Dracopteris liaoningensis gen. *et* sp. nov., a new Early Cretaceous fern from Northeast China

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A new genus of Early Cretaceous fern, *Dracopteris* gen. nov., is proposed. It is based on the type species *Dracopteris liaoningensis* gen. *et* sp. nov. from Fuxin Basin and Tiefa Basin, Liaoning, Northeastern China. The new genus is mainly characterized by: (1) triangular frond, small to medium size; (2) large, rounded sori abaxially borne on the lateral veins, closely arranged, all lobes of a fertile pinnule including the apical ones bearing sori; (3) sporangia small, spherical, with pedicels, annulus incomplete, nearly vertical, composed of about 13 thickened cells, stomium transverse, probably 32 spores per sporangium and (4) spores elliptic to rounded, variable in size, each surrounded by a margo, proximal surface smooth and distal surface sculptured with irregular rugulae, probably monolete.

The new genus is somewhat comparable with the Mesozoic fossil ferns, viz.,*Cyathea, Delosorus, Athyrium, Dryopterites* and *Polypodites*, etc. Its taxonomic position is not clear. The ecological characters of the new fern is discussed.

Key-words – *Dracopteris*, Fern, Early Cretaceous, Northeast China.

INTRODUCTION

THE Early Cretaceous flora from Fuxin Basin, Liaoning Province, Northeastern China (Text-fig. 1), composed of more than 100 species (Sze, 1931; Chen *et al.*, 1981, 1988; Shan, 1985), is dominated by conifers and ferns, of which the ferns constitute one fourth of the flora. The flora from Xiaominganbei Formation of Tiefa Basin, Liaoning (Text-fig. 1) consists of 78 species, including 29 species of ferns (Chen *et al.*, 1988; Deng, 1991b, 1992). Based on the fertile materials, the paper describes a new fern from the two basins.

STRATIGRAPHY

The Late Mesozoic strata of Fuxin Basin are represented by an upward sequence as follows. The basement of the Yixian Formation in Fuxin Basin consists of thick volcanic rocks intersected with sandstones. It belongs to the Late Jurassic age. The Early Cretaceous strata are developed as the Shahai Formation, Fuxin Formation and Sunjiawan Formation. Both of the Shahai Formation and Fuxin Formation are represented by lacustrine sediments and coal-bearing beds, and abound in plant fossils. The Sunjiawan Formation is composed of conglomerates and sandstones.

The features of the Late Mesozoic of Tiefa Basin are similar to those of Fuxin Basin. The volcanic rocks are called the Datai Formation. The Beijiagou Formation consists of conglomerates and sandstones, mudstones and thin coal beds towards the upper parts. The Xiaominganbei Formation, characterized by lacustrine sediments and thick coal-bearing beds, is rich in plant fossils and it is overlain by the Sunjiawan Formation. The stratigraphical correlation between the two basins is shown in Table 1.

Table 1. Stratigraphical correlation between Fuxin Basin and Tiefa Basin

		Fuxin Basin	Tiefa Basin
EARLY CRETACEOUS	Albian Aptian	Sunjiawan Fm.	Sunjiawan Fm.
	Neocomian	Fuxin Fm.	Xiaominganbei Fm.
		Shahai Fm.	Beijiagou Fm.
LATE JURASSIC		Yixian Fm.	Datai Fm.

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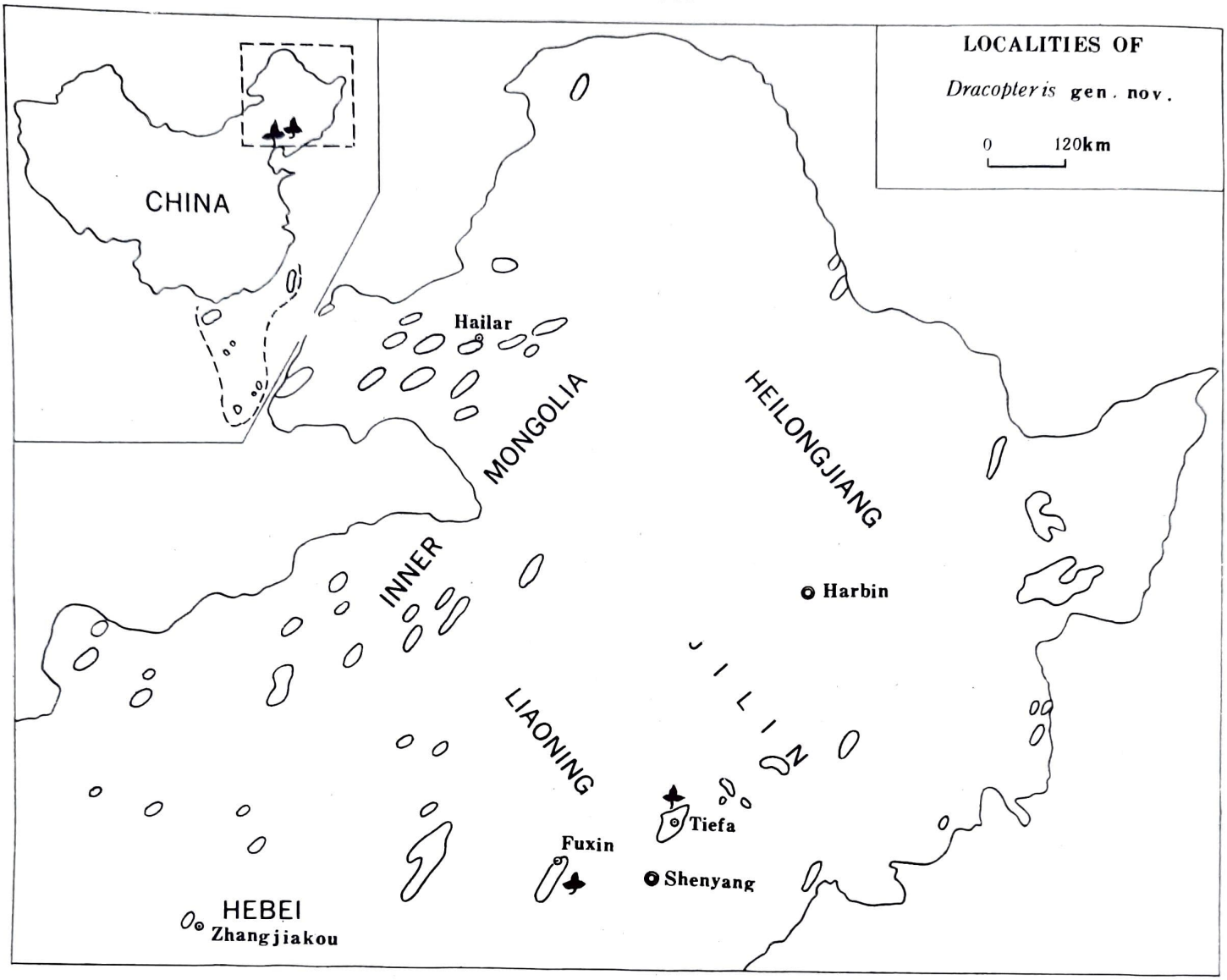


Text-figure 1. Map showing fossil localities

MATERIAL AND METHOD

All the specimens were collected from the Fuxin Formation, except one from the Xiaominganbei Formation, Tiefa Basin. The specimens are compression of fertile parts with black laminae containing well preserved sori. Hand specimens were examined under stereo- binocular microscope. Fragments of laminae with sori were removed from the rock by bulk maceration with hydrofluoric acid or transferred from the rock matrix directly by a needle. Schulze's solution and sodium hypochlorite were then used for clearing of sporangia and *in situ* spores. Other chemicals applied include hydrochloric acid, ammonium hydroxide and anhydrous alcohol. The sori, sporangia and spores were examined under binocular microscope and scanning electron microscope after being coated with gold. In order to count the spore output, some sporangia treated with Schulze's solution were taken individually on a slide before treated with ammonium hydroxide. Spores were counted under stereo-binocular microscope.

Plate 1

All the specimens were collected from Fuxin Basin except one (Pl. 1, figs 2, 2a) from Tiefa Basin.

1-2,2a. Parts of pinnae, 1, x 3, Fxt5-086; 2, x 1, 2a, x 3, TDMe 622.

3. Middle part of a pinnule showing the arrangement of sori, x 12.

4, 4a,5. Showing the arrangement of sori in pinnules. 4, x 1, 4a, x 3, Fxt5-090; 5, x 8.

6. Holotype, a nearly complete frond, showing the outline of the fern, x 1, Fxt 5-087.

7. A fertile penultimate pinna, x 1, Fxt 5-088.

8. Apex of a pinnule, showing sorus in the apical tooth, x 15.

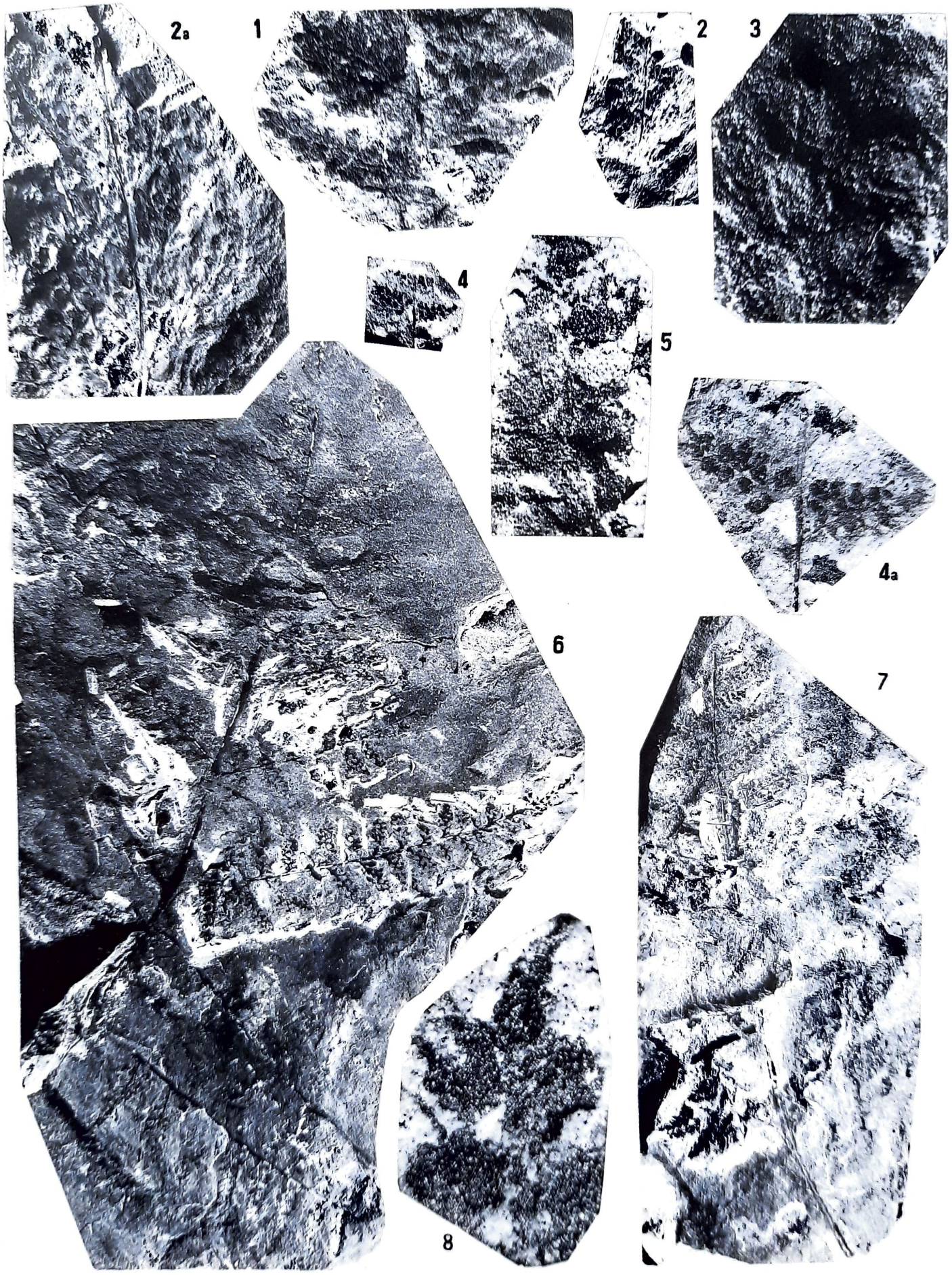
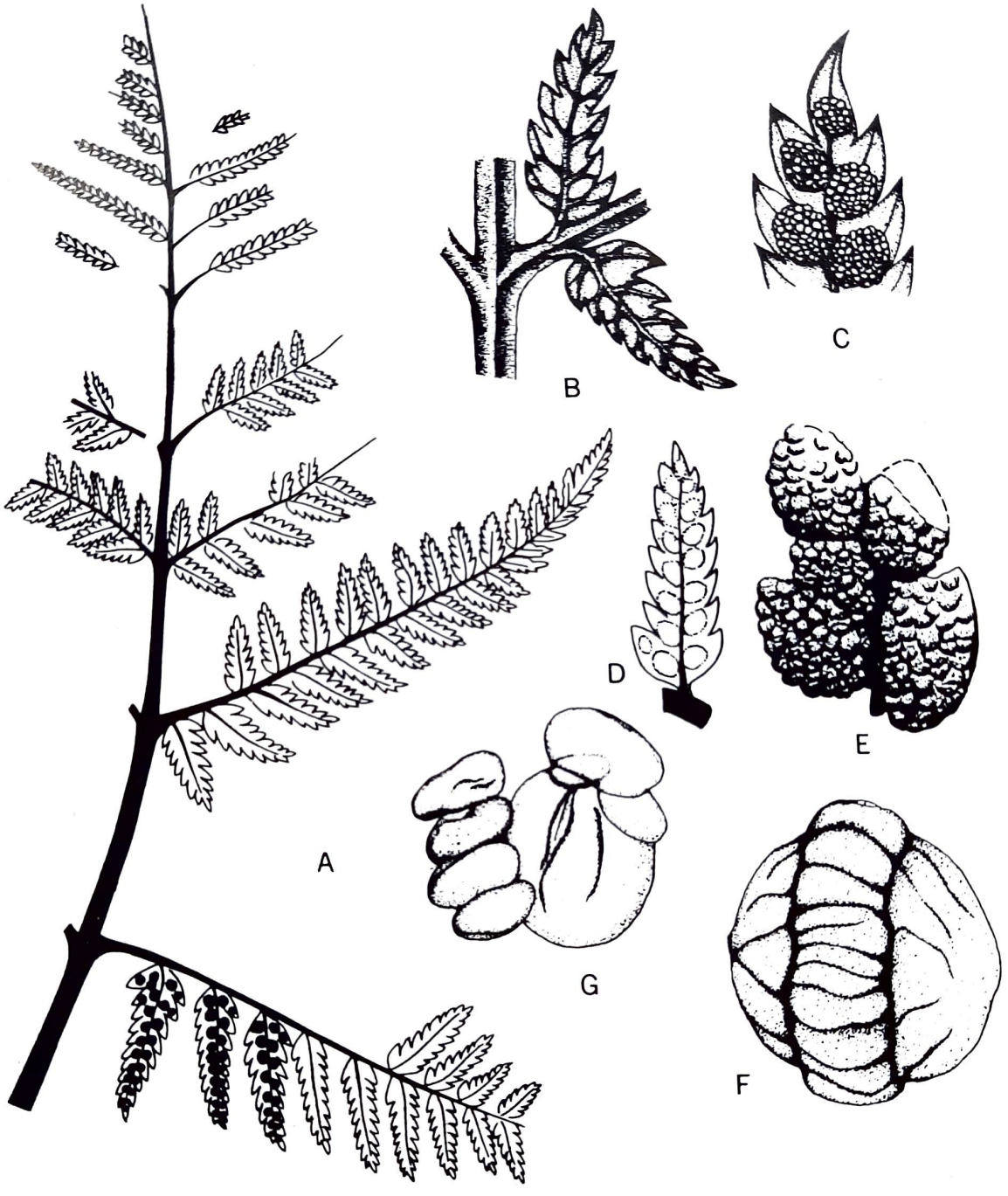


Plate 1



Text-figure 2. *Dracopteris liaoningensis* gen. *et* sp. nov.
A, Showing outline of a frond, x1. **B**, pinnules showing venation, x3. **C**, upper part of a fertile pinnule showing sorus on the apical tooth, x20. **D**, Sori arranged on a pinnule, x3. **E**, closely arranged sori. **F**, sporangium showing annulus, x400.. **G**, spores in different sizes, x100.

Plate 2

1. Ia; Fertile pinnae. 1, x 1; Ia, x 3, Fxt5-089.
2. Sori on the middle part of a pinnule, x 6.
3. Showing veins and sori (indicated by arrows), x 10.
4. Showing veins, x 15.

5, 10. The crowdedly arranged sori and numerous sporangia, x 25.

6,6a. Sporangium with a pedicel (SEM). 6, x 450; 6a, magnification of the pedicel, x 1200.

7-8, 12-13, Spores. 7, 12-13, spores in different sizes, x 528; 8, distal surface of a spore, x 1800 (SEM).

9,11. Rachis. 9, lower surface of an ultimate rachis, x 15; 11, upper surface of a main rachis, x 10.

15. Back-view of a single sporangium, showing "S"-like annulus, x 450 (SEM).

15. Sporangia in a sorus, x 120 (SEM).

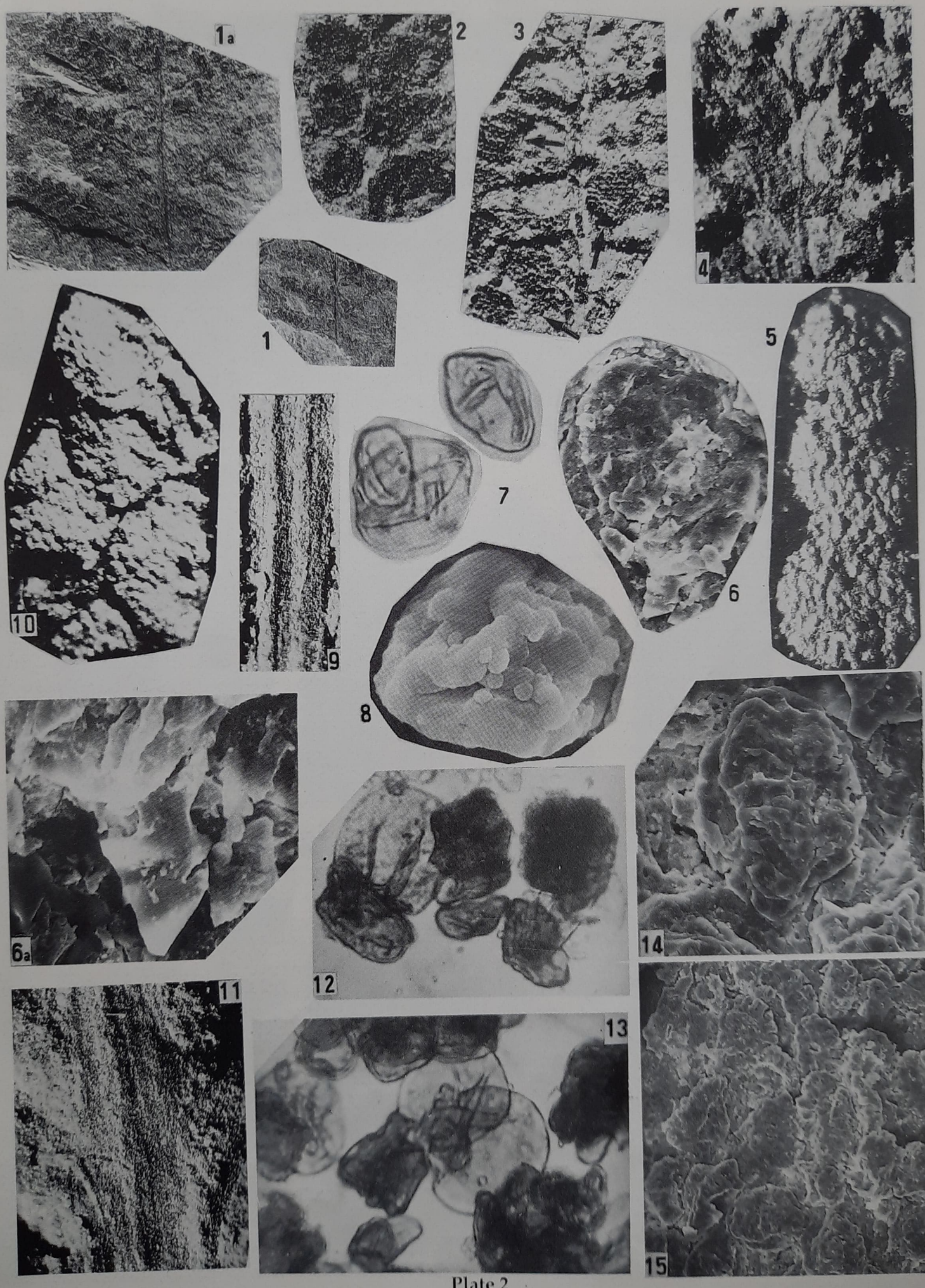


Plate 2

SYSTEMATIC DESCRIPTION

Filice incertae sedis

Dracopteris gen. nov.

Generic diagnosis - Frond triangular, tripinnate, small to medium in size. Rachis smooth, with a longitudinal groove on the upper side and a slender ridge on the lower side. Pinnae lanceolate, a pair of pinnae at the base of the frond asymmetrical, larger than the others.

Sori rounded, large in size, abaxially borne on the lateral vein, laterally and crowdedly arranged in two lines, all lobes of a fertile pinnule including the apical one bearing sori. Sporangia spherical, small in size, with pedicels, each with probably 32 spores. Annulus incomplete, consisting of about 13 thickwalled cells, nearly vertical, stomium transverse. Spores elliptic to rounded, surrounded by a margo, distal surface sculptured with irregular rugulae, probably monolete.

The generic name is from the Latin word "draco".

Type species-*Dracopteris liaoningensis* gen. *et* sp. nov.

Dracopteris liaoningensis gen. *et* sp. nov.

Pl.1, figs 1-8; Pl. 2, figs 1-15; Pl. 3, figs 1-9; Pl. 4, figs 1-9; Text-fig. 2

1992 – *Polypodites polysorus* Deng, pl. 3, fig.1

Frond and rachis - Fronds medium in size, tripinnate, triangular, 15 cm long and 14 cm wide (Pl. 1, fig. 6). The main rachis 2 mm thick, slightly curved, smooth, with a longitudinal groove on the upper side and a ridge on the lower side, the ridge expanded at the position where ultimate rachis arises (Pl. 2, figs 9, 11); penultimate rachis 1 mm wide and ultimate ones less than 1 mm thick, abaxial surface rounded.

Pinnae and pinnules - Penultimate pinnae lanceolate, 8 cm long and 2 cm wide, apices acute, pointed, opposite to subopposite, separately arranged, making angles of 40-60° to the main rachis. A pair of pinnae at the base of the frond borne at right angle and asymmetric in outline, more than 10 cm long and 4 cm wide. The ultimate pinnae on their basiscopic side longer and larger than those on the acroscopic side (Pl. 1, fig. 6; Text-fig. 2-A). Ultimate pinnae lanceolate to elongate lanceolate, typically 2 cm long, 0.5-0.8 cm wide, opposite to alternate, angle of emergence 60-80°. The upper part of the frond bipinnate, penultimate pinnae becoming ultimate, 3-4 cm long and 0.5 cm wide, slightly curved forwards. Pinnules lanceolate, typically 1 cm long and 0.4 cm wide, apice tapering, base contracted, margin dissected into 6-8 pairs of triangular teeth; teeth in odd number including the apical ones; the apical tooth long, triangular, usually 2 mm long and 1 mm wide, with a tapering point; arranged oppositely at the base and anadromically upwards (Pl. 1, figs 6, 8).

Venation - Venation pinnate, *Cladophlebis*-type, midvein rather strong at the base, markedly arising on the abaxial surface of the pinnules and gradually thinning to the apex, lateral veins given out at acute angles, forked once or twice (Pl. 2, figs 3- 4; Text-fig. 2-B).

Sori and sporangia - Sori elliptic, typically 1.5-2.0 mm in diameter, borne on the abaxial surface, situated on the lateral veins, half way to the margins, alternately and closely arranged in two lines on both the sides of midvein; the adjacent sori contiguously arranged, and the sori in one line often cover the midvein into another line, intersected each other (Pl. 1, figs 3-4, 8; Pl. 2, figs 2-3, 5, 10; Text-fig. 2-C, E). All teeth of a pinnule bear sori including the apical one (Pl. 1, fig. 8; Text-fig. 2-C, D), generally each tooth with one sorus but the teeth at the base often with two, the apical teeth usually with a smaller sorus of about 1 mm in diameter at its base (Pl. 1, fig. 8; Text-fig. 2-C). The sorus consists of 100 sporangia. Sporangia spherical in form, quite small, about 100 μm in diameter, with a small number of spores, probably 32 per sporangium. Annulus incomplete, nearly vertical, very few "S"–like in dorsal view, consisting of about 13 thickened cells, stomium transverse (Pl. 2, figs 6, 14-15; Pl. 3, figs 1-2, 4, 9; Text-fig. 2-F), thin walled, cells of sporangia polygonal, 25-35 cells in number. Pedicel slender, 15 μm in diameter, length unknown (Pl. 2. figs 6, 6a).

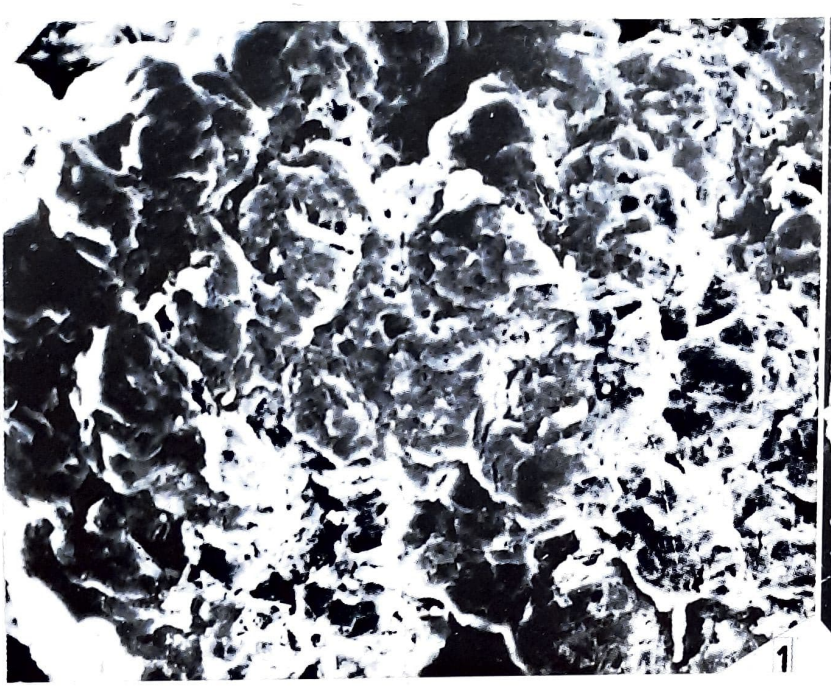
Spores - Spores are in various forms, usually rounded, elliptic (Pl. 2, figs 7, 12-13; Pl. 4, figs 2, 8-9; Text-fig. 2-G), triangular (Pl. 2, fig. 8; Pl. 4, fig. 5) or of irregular shapes (Pl. 3, figs 3, 5- 8; Pl. 4, fig. 4) in polar view and elliptic or kidney–shaped in equatorial view (Pl. 4, figs 1, 3, 6), some well developed ones about 40 μm in diameter or up to 50 μm long and 30-40 μm wide

Plate 3

(All SEM photographs)

1-2, 4,9. Sporangia.
1, Sporangia in a sorus, x 200; 2, back-lateral view of a single sporangium showing annulus, x 880; 4, back-lateral view of sporangia, x 450; 9, top-view of a single sporangium showing vertical annulus, x 680.

3, 5-8. Spores. 3, distal surface, x 1200;5, x 1200; 6, showing spores in sporangia, x 200; 7, x 600; 8, distal surface, x 900.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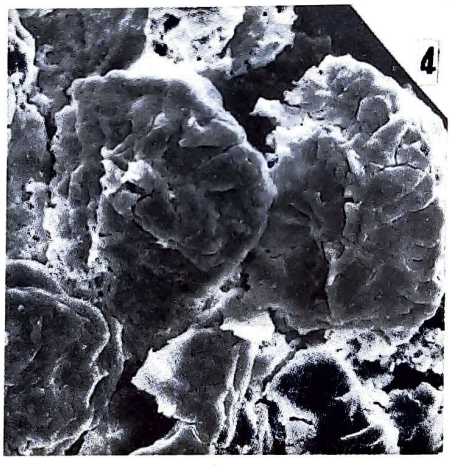
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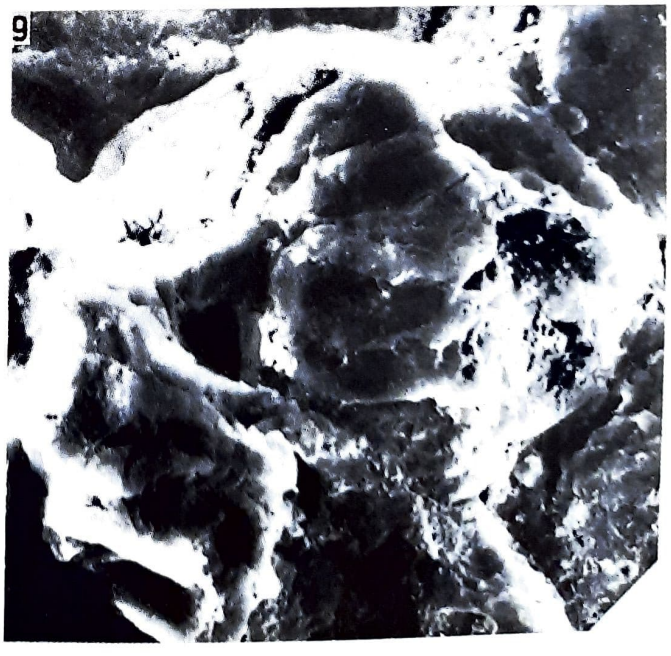
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Plate 3

(Pl. 2, figs 8, 12-13; Pl. 4, fig. 7). Most of the spores usually smaller, some even only 15-20 μm in diameter (Pl. 2, figs 12-13; Pl. 3, figs 3, 8; Pl. 4, fig. 4). A few spores form a sporangium well developed, while the others quite small and in irregualar forms which probably represent the immature ones (Pl. 2, figs 12-13; Text-fig. 2-G). Spore with a margo shown on the proximal surface (Pl. 4, figs 2-3, 5-7). Exine usually sculptured with rugulae on the distal surface (Pl. 2, fig. 8; Pl. 3, figs 3,8) but smooth on the proximal surface (Pl.4, figs 2-3, 5-7). Laesura not very clear, possibly monolete as shown in light microscope view and suggested by the elliptic shape (Pl. 2, figs 7, 12-13).

Holotype - Fxt 5-087.

Horizons - Fuxin Formation and Xiaominganbei Formation.

Locality - Fuxin Basin, Tiefa Basin, Liaoning, Northeast China

Age - Early Cretaceous.

DISCUSSION AND COMPARISON

The outline of the new fern is shown by the holotype (Pl. 1, fig. 6). It is characterized by the triangular frond and asymmetric pinnae at the base of frond. The character that the veins arising on the lamina of pinnule is shown in several specimens (Pl. 2, figs 3-4; Text-fig. 2-B). Although all of the specimens are fertile parts, it seems that the sterile parts are similar to the fertile ones. Large sori borne on all teeth including the apical one and closely arranged (particularly those at the middle-upper parts of the pinnules)strongly suggests that it is a new fern. The annuli look-like vertical in most of the sporangia (Pl. 3, fig. 9), but in some are shown somewhat as "S" form (Pl. 2, fig. 14). That may suggest that the annuli are generally nearly vertical.

The spore output is difficult to determine accurately because they vary in size and form, but it is much less than 64 in number, and seems to be 32. The sculpture of the spores is considered as an important feature of this genus. The variation in the size of spores is probably due to their abortion and this perhaps has an evolutionary significance.

The laesura is not clear, but is possibly monolete based on the elliptic shape of spores (Pl. 2, figs 7, 12-13; Pl. 4, figs 1, 3, 7) and some observations under the light microscope (Pl. 2, fig 7, 12-13).

Of the Mesozoic ferns, *Cyathea tyrmensis* (Krassilov, 1978), *Polypodites polysorus* Prynada (Krassilov, 1976; Pl. 24, figs 4-6) and *Delosorus heterophyllum*(Fontaine) Skog (Skog, 1988) are similar to the present fossil fern in their sorus forms. However, their sori are mostly arranged separately and the upper parts of the fertile pinnules are usually sterile. In *Delosorus heterophyllum*, the annuli are oblique, spores are trilete and the spore output is more than 64, although it is difficult to determine (Skog, 1988).

An Early Cretaceous monolete fern *Egymnocarpium sinense* Li *et al.*, from Shansong, Jilin, Northeast China, possesses rounded sori. But its spores have smooth surface; annuli are oblique; spore output varies from 48-128; the sori are arranged separately and the upper parts of the fertile pinnules are bare. Similarities have been found between the new genus *Dracopteris* and *Dryopterites*, the latter is close to the living monolete spore fern *Dryopteris* (Berry, 1911). Some species of *Dryopterites* produce smooth monolete spores (Deng, 1992), but their sori are usually separately borne on the lower-middle part of the fertile pinnules. The fossils of *Athyrium* from the same horizon and same localities as the new genus (Chen *et al.*, 1988; Deng, 1992) and *Polypodites polysorus* Pryn. (Probably belongs to *Athyrium*) from the Early Cretaceous of Omusukchan (Samylina, 1976; Pl. 12, figs 1-3) are similar to the new genus in the shape of pinnae and pinnules but their sori are hoof or hook- shaped.

A specimen from Xiaominganbei Formation, Tiefa Basin, originally placed in *Polypodites polysorus* (Deng, 1992), is very similar to the new species in the form and arrangement of its sori. Therefore it is transferred to the new species (Pl. 1, figs 2, 2a).

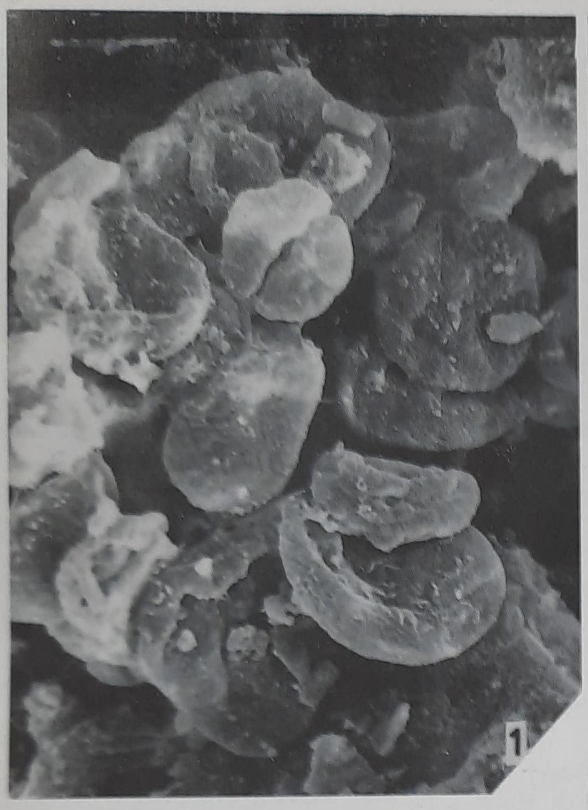
PALAEOECOLOGY

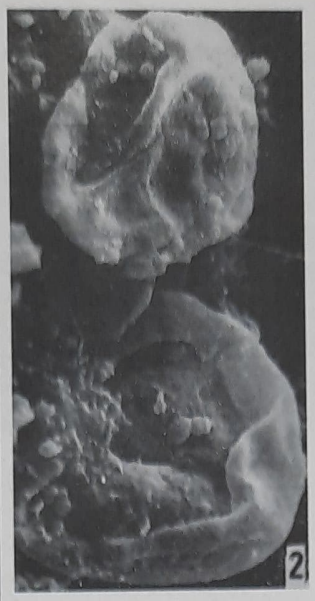
The specimens collected from the greyish-black thin bedded mudstones of the Fuxin Basin are well preserved. Several pinnae collected together in the rocks indicates that they had not been transported for very long distance before burial. This fern is a member of the assemblage of *Acanthopteris gothani-Dicksonia silapensi-Athrotaxites berryi*. The two ferns, *A. gothani* and *D. silapensis* are very abundant in the Early Cretaceous

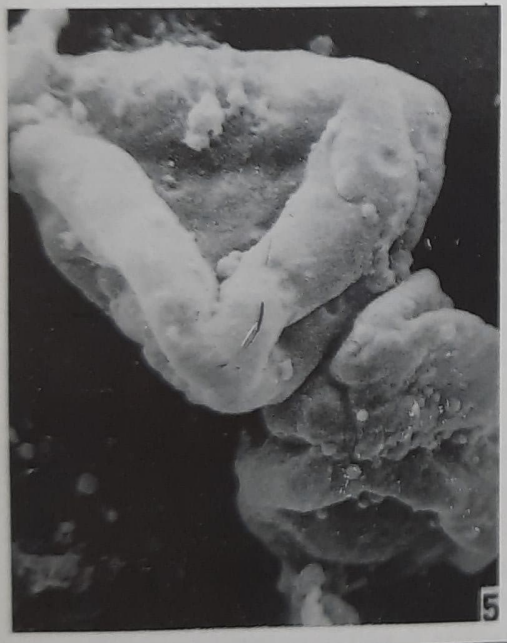
Plate 4

(All SEM photographs)

1-9. Spores.
1, x 800; 2, proximal surface, x 1000; 3, proximal surface, x 800; 4, showing the immature ones, x 1200; 5, proximal surface, x 1800; 6, 1000; 7, proximal surface, x 1200; 8-9, x 1000.







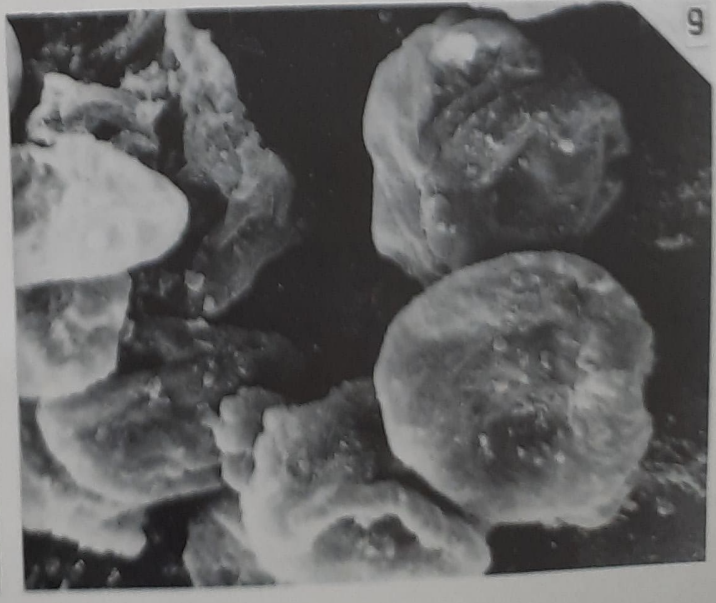


Plate 4

lacustrine sediments in Northeast China and Siberia, Russia. They probably grow in the low land or marshy area. The conifer *Athrotaxites berryi*, widely distributed in the Early Cretaceous coal-bearing beds of America and Northeast China, is considered possibly as a marshy tree, providing the over-story of the marsh forests (Miller & Lapasha, 1983; Lapasha & Miller, 1984; Chen & Deng, 1990). Therefore, *Dracopteris* seems to have lived in marshy or low land areas. Moreover, the triangular frond and the separately arranged pinnae show that it is probably a shade loving fern.

Fuxin Basin and Tiefa Basin were located in the temperate zone during Early Cretaceous (Chen *et al.*, 1990). The palaeolatitude is very close to that of the modern time (Fan, 1990). Judging from the composition and the characteristics, the Fuxin and Tiefa floras represent the North Palaeofloristic Province of the Early Cretaceous of China (Chen *et al.*, 1988; Chen, 1990) corresponding to the Siberian or Canadian-Siberian province (Vakhrameev, 1964). The flora indicates a warm and humid climate (Chen *et al.*, 1988; Chen, 1990; Deng, 1991b). Besides, a temperature drop accompanied by moisten event has been recognized in Valanginian-Barremian mainly based on the palaeobiogeographical realm studies (Liu *et al.*, 1986, 1988, 1992). This is supported by epidermal-cuticular analyses of gymnosperms, palynofloral assemblages (Deng, 1991b) and palaeogeomagnetic information (Fan, 1989). Consequently, the new genus is probably a thermophilic and hygrophilous fern.

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