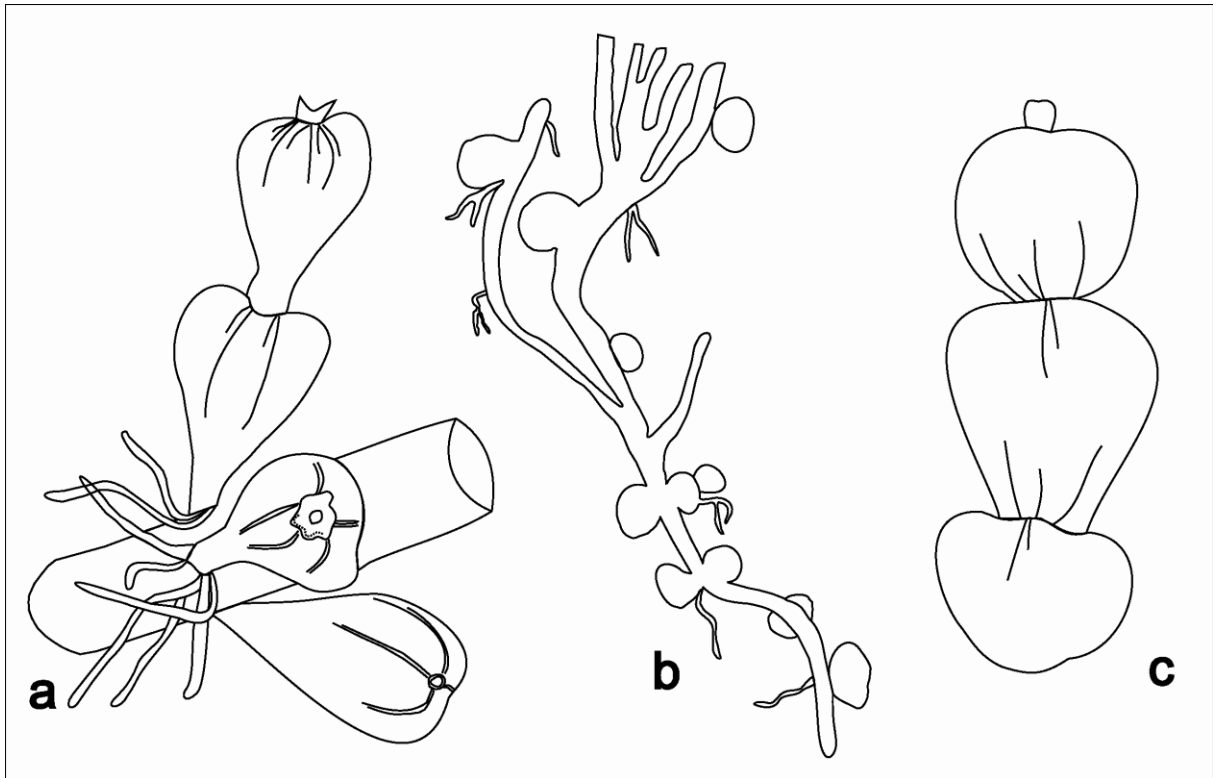


Fig. 3

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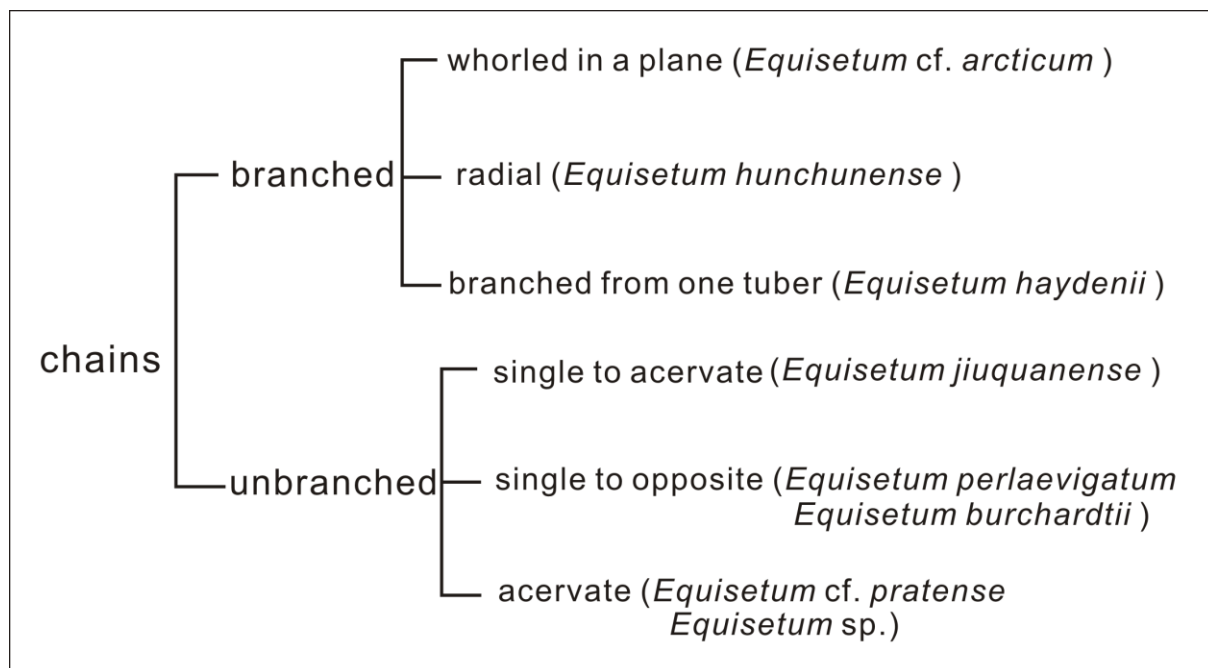


Fig. 4

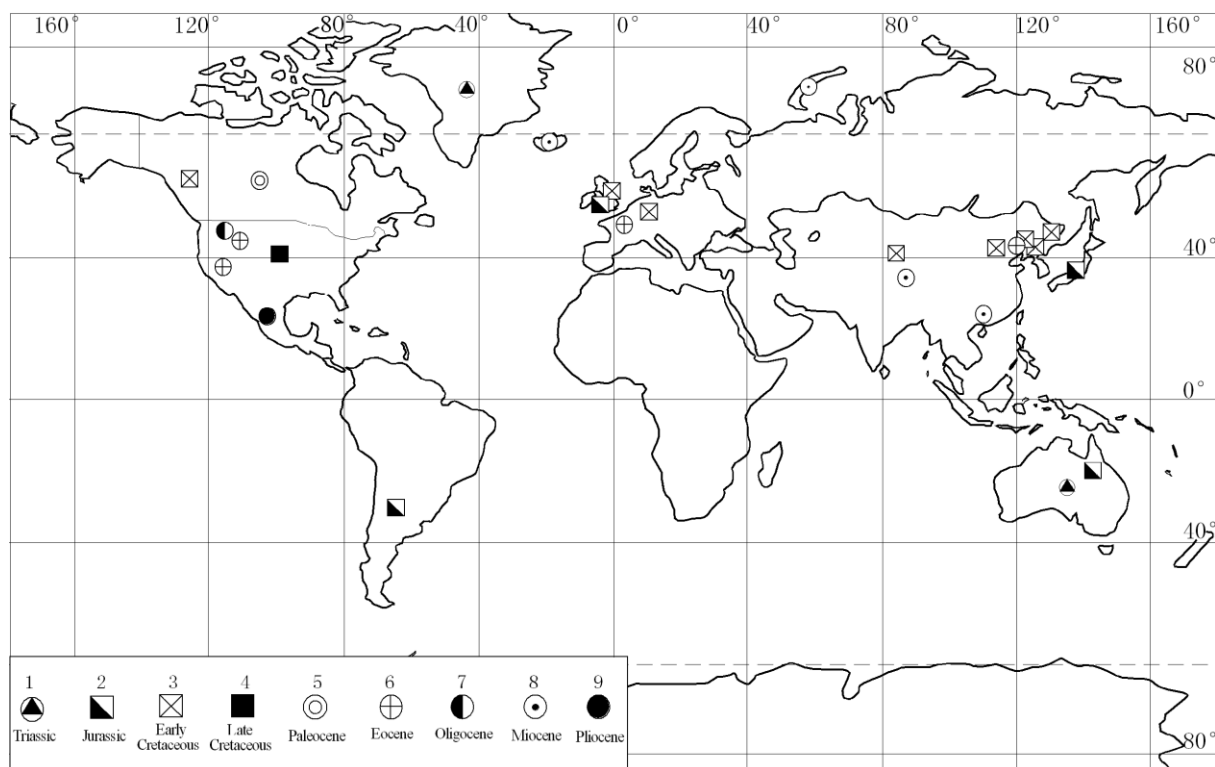


Fig. 5

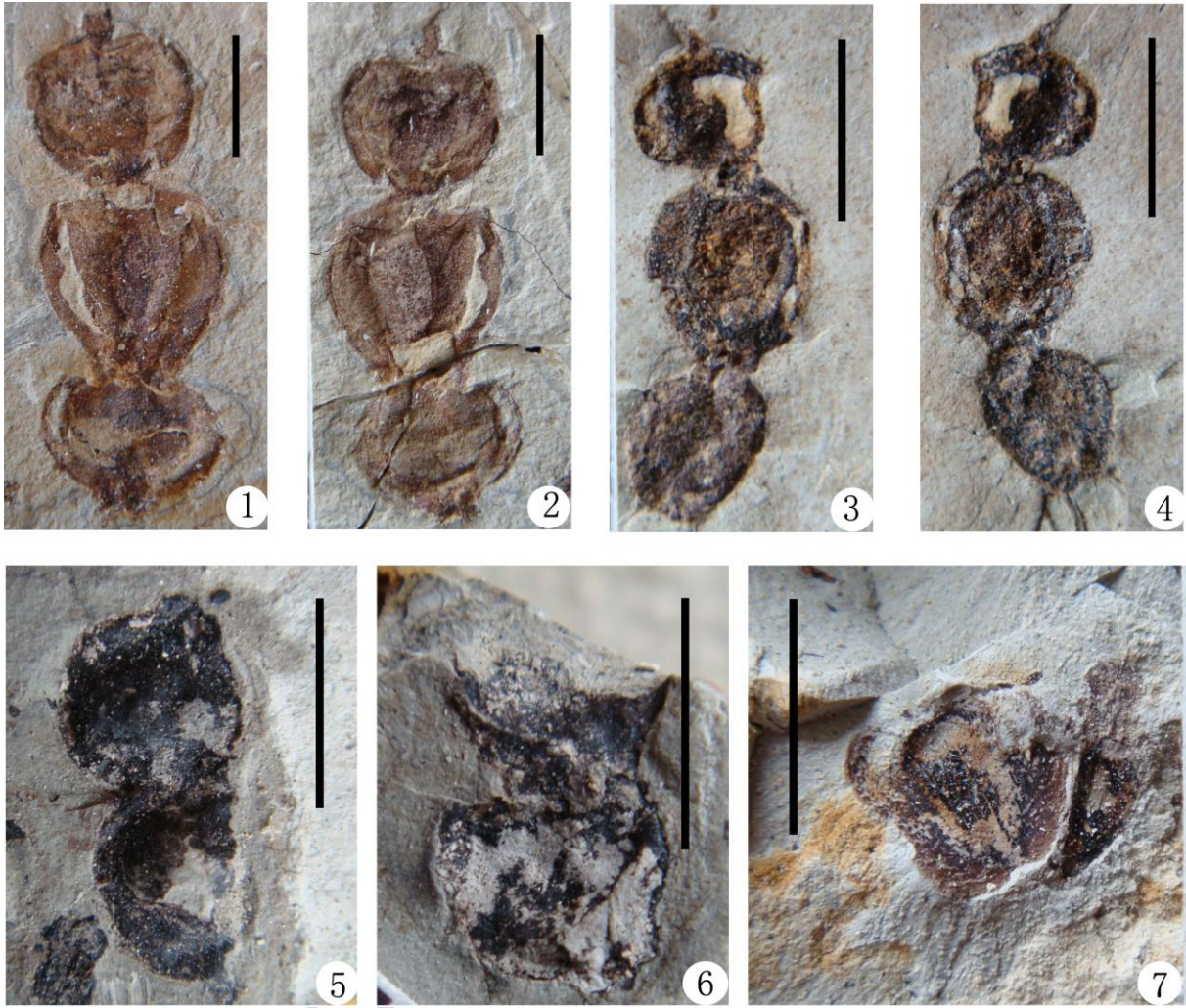


Plate 1

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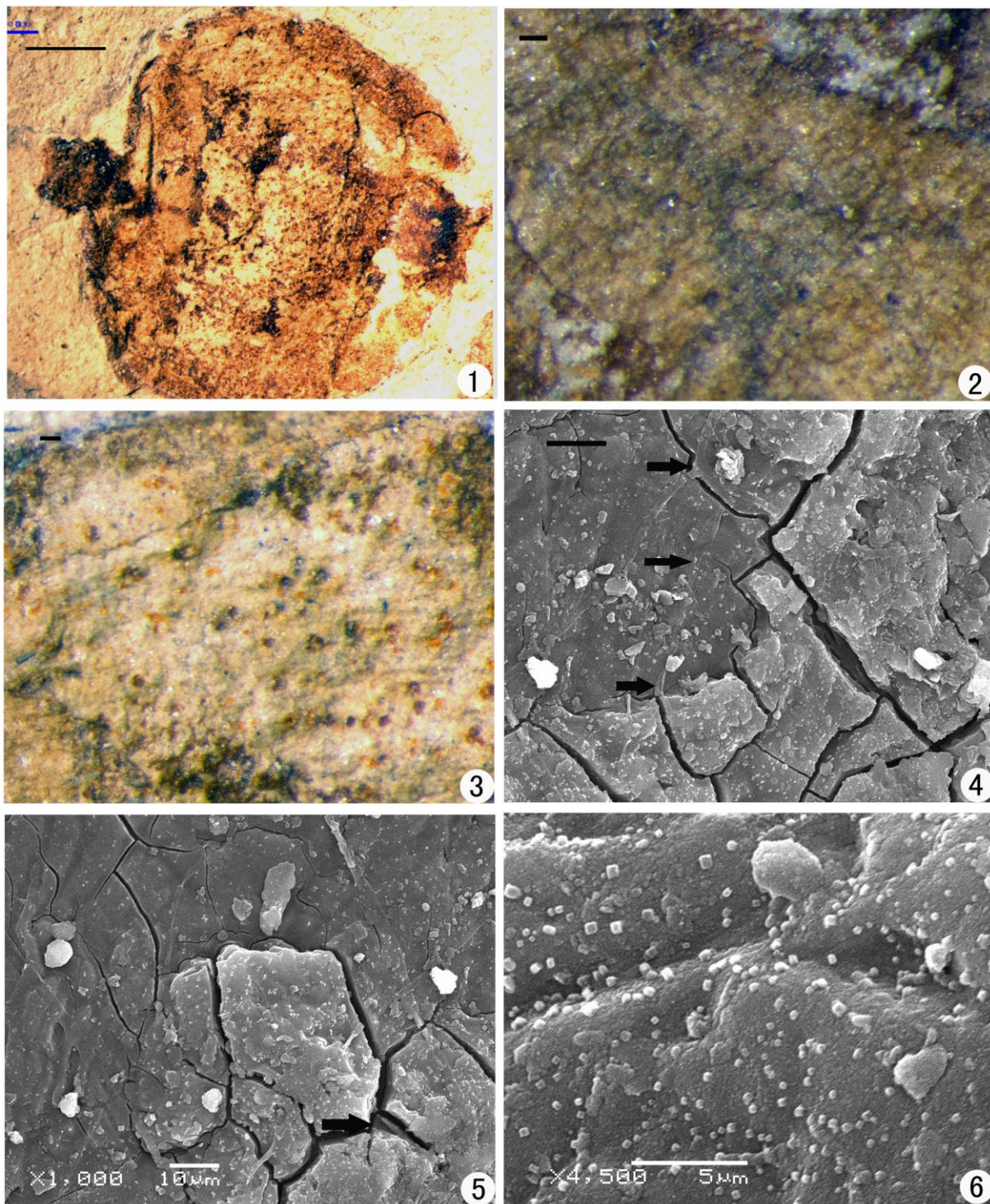


Plate 2

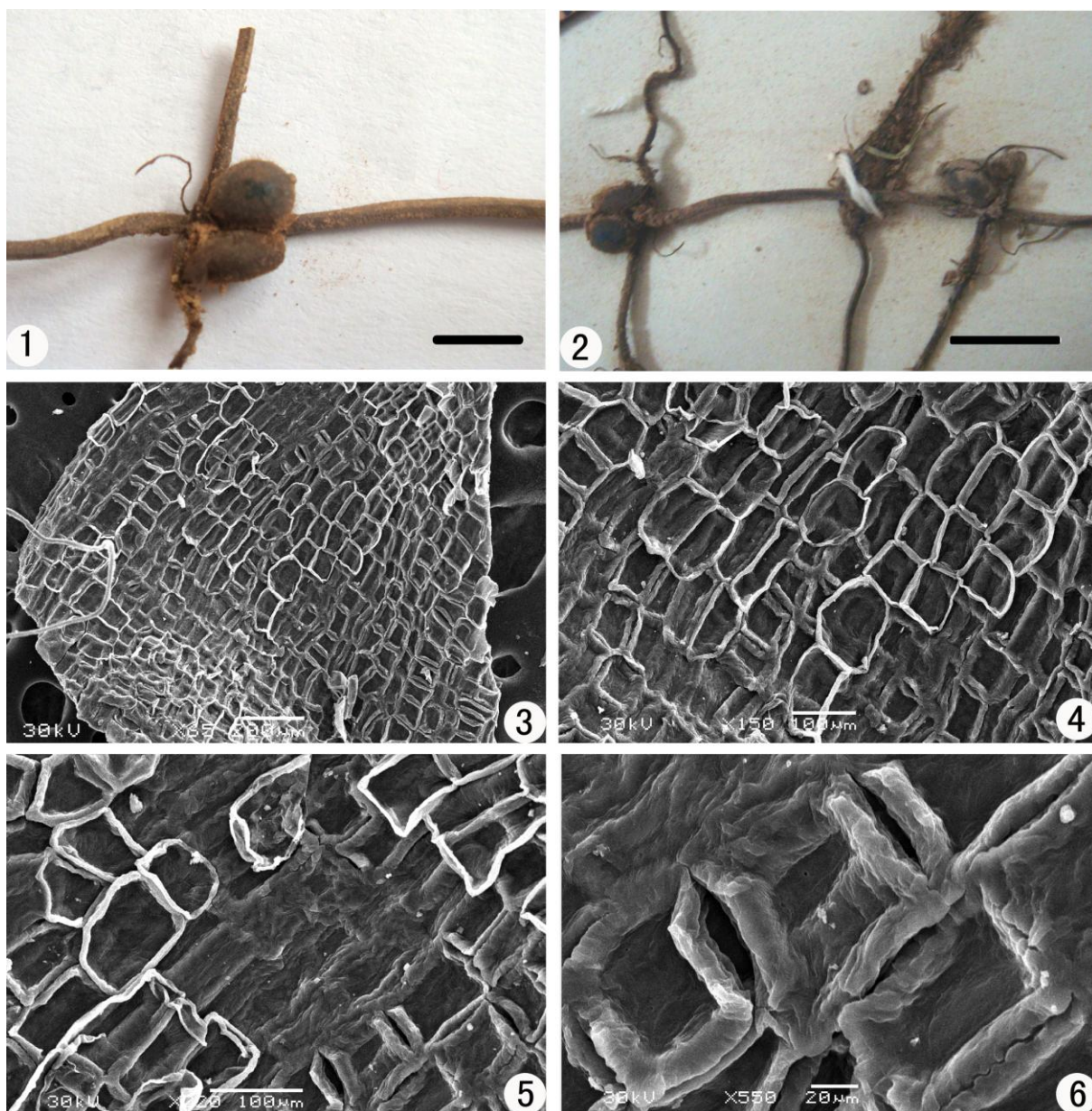


Plate 3

Table. 1 Morphological comparisons between fossil Equisetum from Jiuquan Basin and extant tuberous Equisetum species

Species	Size (length/width)	Shape	Number	Arrangement	Reference
<i>Equisetum arvense</i>	13–14mm 11-13mm	Elliptical, round	1	Single or in pairs, acervate	Hauke, 1978;
<i>Equisetum diffusum</i>	11-12mm 8-9mm	Elliptical	1-3	Single	Mehra and Bir, 1959; Bir, 1978
<i>Equisetum palustre</i>	-	-	1	Single	Bir, 1978
<i>Equisetum pratense</i>	5-14mm 5-9mm	Elliptical or round	2-3	Single to acervate	Thomé, 1885; Zhang et al., 2007
<i>Equisetum sylvaticum</i>	-	-	1	Acervate	Bir, 1978
<i>Equisetum telmateia</i>	9-13mm 8-10mm	Round, ovate	1	Acervate	Campbell, 1928; Hauke, 1978
<i>Equisetum jiuquanense</i>	3-8mm 4-7mm	Elliptical, ovate, round	2-3	Single to acervate	The present paper

Table 2. Morphological comparisons between *Equisetum jiuquanense* and tuberous *Equisetum*-like fossils in China in the Early Cretaceous

Species	Size(length /width)	Shape	Number	Arrangement	Age	Locality and stratigraphy	Reference
<i>Equisetites burejensis</i>	2.5-4.5mm 2-9mm	Round, ovate or spindle-shaped	1-3	Single, whorled commonly opposite	Early Cretaceous	Muleng Formation, Heilongjian; Fuxin Formation, Fuxin, Liaoning; Yimin Formation and Huolinhe Formation, Inner Mongolia	Chen et al., 1988; Deng, 1995; Deng et al., 1997; Yang, 2003
<i>Equisetites macrovalis</i>	23-50mm 12-26mm	Ovate	1	Single	Early Cretaceous	Damoguaihe Formation and Huolinhe Formation, Inner Mongolia	Deng, 1995; Deng et al., 1997
<i>Equisetites naktongensis</i>	10-20mm 5-10mm	Elliptical	1-2	Single or opposite	Early Cretaceous	Damoguaihe Formation, Inner Mongolia	Deng et al., 1997
<i>Equisetites exiliformis</i>	8-10mm 10-12mm	Round or elliptical	1-2	Single or opposite	Early Cretaceous	Jianshangou Formation, Liaoning	Sun et al., 2001
<i>Equisetites longevaginat us</i>	3-5mm 5-8mm	Round or elliptical	1-3	Single or opposite	Early Cretaceous	Yixian Formation, Beipiao, Liaoning	Sun et al., 2001; Zhou et al., 2003
<i>Equisetites</i> sp.	15mm 10mm	Ovate	1-2	Single or opposite	Early Cretaceous	Huolinhe Formation, Inner Mongolia	Deng, 1995
<i>Equisetum</i> cf. <i>pratense</i>	6-21mm 5-12mm	Elliptical, ovate, nearly round or spindle-shaped	2-4	Acervate	Miocene	Lühe, Yunnan	Zhang et al., 2007
<i>Equisetum jiuquanense</i>	3-8mm 4-7mm	Round, elliptical, ovate	1-3	Single or acervate	Early Cretaceous	Zhonggou Formation, Jiuquan, Gansu	This paper

**Highlights**

>Tubers of *Equisetum* are described from the Early Cretaceous of Zhonggou Formation. >The dominated scale-leaved conifers suggest an arid climate. >The occurrence of fossil *Equisetum* indicates a locally wet habitate. >The distribution and evolution of fossil *Equisetum* are discussed.

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