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Discovery of *Pseudofrenelopsis gansuensis* from the Lower Cretaceous of Wangqing, Jilin Province, and Its Significance in Correlation of Cretaceous Red Beds in China

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Abstract: New data from abundant vegetative shoots and cuticular analysis are provided for the Cretaceous cheirolepidiaceous conifer *Pseudofrenelopsis gansuensis* Deng, Yang et Lu. The material was found from a new locality of the Lower Cretaceous strata in the Luozigou Basin, Wangqing, Jilin Province, northeastern China. *Pseudofrenelopsis* is a common plant in the Dalazi Formation of the Yanji Basin about 150 km from Wangqing, but there exists different species, *Pseudofrenelopsis dalatzensis* only. Both *P. dalatzensis* and *P. gansuensis* have been recorded from the Lower Cretaceous of Jiuquan, Gansu Province, but they are in different stratigraphic horizons. The Lower Cretaceous plant-bearing strata in Luozigou have used to correlate with the Dalazi Formation of the Yanji Basin. The discovery of *P. gansuensis*, which is lower in horizon than *P. dalatzensis* in Jiuquan, may indicate that they are also different in horizon in Jilin. Cheirolepidiaceous conifers are among the few fossils of red beds of the Early Cretaceous in China. The present discovery of *Pseudofrenelopsis gansuensis* provides important evidence for classification, correlation and determination of geological ages of the Early Cretaceous non-marine red deposits of the two separate basins in remote areas of North China.

Key words: Cheirolepidiaceae, Cretaceous, Dalazi Formation, *Pseudofrenelopsis*, red beds, stratigraphic correlation

1 Introduction

Fossil plants from the Cretaceous plant-bearing strata, the "Lo-Tzu-Kou Series", in the Luozigou Basin, Wangqing, Jilin Province, were firstly studied by Oishi, a Japanese paleobotanist (1941). Totally 9 taxa were recognized by him, viz. *Cladophlebis exiliformis* (Geyler) Oishi, *Gleichenites nipponensis* Oishi, *Elatocladus curvifolia* Dunker, *Sphenolepidium sternbergianum* Dunker, *Pityocladus iwaiana* (Oishi) Chow. Although many Chinese geologists have worked in the Luozigou district since 1949 and made some collections of fossil plants, yet there is no detailed study on the Luozigou flora except for some additions to the plant list: *Coniopteris saportana* (Heer) Vachr., *Onychiopsis elongate* (Geyler) Yok., *Pagiophyllum* sp., *Brachyphyllum crassum* Lesq., *Brachyphyllum ningshiaense* Chow and Tsao, *Phyllites* sp, *Otozamites* sp., *Frenelopsis*? sp., *Sassafras*? sp., *Paliurus*? sp., *Pityolepis* sp. (Zhou et al., 1980; Bureau of Geology and Mineral Resources of Jilin Province, 1992).

The plant-bearing strata in the Luozigou Basin have been considered to belong to the Lower Cretaceous Dalazi Formation (Zhou et al., 1980; Bureau of Geology and Mineral Resources of Jilin Province, 1997), which is well developed in Dalazi, Zhixin Town, Longjing County in the Yanji Basin, Northeast Jilin Province (Fig. 1). Up to now, several cheirolepidiaceous conifers have been reported from the Yanji Basin (Chow and Tsao, 1977; Zhang et al., 1980; Zhang, 1986; Zhou, 1995), but none has been reported from Luozigou. During a recent field trip to Luozigou, one of the present authors (Yang) collected abundant shoots of cheirolepidiaceous conifers, which belong without doubt to *Pseudofrenelopsis*, and some of them are branched. A study on the cuticle shows that they are not similar to *Pseudofrenelopsis dalatzensis* (Chow and Tsao) Cao ex Zhou (Zhou, 1995), which is the most common plant found in the Dalazi formation of the Yanji Basin, but resemble *Pseudofrenelopsis gansuensis* (Deng et al., 2005) from the Jiuquan Basin, Gansu Province, Northwest China. So far, *P. gansuensis* has been known to occur only in the Lower Cretaceous Xiagou Formation of Jiuquan and the material is rather fragmentary. The

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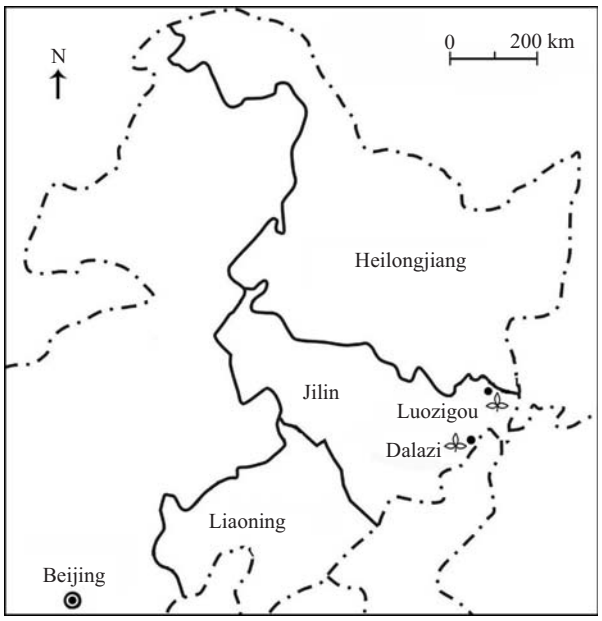

Fig. 1. A sketch map showing the location of Luozigou, Wangqing County, Jilin Province.

discovery of well-preserved specimens in Luozigou provides more detailed morphological information of this species. It is of significance not only in paleophytogeography, but also in correlation of the fossil-barren Cretaceous red beds in China.

2 Material and Methods

The material was collected from the fossiliferous strata of Luozigou, which has been correlated with the late Early Cretaceous Dalazi Formation in the Yanji Basin, about 150 km southwest to Wangqing (Fig. 1).

The specimens are compressions with cuticles preserved. Pieces of the cuticle were removed from the specimens, firstly treated with hydrofluoric acid (HF) for 12 hours followed by maceration with Schulze's solution (nitric acid and potassium chlorate). The time for oxidation depended upon the degree of coalification of the compressed specimen, usually about 5–8 h. After the specimens became yellow and translucent, they were rinsed with water and then treated with dilute 5% KOH for a few seconds, and a finally thorough washing with water. Samples for scanning electron microscopy (SEM) were mounted on stubs using double-sided adhesive tape, coated with gold, and observed and photographed with a Hitachi S-4300 SEM at the SEM Laboratory of the Swedish Museum of Natural History, Stockholm, Sweden.

All specimens (PB21041-21045) and stubs are deposited in the Nanjing Institute of Geology and Paleontology, Chinese Academy of Sciences.

3 Systematic Description

Family: Cheirolepidiaceae

Genus: *Pseudofrenelopsis* Nathorst 1893

Pseudofrenelopsis gansuensis Deng, Yang et Lu 2005

***Pseudofrenelopsis gansuensis*, Deng et al., 2005 p.508, pl. I, figs. 1, 2; pl. II, figs 1–9; text-fig. 2**

Emended diagnosis: Isolated shoots 3–8 mm wide, up to 110 mm long. Shoots branched sparsely at about 40º angles. Internodes 5–14 mm long, on the surface with parallel fine longitudinal ridges and grooves converging towards the leaf apex. Leaves adpressed on the shoot, the free part of leaves small, loosely and spirally arranged, with an acute apex. Abaxial cuticle thick with distinct longitudinally arranged stomatal- and non-stomatal files. Outer surface smooth, without hairs or papillae. Epidermal cells square, polygonal but rectangular in non-stomatal files; cuticle of periclinal walls usually thinner along anticlinal walls. Stomata elliptical to more or less rounded, usually arranged in uniseriate file, or sometimes in short biseriate files, separated from each other by 1–4 ordinary cells or occasionally in contact with each other in the file but never share subsidiary cells. Stomata deeply sunken, guard cells usually represented by small cutinized patches, each stoma bearing (5–) 6–7 (–8) subsidiary cells, with rounded stomatal pit mouth. Apertures of stoma oriented longitudinally or obliquely.

Remarks of the species: The original diagnosis given by Deng et al. (2005), based on a single fragment of shoot proves to be essentially correct but some emendations are made here based on the abundant additional material described in this article.

Description: The shoots are up to 110 mm long and 3–8 mm wide. Most of them are not branched and occur in great mass throughout the fossiliferous bed. The shoot segments consist of at least five to eleven internodes (Pl. I, A–C). They appear to break easily at the nodes. Shoots are branched sparsely at about 40º angles (Pl. I, D); some reach 110 mm long without branches (Pl. I, A). The internodes are usually 7–14 mm long, and slightly contracted at the node (Pl. I). On the outer surface, the internode bears fine parallel longitudinal ridges and grooves (about 7–9 in number per mm), which become convergent towards the leaf apex (Pl. I, E). Leaves are adpressed on the axis. The free part is triangular, very small, about 0.5–1 mm long with an acute apex, and loosely and spirally arranged on the stem (Pl. I, A–C).

The internode cuticle is about 21–28 μm thick, typically 21–25 μm, and 8–15 μm in thinner shoots. The cuticle consists of well defined stomatal and non-stomatal files (about 7–9 per mm), which are clearly visible on both outer and inner surfaces (Pl. II, A). The outer surface is normally smooth without hairs or papillae (Pl. I, B). The epidermal cells usually have thin periclinal walls along anticlinal walls, and most of these periclinal walls irregularly split to

form fissures along the anticlinal wall on the outer surface except at the cell corner (Pl. II, C). In the stomatal files, epidermal cells are more or less square in outline, or isodiametrically polygonal, about 12–30 μm×14–25 μm in size; in the non-stomatal files, epidermal cells are arranged in one or two rows, square or somewhat rectangular, about 12–35 μm×12–18 μm in size (Pl. II, A–D). Stomata are usually arranged in uniseriate rows (Pl. II, A) or sometimes in short biseriate rows (Pl. II, D, F), 11–12 in number per mm in file. In stomatal files, stomata are separated from each other by 1–4 ordinary epidermal cells or occasionally contiguous but never share subsidiary cells (Pl. I, D). Encircling cells and Florin-rings are absent. Stomata are elliptical to more or less rounded in outline, about 60–80 μm × 60–90 μm in size, actinocytic and mostly oriented longitudinally or obliquely (Pl. I, D, E). Stomata are deeply sunken, each stoma bears 5–8 subsidiary cells (typically 6–7), which are smooth on the surface with no papillae. Guard cells are only partly cutinized. The stomatal pit is rounded to oblong in outer surface view, about 10–24 μm in diameter (Pl. II, A–C). Cutinized hypodermis developed well in some thinner shoots. The hypodermal cells are elongate or rectangular, covered the non-stomatal files in the inner surface of the cuticle (Pl. II, G).

4 Discussion

4.1 General comparison and discussion

The species *P. gansuensis* was originally founded from the Early Cretaceous Xiagou Formation in the Jiuquan Basin based on a fragmentary vegetative shoot with well preserved cuticle (Deng et al., 2005). All the morphological and structural characters known of the type specimen, such as internodes with fine longitudinal ridges and grooves on the outer surface, epidermal cells mainly square or rectangular, rounded or sub-rounded stomata in well-defined files, without hairs and papillae, subsidiary cells typically 6–7 in number, having no papillae, are recognized in the present material. The close similarities clearly support an attribution of the present specimens to *P. gansuensis*.

The present material consists of numerous specimens which vary to a certain extent in gross morphology. The length of internode in some shoots is irregular (Pl. I, A); and sometimes slender shoots have longer internodes, but their cuticular characters are similar to the others. The thickness of cuticle may vary from 8 μm to 30 μm in different specimens; the presence or absence of hypodermis does not relate to the thickness of cuticle, in some specimens hypodermis could not be recognized (Pl. II, A) but in some others hypodermal cells are well developed and cover almost the whole non-stomatal files in the inner surface of cuticle (Pl. II, G).

The present specimens differ easily from other known species of *Pseudofrenelopsis* in having no papillae and hairs on the outer surface of cuticles and no Florin rings around the stoma (Watson, 1988; Zhou, 1995; Saiki, 1999). A detailed comparison with other pseudofrenelopsids has already been given in erection of *P. gansuensis* (Deng et al., 2005).

The described specimens were collected from the plant-bearing strata in the Luozigou Basin, which have been referred to the Lower Cretaceous Dalazi Formation (Zhou et al., 1980; Bureau of Geology and Mineral Resources of Jilin Province, 1997). In gross morphology it also resembles *P. dalatzensis* from the Dalazi Formation of Zhixin, which yields abundant animal and plant fossils in the Yanji Basin (Zhang, 1986; Tao, 2000). In recent years we found that *P. dalatzensis* was one of the most common plants in the Dalazi Formation in some dark gray-yellow fine-siltstone. So when similar specimens occur in the Luozigou Basin, we assumed that they belong to *P. dalatzensis*. However, a detailed study shows that they cannot be assigned to *P. dalatzensis* for their cuticular features are very different. Papillae are inevitably present on the outer surface of cuticle *P. dalatzensis* even though it shows considerable variations in other gross morphological characters. Another important character that separates *P. dalatzensis* readily from the Luozigou specimens is that the stomata always bear papillae and Florin rings, with 5–6 subsidiary cells forming a narrow, stellate pit mouth.

4.2 Distribution and horizon of *P. gansuensis*

P. gansuensis previously only reported from the Jiuquan Basin. The Lower Cretaceous strata in the Jiuquan Basin are divided into the Chijinpu Formation, Xiagou Formation and Zhonggou Formation (Ye et al., 1990). The Xiagou Formation belongs probably to Barremian of Early Cretaceous based on micropaleontological and palynological data (Lu et al., 2002; Deng et al., 2005). The plants, spores and pollen from the overlying Zhonggou Formation indicate that it is Aptian-Albian in age (Lu et al., 2002; Deng and Lu, 2007), which is coeval with the Dalazi Formation of the Yanji Basin.

So far, *P. gansuensis* without papillae was found from the Xiagou Formation while *P. dalatzensis* with heavy papillae was found from the Zhonggou Formation in the Jiuquan Basin (Deng et al., 2005). The stratigraphic positions of *P. gansuensi* and *P. dalatzensis* in the Jiuquan Basin (Ye et al., 1990; Deng et al., 2005) appear to be coincided with the trend noted by Oldham (1976) that numbers of epidermal papillae on shoot internodes tend to increase with the times in the English Wealden. Now, *P. gansuensis* is found from the Luozigou Basin while *P. dalatzensis* has been found from the Yanji Basin. The Yanjin Basin and Luozigou Basin are not far from each other and are in the east of Jilin Province. Although some geologists and paleobotanists have suggested to attribute

Table 1 Localities and stratigraphic horizons of *Pseudofrenelopsis* in China

Taxa	Locality	Horizon	Reference
P. dalatzensis	Jiuquan, Gansu; Longjing, Jilin	Aptian-Albian	Deng et al, 2005; Lu, 2002; Zhou, 1995
P.gansuensis	Jiuquan, Gansu; Wangqing, Jilin	Barremian	Deng et al, 2005; Deng and Lu, 2007; this paper
P. heishanensis	Lingxiang, Hubei	Pre-Aptian	Zhou, 1995
P. papillosa	Hualong, Qinghai; Guyuan, Ningxia; Xinchang, Zhejiang	Pre-Aptian	Zhou, 1995

the "Lo-Tzu-kou Series" (Oishi S., 1941) to the Dalazi Formation (Zhou et al., 1980; Bureau of Geology and Mineral Resources of Jilin Province, 1997), the present discovery of *P. gansuensis* shows that the "Lo-Tzu-Kou Series" in Luozigou is possibly lower in stratigraphic horizon than the Dalazi Formation in Zhixin. Such a conclusion can only be reached after future detailed studies on stratigraphy and paleotology in this region. The associated plants of *P. gansuensis* in the "Lo-Tzu-Kou Series" appear to be also somewhat different in composition as compared with those associated with *P. gansuensis*.

4.3 Significance in correlation of Cretaceous red beds in China

In the Cretaceous time, continental deposits were dominated in almost the whole China except for the southern Tibet, eastern Heilongjiang and westermost Xinjiang where there were marine beds (Huang et al., 2007; Jiang et al., 2006). During the Early Cretaceous red beds developed well in a large area of China in which fossil plants, spores and pollen are rare. Classification, correlation and determination of geological ages of the Early Cretaceous non-marine deposits are very difficult because the red beds are always fossil-deficient or even barren.

Cheirolepidiaceae is one of the important Mesozoic coniferous family. Most species of this family bear xeromorphic characters and can suffer hot and dry continental climate (Watson, 1988). Cheirolepidiaceous conifers usually occur with only very few other megafossils in the Early Cretaceous sediments in China (Zhou, 1995). So any discovery of cheirolepidiaceous conifers from the Early Cretaceous red-beds may provide important fossil clues for the classification, correlation and determination of geological ages of the Early Cretaceous non-marine fossil-barren deposits in China.

Although specimens assigned to *Pseudofrenelopsis* are frequently encountered in the Lower Cretaceous sediments, the genus is only represented by four species *P. dalatzensis*, *P. gansuensis, P. heishanensis* and *P. papillosa* (Zhou, 1995; Deng et al., 2005) so far as known in China. Among them only *P. papillosa* is in a wider distribution and better known (Zhou, 1995; Yang, 2005) while the three other species have been all restricted in distribution (Table 1). The present discovery of *P. gansuensis* and the previous stratigraphical and geological reports on *P. dalatzensis* and *P. gansuensis* (Zhou, 1995; Deng et al., 2005) indicate that lower Cretaceous beds of the Luozigou Basin and the Jiuquan Basin can be correlated and the vegetations of the two remote continental basins belong to the same floristic province of the Early Cretaceous with a similar climate and environment.

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Explanation of Plates

Plate I

Pseudofrenelopsis gansuensis. Specimens: PB21041-21045. Scale bars: 10 mm (A), 5 mm (B, C, D), 2 mm (E). A (right), B and C, showing a long shoot without lateral branch; arrows indicating free leaves. Note that two internodes (arrows) are shorter than the others in A. D, showing a shoot with branch. E, a segment of shoot, showing fine parallel, longitudinal ridges and grooves on the outer surface.

Plate II

Pseudofrenelopsis gansuensis. Scanning electron micrographs of internode cuticle. Specimens: PB21043 (Figs. A–F), PB21041 (Fig. G).

A. Abaxial cuticle with distinct longitudinal arrangement of stomatal- and non-stomatal files viewed in both inner and outer sides. Scale bar: 150 μm.

B. Outer surface view of abaxial cuticle, note that papillae or hairs are totally absent. Scale bar: 50 μm.

C. Outer surface view of abaxial cuticle, showing pit mouth of a stoma, note that irregular fissures usually present on the periclinal walls along anticlinal walls. Scale bar: 20 μm.

D. Inner surface view of abaxial cuticle. Scale bar: 50 μm.

E. Inner surface view of abaxial cuticle, showing a stoma with 6 subsidiary cells. Scale bar: 10 μm.

F. Inner surface view of abaxial cuticle, showing two stomata contiguously arranged in biseriate rows, one bearing 7 subsidiary cells (left) and another bearing 8 (?) subsidiary cells (right). Scale bar: 20 μm.

G. Inner surface view of abaxial cuticle, showing hypodermal cells (arrows) developed well along the non-stomatal files. Scale bar: 40 μm.

Plate I

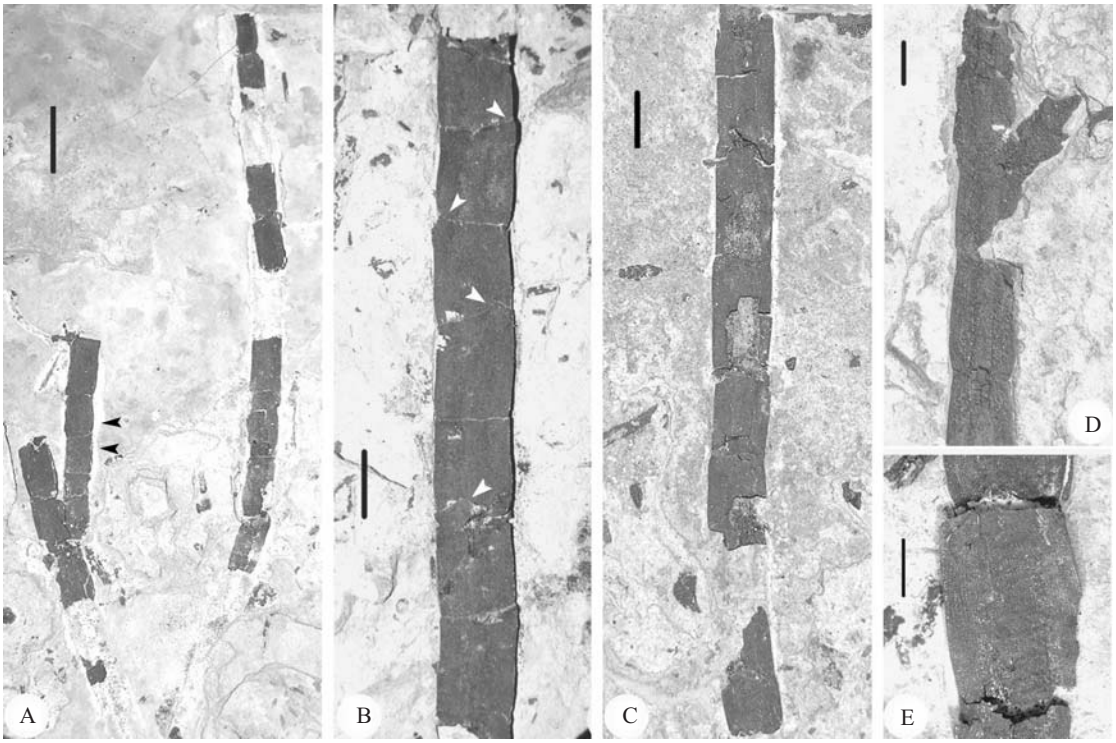

Plate II