

# *Brachyphyllum liaoningense* sp. nov. from the Upper Jurassic of Northeast China

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## ABSTRACT

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Fossil conifer twigs and foliage referred to *Brachyphyllum liaoningense* sp. nov. were collected from the Tuchengzi Formation of Beipiao Basin, Liaoning Province, Northeast China. The leaves are arranged spirally on twigs, with a basal cushion tapering into a small free part. The length of the free part is little less than the width. Stomata exist on both adaxial and abaxial cuticles, but more on the abaxial side. The stomata are rounded or elliptic in form and arranged in longitudinal files in the abaxial cuticle, the epidermal cells between the stomatal files are elongated rectangular or in strip-form. The guard cells are sunken. The subsidiary cells are monocyclic, 5-7 in number, lack encircling cells. A few stomata are scattered on the adaxial cuticle, which are similar to those of the abaxial cuticle except that they have encircling cells. It is presumed that the subsidiary cells of *Brachyphyllum* show a tendency of increasing in number from Jurassic to the Early Cretaceous.

**Key-words**—Upper Jurassic, Conifer, Leafy twig, China.

उत्तर-पूर्वी चीन से प्राप्त उपरि जुरासिक युगीन *ब्रैकीफिल्लम लायनिंगेन्साइ* नवप्रजाति

शेंग हुइ डेंग एवं पिंग शांग

सारांश

उत्तर-पूर्वी चीन के लायनिंग प्रान्त की बेइपियाओ द्रोणी के तुकेंगज़ाई शैलसमूह से *ब्रैकीफिल्लम लायनिंगेन्साइ* नवप्रजाति से सन्दर्भनीय अशिमित शंक्वाकार टहनियाँ तथा पर्णसमूह संग्रहीत किए गए। पत्तियों को एक छोटे स्वतंत्र भाग के अन्दर आधारीय उपधान द्वारा टहनियों पर सर्पिलाकृति में व्यवस्थित किया गया। इस स्वतंत्र भाग की लम्बाई चौड़ाई से किंचित् कम रखी गयी। यद्यपि स्टोमैटा दोनों अभ्यक्ष तथा अपाक्ष उपचर्मों पर विद्यमान है, परन्तु यह अपाक्ष के अधिक निकट है। स्टोमैटा चक्राकार अथवा दीर्घवृत्तीय है तथा यह अपाक्षीय उपचर्म में अनुदैर्घ्य तंतु में व्यवस्थित है। स्टोमैटा की तंतु के मध्य की अधित्वचीय कोशिकाएँ प्रदीर्घ चतुर्भुजाकार अथवा पट्टिकाओं के रूप में हैं। इसकी द्वार कोशिकाएँ धँसी हुई हैं। 5-7 सहायक कोशिकाएँ एकचक्रीय हैं तथा इनमें परिवेष्टित कोशिकाएँ अनुपस्थित हैं। कुछ स्टोमैटा अभ्यक्ष उपचर्म पर परिक्षिप्त हैं, जो अपाक्ष उपचर्म के निकटस्थ हैं, इनमें एक मात्र अन्तर यह है कि इनमें परिवेष्टित कोशिकाएँ विद्यमान हैं। यह आनुमानित किया जाता है कि *ब्रैकीफिल्लम* की सहायक कोशिकाएँ जुरासिक से प्रारंभिक क्रिटेशस के मध्य संख्या में वृद्धि का रुझान प्रदर्शित करती हैं।

**संकेत शब्द**—उपरि जुरासिक, शंक्वाकार, पर्ण टहनी, चीन.

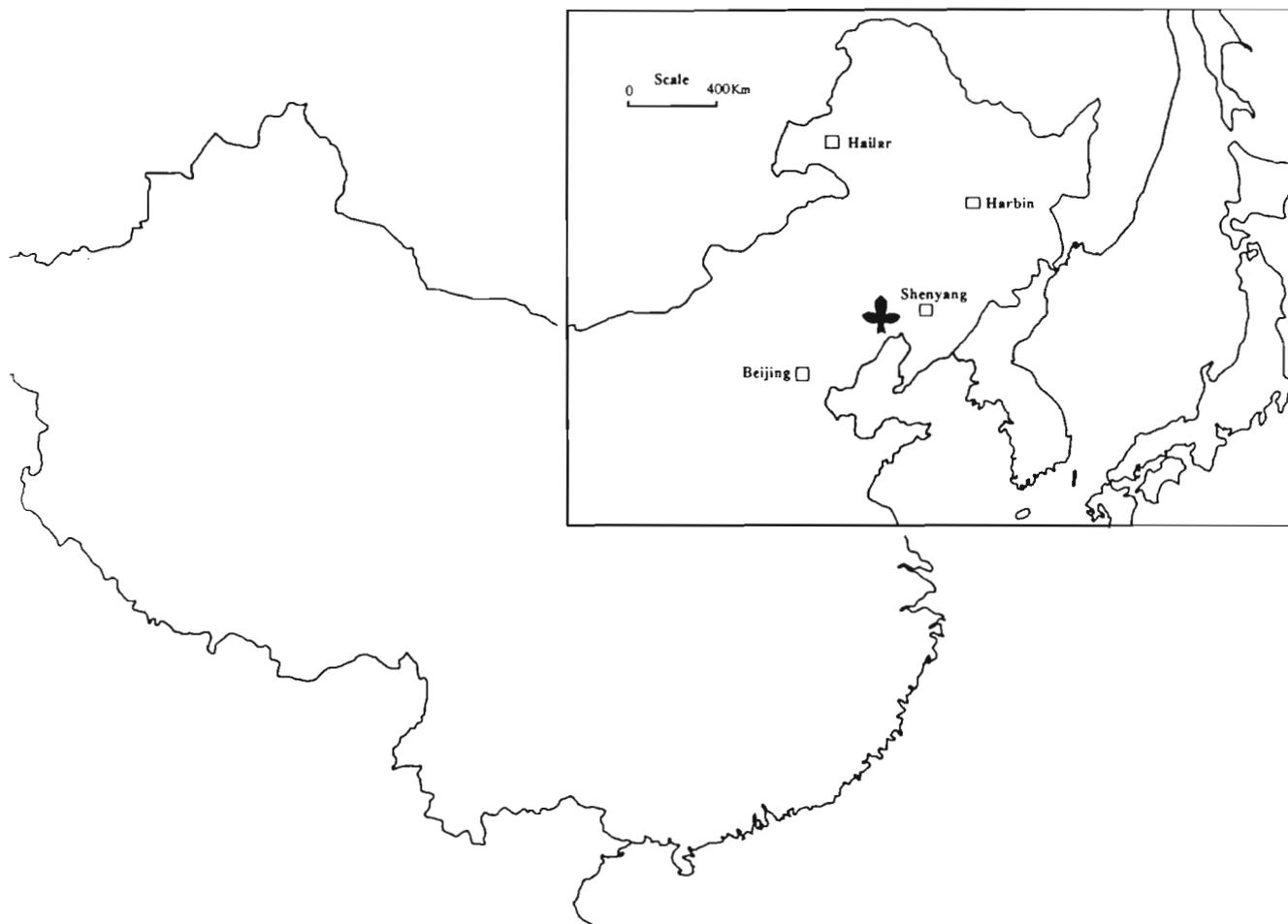


Fig. 1—Locality of the conifer fossils.

## INTRODUCTION

**D**URING the Late Jurassic, the climate in the most parts of China was probably dry. The plant fossils are rare in the Upper Jurassic sediments and as such there are few references in literatures (Wang, 1984). However in recent years, numbers of plant fossils including some angiosperms (Sun *et al.*, 1998; Wu, 1999) have been collected from the Yixian Formation of western Liaoning, NE China, as well as various birds and dinosaurs (Hou *et al.*, 1995, 1999; Chen *et al.*, 1997; Ji *et al.*, 1998). The age of the Yixian Formation is still controversial. It

is assigned to the Upper Jurassic based on conchastraca, insects and birds (Chen, 1999; Hou *et al.*, 1995), while considered as the Lower Cretaceous on the bases of studies on dinosaurs, spore-pollen, ostracods, gastropods fossils, and this is supported by palaeomagnetic and isotopic dating (Pu & Wu, 1985; Zhang, 1985; Wang *et al.*, 1999; Swisher *et al.*, 1998, 1999). The Tuchengzi Formation, overlain discordantly by the Yixian Formation, is characterized by red coloured sediments, which have rare records of plant fossils (Zheng *et al.*, 2001). Recently, the authors collected many coniferous fossils and a few specimens of *Equisetites* from this formation in Beipiao

## PLATE 1

(All the specimens described are housed in Research Institute of Petroleum Exploration and Development, Beijing, China)  
*Brachyphyllum liaoningense* sp. nov.

- 1-7 Twigs. **1**, Holotype, XJG020; **2**, XJG024; **3**, XJG022; **4**, XJG023; **5**, XJG021; **6**, XJG025; **7**, XJG026; 1-3, 5-7, x2; **4**, x4.
- 8-11. leaves. **8-9**, light photographs, showing stomatal furrows, x15; **10**, light photograph, showing the adaxial surface of the leaf, x 20; **11**, SEM photograph, showing the abaxial surface of the leaf, x20.
- 12-13. Outer surface of the adaxial cuticle (SEM), **12**, x300; **13**, x350.
14. Out surface of the abaxial cuticle (SEM), x350.
15. SEM photograph, showing the inner surface of the adaxial cuticle (left side) and abaxial cuticle (right side), x 220.

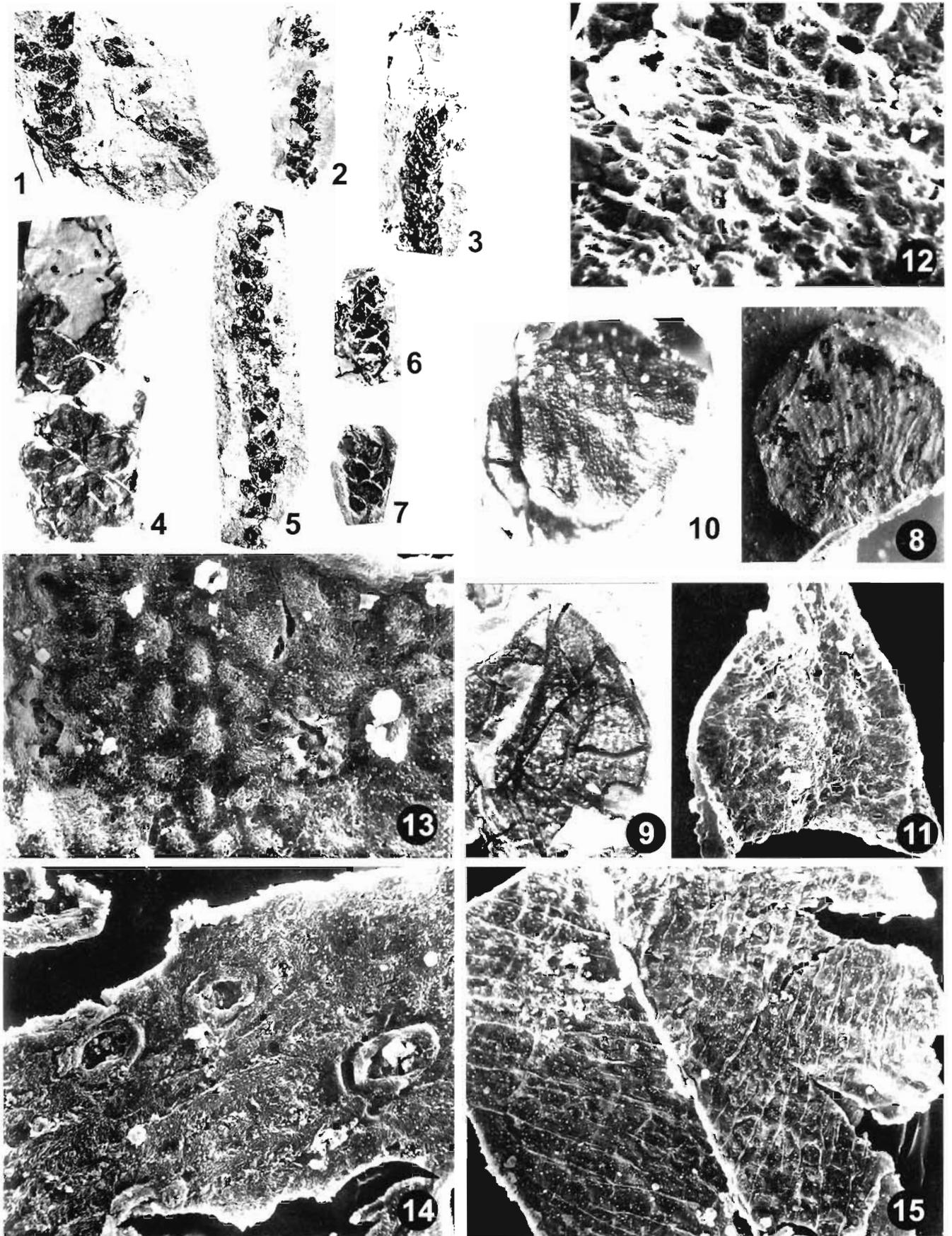


PLATE 1

Basin, Western Liaoning Province (Fig. 1). The fossils are well preserved in greyish green mudstone. But unfortunately, most of them are broken into small pieces soon after they are exposed to the air.

The fossils are leafy twigs with scale like leaves. The leaves consist of basal cushions and free parts. The width of the free part is greater than the height, a characteristic of the genus *Brachyphyllum*. It is identified as a new species *Brachyphyllum liaoningense* (sp. nov.) on the bases of epidermal features.

### STRATIGRAPHY AND MATERIALS

The Upper Jurassic Tuchengzi Formation, Beipiao Basin, Liaoning, NE China, is mainly composed of purple or varicolored clastic rocks, which overlies the Middle Jurassic volcanic rock unit Lanqi Formation and is overlain discordantly by the Yixian Formation that yields a great number of fossils of early birds, dinosaurs and early angiosperms (Sun *et al.*, 1998; Wu, 1999; Hou *et al.*, 1995; Chen *et al.*, 1997; Ji *et al.*, 1998). The Tuchengzi Formation is divided into three portions. The lower part consists of purple coloured sandstone, siltstone and mudstone intercalated with greyish green mudstone and siltstone; the middle part is of conglomerates intercalated with sandstone and shale; and the upper part has greyish green sandstone with great cross beds and intercalated with purple conglomerate and tuff at the top. The mudstone of the lower part is rich in *Conchastraca* and a few plant fossils. The plant fossils studied in the present paper were collected from greyish green mudstone-siltstone beds, which are intercalated in the upper portion of the lower part. A lot of well preserved compressions of coniferous twigs and shoots are scattered on the surface of the mudstone. Some of the axes are up to 1 cm thick. Being very fragile, the mudstone breaks up when air-dried and consequently most of the specimens were broken into fragments before they were brought to the laboratory from field.

The fossils were first examined and photographed under a stereo microscope. Then a small piece of the rock with leaf material was immersed into hydrofluoric acid for 48 hours. The obtained leaves were macerated with Schulze's solution or sodium hypochlorite for 24 hours followed by treatment with ammonium hydroxide or sodium hydroxide solution. The adaxial and abaxial cuticles were separated with a needle and then the cuticles were examined both under light and scanning electron microscopes.

## SYSTEMATICS

### CONIFEROPSIDA

#### BRACHYPHYLLUM Brongniart

#### BRACHYPHYLLUM LIAONINGENSE sp. nov.

Pl. 1·1-15; Pl. 2·1-6; Fig. 2A-E

*Diagnosis*—Conifer twigs, pinnately branched in one plane. Axis up to 1 cm thick, length unknown. Leaves sparsely borne on the main axis, spirally and densely arranged on the twigs (Pl. 1·1-7). Twigs 0·4-0·6 cm thick, straight or curved. Leaves scale-like, with cushions and free parts (Pl. 1·8; Fig. 1A-C). Whole leaf 2-3 mm long and 2-3 mm broad; the free parts about 2 mm long and 2·5 mm broad, typically triangular, apices tapering, acute or round. Margin entire. Substance of leaf very thick. The abaxial surface of the leaf without keels, but with longitudinal stomatal furrows radiate (Pl. 1·8-10). The furrow composed of small holes representing the stomata (Pl. 1·9).

Both adaxial and abaxial cuticles thin and fragile, especially the adaxial one. External surface of the adaxial cuticle uneven (Pl. 1·11-12), with obvious papillae (Pl. 1·13) or holes some times in the center of the epidermal cells (Pl. 1·12). The ordinary epidermal cells in the inner area of the adaxial epidermal rectangular or near square, about 20-25  $\mu\text{m}$  long and 18-22  $\mu\text{m}$  wide, walls obviously thickened, about 5-6  $\mu\text{m}$  thick (Pl. 1·15). The corners of the cells thickened. The cells near the margins elongate, about 30-35  $\mu\text{m}$  long, and 10-15  $\mu\text{m}$  wide, walls usually thickened but the corners un-thickened. A few stomata scattered on the adaxial cuticle. Stomata elliptic (Pl. 2·5), about 70  $\mu\text{m}$  long and 50  $\mu\text{m}$  wide. Stomatal pits rounded or elliptic, thinly cutinized, guard cells indistinct, subsidiary cells 5-7, rectangular or elongated polygonal in form, a little larger than that of the ordinary epidermal cells, about 30  $\mu\text{m}$  long and 25  $\mu\text{m}$  broad, surrounding the stomatal pits, with stripes on the surface. With 8-10 encircling cells (Pl. 2·5).

The abaxial cuticle little thicker than the adaxial one. Stomata oriented into lines on the external surface of the cuticle and with a furrow between the stomatal lines, stomata elliptic and longitudinally oriented (Pl. 1·14), placed in single files on the inner surface (Pl. 2·1-2), stomatal files about 50-80  $\mu\text{m}$  wide, expanded in the region of stomatal, with a space of 100-110  $\mu\text{m}$  between the adjacent stomata. Epidermal cells in the stomatal files strongly cutinized, especially near the stomata (Pl. 2·1-3). Stomatal files obviously raised, over the surface of the ordinary

### PLATE 2

(SEM photographs)

*Brachyphyllum liaoningense* sp. nov. →

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|--|--|
| 1-2. Showing the stomatal files and the strip-like cells between the files in abaxial cuticle. x300. | 4. A stoma with six subsidiary cells, abaxial cuticle. x700. |
| 3. A stoma with strongly cutinized subsidiary cells. x700.   | 5. A stoma on adaxial cuticle. x700.                         |
|  | 6. A stoma on abaxial cuticle. x700.                         |

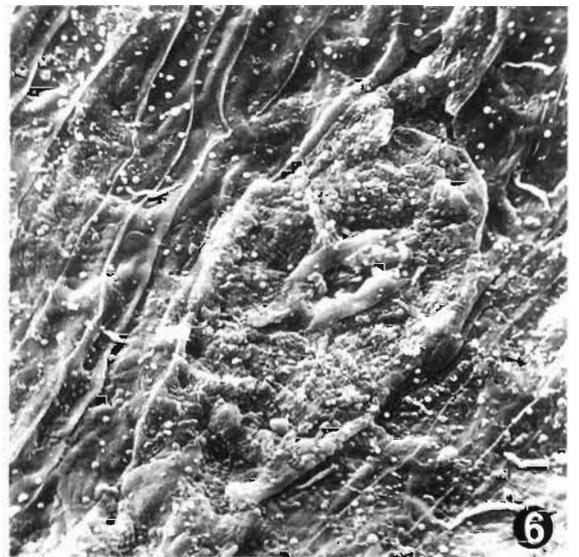
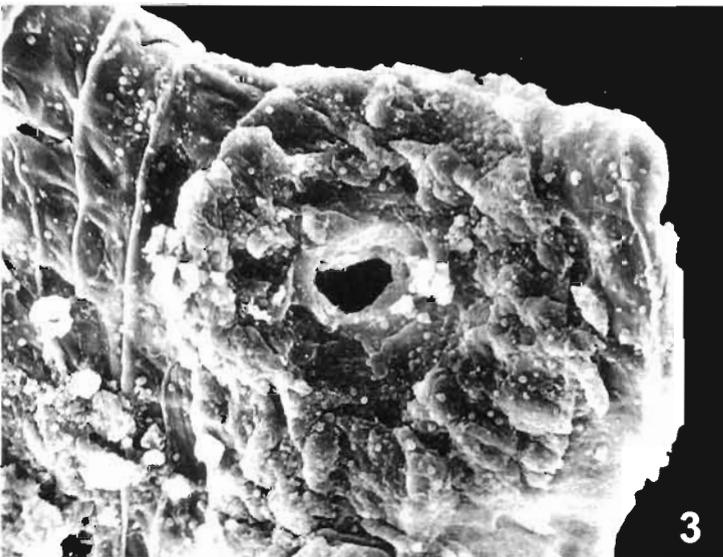
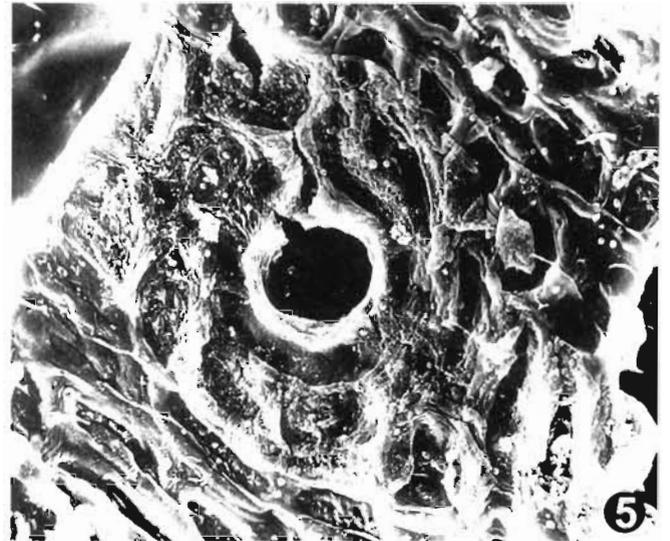
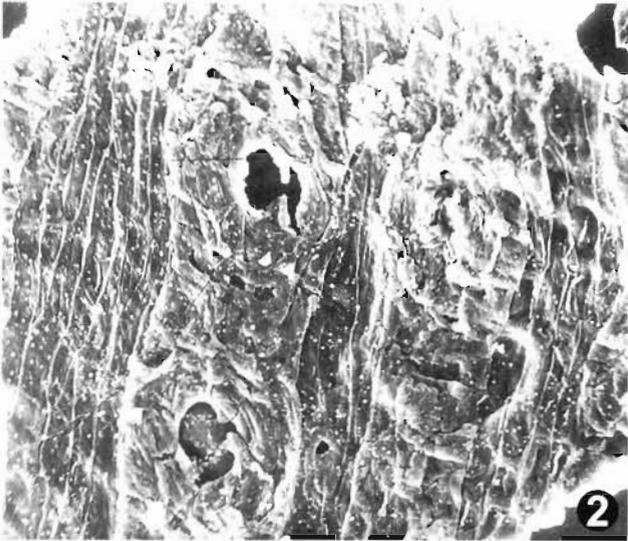
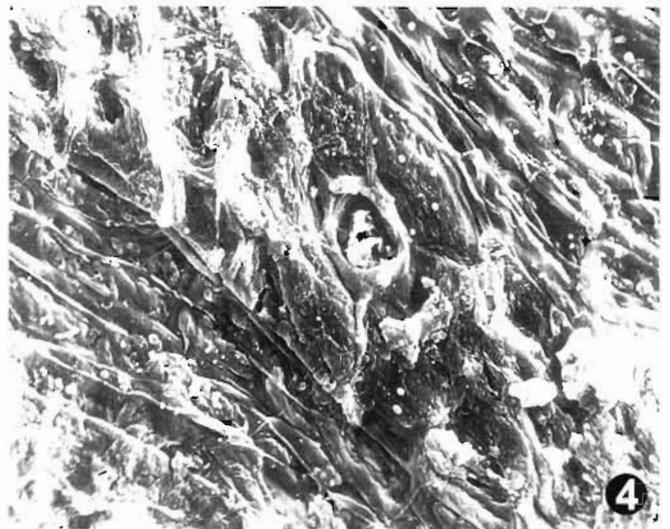
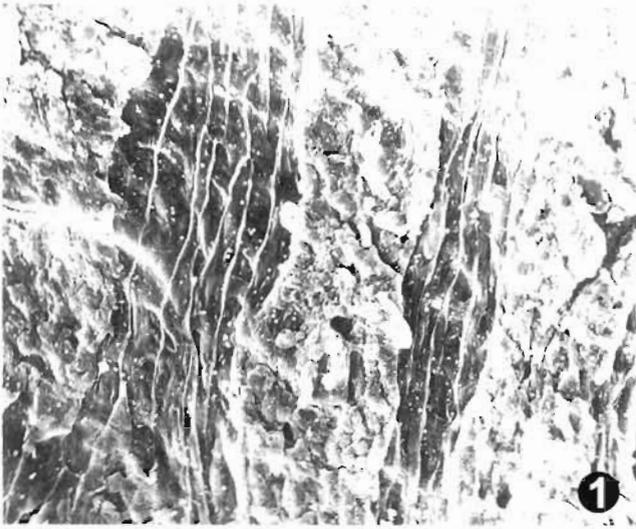


PLATE 2

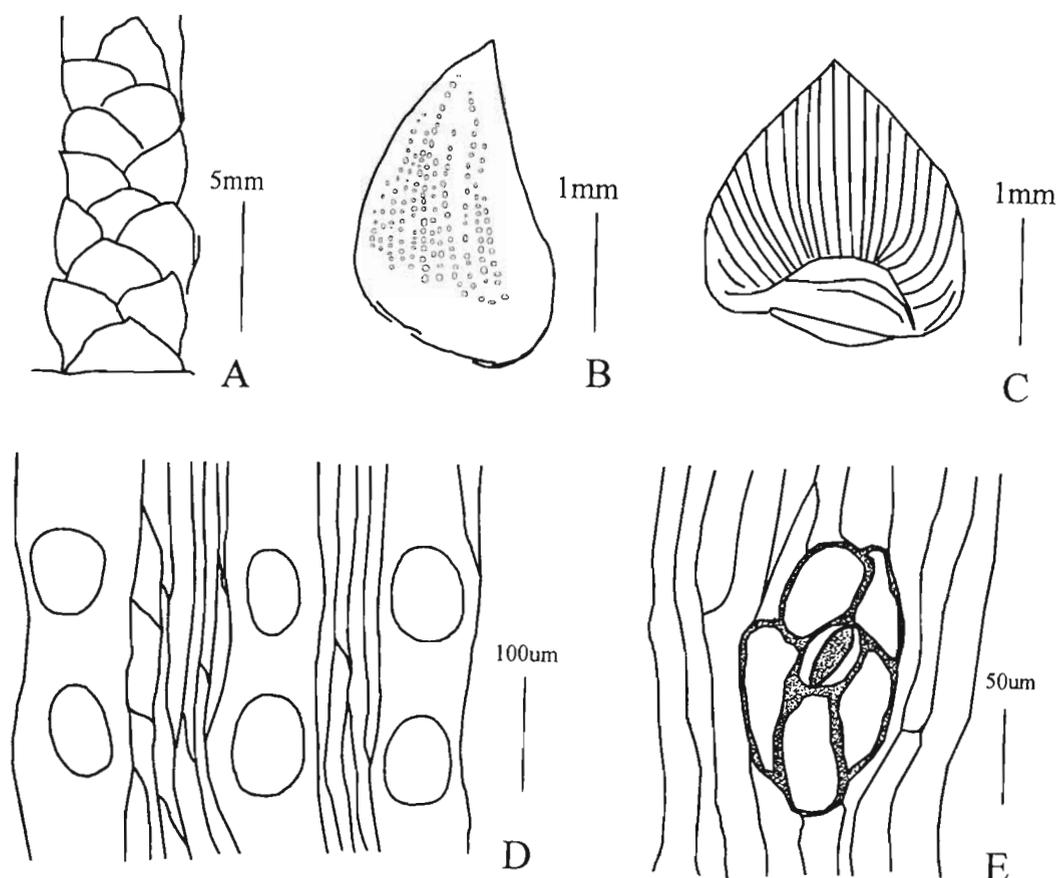


Fig. 2—*Brachyphyllum liaoningense* sp. nov. A. Twig (after Pl. 1·4), showing the arrangement of the leaves; B. Lateral-view of a leaf (after Pl. 1·9), showing the arrangement of the stomata (abaxial surface); C. Showing leaf form (after Pl. 1·8); D. Showing the stomatal files and the cells between the files (abaxial surface), E. A stoma (after Pl. 2·6).

cells. The structure of the epidermal cells in the stomatal file indistinct (Pl. 2·1-3) or possibly squarish form (Pl. 2·4). The space between the two stomatal files 20-70  $\mu\text{m}$ , consisting of 3-8 lines of cells (Pl. 2·1-2). The epidermal cells longitudinally arranged in irregular rows, elongated, 5-15  $\mu\text{m}$  wide and more than 100  $\mu\text{m}$  long. Transverse walls usually indistinct and the longitudinal ones sinuous (Pl. 2·1-3, 6). Wall is usually unthickened, less than 1  $\mu\text{m}$  thick. Stomata elliptical, about 50-70  $\times$  40-50  $\mu\text{m}$  in size. Stomatal pits elliptic, slightly oblique to the stomatal line (Pl. 2·4, 6), 20-30  $\mu\text{m}$  in diameter. In some times, the surface lightly and irregularly thickened (Pl. 2·4). In some relatively slightly thickened stomata, the outlines and the structure of the stomata clear. Guard cells unclear or partly seen (Pl. 2·6), subsidiary cells 6-7 in number. Subsidiary cell wall 2-5  $\mu\text{m}$ . Surface of the subsidiary cells slightly thickened, stomata elevated on the epidermal cells, lack encircling cells.

*Locality*—Beipiao of Liaoning Province, China.

*Stratigraphy*—Tuchengzi Formation.

*Age*—Late Jurassic.

*Etymology*—The species name is after the locality.

*Holotype*—XJG020 (Pl. 1·1).

*Repository*—Research Institute of Petroleum Exploration and Development, Beijing, China.

## DISCUSSION

The present fossils are similar to the Late Mesozoic scale or awl-like leaf conifers *Pagiophyllum*, *Athrotaxites* and *Brachyphyllum*, but can be undoubtedly assigned to *Brachyphyllum* on the basis of their structure of leaves and attachment.

The difference between *Pagiophyllum* and *Brachyphyllum* is that the free part of the leaf of the former is larger than width, while the free part of the latter is smaller than the breadth. The cuticle of the two genera are similar to each other (Kendall, 1947, 1948; Harris, 1979). In most *Pagiophyllum* species of the Yorkshire Flora, the stomata are chiefly arranged in regular files. But four species from Lower Cretaceous of Zhejiang, Southeast China have scatteredly arranged stomata (Cao, 1991). Recently, Cao (1999) described

a new species from the same stratum and locality, which is characterized by the stomata oriented in rows. It is difficult to differentiate these two genera on their epidermal features.

*Athrotaxites*, an Early Cretaceous conifer, is characterized by spirally borne scale leaves. The free parts of its leaves are larger than broad. *Athrotaxites berryi* Bell, *A. magnifolius* (Chen and Meng) Chen and Deng and *A. orientalis* Deng and Chen have been described on the structure of cuticle (Miller & Lapasha, 1983; Chen & Deng, 1990; Deng, 1995). The stomata of these species are restricted to the middle-upper portion near the two sides of the leaves, and differs from *Brachyphyllum*, in which stomata are distributed on the whole surface of the leaf. The stomata in *Athrotaxites berryi* are oriented in rows, while those of *A. magnifolius* and *A. orientalis* are scattered or concentrated into groups. Sometimes, the adjacent stomata unite and have common subsidiary cells. Thus the stomatal distribution pattern of *Athrotaxites* is different from that of *Brachyphyllum*. Moreover, *Athrotaxites* is a seasonally defoliated swamp tree (Miller & Lapasha, 1983; Chen & Deng, 1990) and are usually preserved in the coal-bearing sediments, while *Brachyphyllum* is usually preserved in grey or multicoloured rocks representing rather dry climates. They have totally different habits. *Athrotaxites* is considered to have affinity with the Taxodiaceae *Athrotaxus* presently grows in Tasmania, Australia, but *Brachyphyllum* probably belongs to various conifer groups based on epidermal features. For examples, *Brachyphyllum crucis* is possibly related to Himmerellaceae, while many others to the Araucariaceae (Kendall, 1947; Harris, 1979).

*Brachyphyllum* has spirally borne leaves, in which the free part is short and not exceeds the width of the leaf cushion (Kendall, 1947; Harris, 1979). Cuticles of a number of twigs and associated cones were described by (Kendall, 1947; 1949) and Harris (1979) from the Middle Jurassic of Yorkshire, England. Konijnenburg-V. Cittert J.H.A. van (1971) successfully obtained some pollens *in situ* of this genus, and made a comparison with the dispersed pollens of *Classopollis*. Based on the observation of the cuticle, cones and pollen grains *in situ*, the affinity of this genus was also discussed by Kendall (1947) and Florin (1958) who believed that some species of this genus were related to *Araucaria* of Araucariaceae.

Since *Brachyphyllum* twigs from different ages bear a similar morphology, epidermal features constitute important tools in species identification. Kendall (1947, 1949) and Harris (1979) gave importance to the epidermal features in identification of species of *Brachyphyllum*. In most of the Yorkshire species epidermal cells are squarish and oriented transversely. In the present materials the adaxial epidermal cells are similar to the Yorkshire materials but the abaxial cuticle has strips arranged in longitudinal rows. In Yorkshire species of *Brachyphyllum* stomata are hypostomatic and mostly restricted to margins, subsidiary cells 2-6 and with encircling

cells even dicyclic. The present materials are amphistomatic, have 5-7 subsidiary cells and without encircling cells on the abaxial cuticle.

*Brachyphyllum praetermissum* Wesley from the Upper Lias of Italy has hypostomatic leaves (Wesley, 1956), and is different from the amphistomatic pattern of the present fossils. *Brachyphyllum lorchii* Raab *et al.* from the Upper Jurassic of Israel (Raab *et al.*, 1986) is somewhat similar to the present specimens in the arrangement and structure of stomata but differs in the form of leaves and epidermal cells.

Summarily, the present specimens are characterized by amphistomatic leaves, with a few stomata scattered on the adaxial cuticle and a lot arranged in rather regular single files on the abaxial cuticle. The guard cells are usually indistinct. The subsidiary cells are 5-7 in number, with encircling cells on the abaxial cuticle but without this cell on the adaxial cuticle. Therefore, the present materials are different from the known Jurassic *Brachyphyllum*.

*Brachyphyllum castatum* Waston *et al.* a species from the English Wealden (Lower Cretaceous) (Watson *et al.*, 1987), which is characterized by circular stomata with 5-12 subsidiary cells and is either monocyclic or dicyclic. In China, *Brachyphyllum* is also frequently found from the Lower Cretaceous, and mostly are in the South Phytogeographical Province of China (Chow & Tsao, 1977; Cao, 1989), e.g., *B. obtusum* Chow & Tsao from Lingbi, Anhui Province, *B. ningshiaensis* Chow & Tsao from Liupanshan Basin, Ningxia (Chow & Tsao, 1977) and *B. elegans* Cao from the Lower Cretaceous Linan, Zhejiang (Cao, 1989). The common features of these species are that the stomata on the abaxial cuticle are arranged in single files separated by several elongate cells. The epidermal cells in the stomatal files are short and markedly thick. The guard cells are usually unclear. These features are also observed in the present materials, in the latter, the stomata are strongly thickened, regularly arranged in single files, and within the files the spaces between the adjacent stomata are rather stable. In the stomata, the number of subsidiary cells are variable, e.g., *B. ningshiaensis* (6-9 in number), *B. elegans* (6-8) and *B. obtusum* (7-11) and are more than that of the present new species (5-7). Furthermore, the leaves of *B. ningshiaensis* and *B. obtusum* are triangular in form, with lower free parts and arc-like margins, while those of the present specimens are triangular with rather higher free parts and quite straight sides. The adaxial cuticle of *B. elegans* is unknown, and there have several regularly arranged oblong cells between the stomatal files on the abaxial cuticle.

Consequently, study of the epidermal features show that the present materials belong to a new species of *Brachyphyllum*.

An increase of number of subsidiary cells and decrease of encircling cells possibly indicate an evolutionary trend in the taxon *Brachyphyllum*. The species from the Middle Jurassic of England have 2-6 subsidiary cells, while those of

the Early Cretaceous from China have 6-12. The new species from the Late Jurassic possibly represents a transition type with 5-7 subsidiary cells. Similarly, almost all the Middle Jurassic species from England have encircling cells, while those of the Early Cretaceous including the new species are devoid of encircling cells.

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