Morphological and microscopical study on *Scolecopteris* from China

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The fossil genus *Scolecopteris* of Marattiales has recently been discovered from the Permian coal-bearing series of southern north and South China. Three species of *Scolecopteris* are known in China, namely, *Scolecopteris cathaysicus* sp. nov., *S. sinensis* sp. nov. and *S. unifercata* (Yang et Chen) emend. The former two species were collected from the Xiaofengkou Formation and the Shenhou Formation of Middle Permian in the Pingdingshan Coalfield, Henan Province. *S. unifercata* was collected from the Longtan Formation of Late Permian in Guangdong Province (and also in Fujian and Guizhou Provinces). Fairly detailed researches on the morphology of these three species, especially on the *in situ* spores *S. catspores obaysicus* and *S. sinensis* have been done. Furthermore, the Chinese species of the genus *Scolecopteris* are compared with those from Euramerica and a preliminary study on the ecology of *Scolecopteris* has also been made.

Key-words—Marattiales, *Scolecopteris*, Morphology, Spores, Permian, China.

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सारांश

चीन से *स्कोलिकॉप्टेरिस* का आकारिकीय एवं सूक्ष्मदर्शीय अध्ययन

याँग गुआँक्सियु, वाँग हाँगशान एवं शैंग ऐक्सिंग

दक्षिणी उत्तर एवं दक्षिण चीन की परमियन कोयला धारक संस्तरों से मैरेटिटएल्स की एक प्रजाति *स्कोलिकॉप्पटेरिस* उपलब्ध हुई है। चीन से स्कोलिकॉप्टेरिस की तीन जातियाँ–स्को. *कैथेसिकस* नव जाति, *साइनेन्सिस* नव जाति एवं *स्को. यूनीफर्केटा* (याँग व चेन) संशोधित ज्ञात हैं। इनमें से पहली दो जिआउफेंगकाऊ शैल-समूह से एवं हेनान प्रान्त में पिंगडिंगशान कोयला क्षेत्र में मध्य परमियन के लौंगटान शैल-समूह से एकत्र की गई थी तथा तीसरी *स्को. यूनीफर्केटा* ग्वाँगडाँग प्रदेश में अनंतिम परमियन लौंगटान शैल-समूह से एकत्र की गई थी। इन तीनों जातियों का विस्तृत आकारिकीय अध्ययन किया गया है इसके अतिरिक्त इन जातियों की यूरामेरिका से उपलब्ध जातियों से तुलना की गई है तथा *स्कोलिकॉप्टेरिस* के पारिस्थितिकीय अध्ययन का भी प्रयास किया गया है।

ABOUT twenty species of *Scolecopteris* are known from Euramerica and the *in situ* reproductive organs of these species have been studied in detail. As all the materials are from permineralized coal balls, the

PLATE 1

1-8. Vegetative fronds of *Scolecopteris cathaysicus* Yang et Wang sp. nov.

1. Left half part of penultimate pinna, measuring 14 cm long. No. HEP5007.
2, 2a., Relatively small pinnules, slightly curved upward. 2a, X 2. No. HEP4983.
3, 3a. Traces of hairs on pinna rachis; pinnules straight. 3a, X 3. No. HEP5600.
4. Penultimate pinna rachis at least 2 cm wide. No. HEP5008.
5, 5a. Anterior branch dividing once more occasionally after first bifurcation near the midrib. 5a, X 2. No. HEP4981.
6, 6a. Scars of hairs on midrib. 6a, X 4. No. HEP5012.
7, 7a. Relatively large pinnules anterior branch dividing once more after first bifurcation near the midrib. 7a, X 2. No. HEP4336.
8, 8a. Scars of hairs on ultimate pinna rachis and midrib. 8a, X 2. No. HEP5601
9. Fertile frond, ultimate pinna 15 cm long. No: HEP5219.

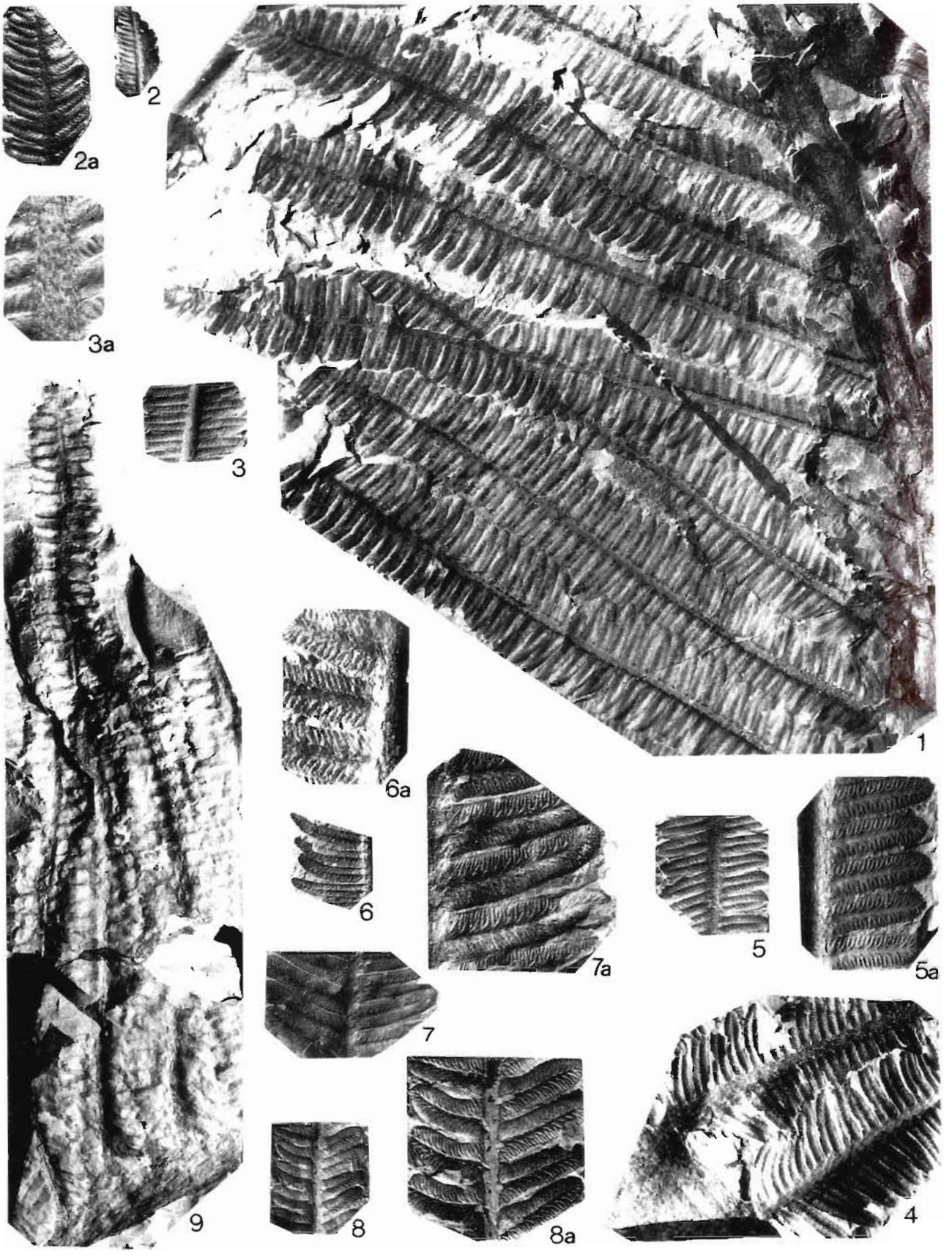


PLATE 1

studies are restricted to peels of the reproductive organs and little is known about the gross morphology of vegetative and fertile fronds and the relationship between them. The three species studied have well preserved compressions and the relationship between vegetative and fertile fronds is distinct. Among them, *Scolecopteris cathaysicus* sp. nov. and *S. sinensis* sp. nov. are well preserved with *in situ* reproductive organs. The study of these specimens may provide some important data on the morphology of fronds and the relationship between vegetative and fertile fronds.

MATERIAL AND METHODS

Specimens of *Scolecopteris sinensis* sp. nov. and *S. cathaysicus* sp. nov. were collected respectively from the Shenhou Formation (early Middle Permian) and the Xiaofengkou Formation (late Middle Permian) in the Pingdingshan Coalfield, Henan Province; specimens of *S. unifercata* were collected from the Longtan Formation (early Late Permian) in Renhua County, Guangdong Province. *In situ* spores of the former two species were obtained from the compression specimens. To study the specimens first they were moved mechanically from specimens, then put in hydrochloric acid (20%) followed by hydrofluoric acid (40%), then in Schulze Solution and then in alkaline solution (ammonia or other alkaline solutions such as sodium hydroxide solution) and in the last were dehydrated with alcohol. Now the material can be observed by means of SEM or light microscope.

DESCRIPTION

Marattiales

Scolecopteris Zenker emend. Millay

Scolecopteris cathaysicus Yang et Wang (sp. nov.)
Pl. 1, figs 1-9; Pl. 2, figs 1-8; Pl. 3, figs 1-5

Description—Sterile fronds (Pl. 1, figs 1-8) bipinnate; pinnules and pinnae of different orders attached to the adaxial side of rachis. Pinnules *Pecopteris* type, relatively variable in size, 3 x 1.5 mm (Pl. 1, figs 2, 2a) to 15 x 4.5 mm (Pl. 1, figs 7, 7a), slightly curved upward or straight (Pl. 1, figs 3, 3a, 5, 5a); midrib and lateral veins strong. Lateral veins bifurcating once in wide angles near the midrib, with the anterior branch bifurcating once more or not; hairs on the raches of different orders (Pl. 1, figs 3, 3a, 8, 8a) or even on the midrib (Pl. 1, figs 6, 6a), penultimate pinna rachis (Pl. 1, fig. 4) 2 cm wide; ultimate pinna linear (Pl. 1, fig. 1), 14 cm long, with 50-54 pairs of pinnules.

Fertile fronds (Pl. 1, fig. 9; Pl. 2, figs 1-8) tripinnate. Penultimate and triultimate rachis 3 x 4 cm wide respectively, with hairs on their surface (Pl. 2, fig. 1); fertile pinnules relatively shorter and wider compared with vegetative ones. Pinnules attached to the adaxial side of rachis (Pl. 2, figs 2, 2a) to form a wide "V" shaped angle; margins curved abaxially (Pl. 2, figs 2, 4). Pinnules of one side of ultimate pinna preserved flat, whereas the basal parts of pinnules of the other side (Pl. 2, figs 3, 5, 6, 8) are visible. Lateral veins simple and sparse (Pl. 2, figs 3a, 7a). Ultimate pinna linear, 15 cm long, composed of at least 50 pairs of fertile pinnules (Pl. 1, fig. 9).

Synangia pendant to the lateral veins from the abaxial surface of fertile pinnule and arranged in a single row on each side of midrib, with 6-9 synangia in each row (Pl. 2, figs 3, 5a, 8a; Pl. 3, figs 1, 1a, 2, 2a); synangium composed of four tubiform sporangia with acute or obtuse end and only connected at the base. Sporangia about 1.8-2.2 mm in length, 0.35-0.65 mm in breadth. Sporangiophore not seen. Wall cells of sporangium elongate (Pl. 3, figs 1, 1a, 2, 2a); *in situ* spores spherical, monolete, occasionally. Exine smooth, generally about 30 μm in diameter (Pl. 3, figs 3-5).

PLATE 2 →

1-8. Fertile fronds of *Scolecopteris cathaysicus* Yang et Wang sp. nov.

1. At least tripinnate. No. 4958.
2, 2a. Relatively small fertile pinnules, obviously attached to the adaxial side of pinna rachis. 2a, X 2. No. HEP4923.
3, 3a. Pinnules curved adaxially, lateral veins simple. 3a, X 3. No. HEP4323.
4. Ultimate pinna rachis convex, pinnules attached to the adaxial side of pinna rachis. No. HEP4964.
5, 5a. Relatively large pinnules. 9 pairs of synangia attached to one pinnule. 5a, X 2. No. HEP4972.
6. Ultimate pinna. No. HEP4918.
7, 7a. Vegetative pinnules on the end of ultimate pinna. 7a, X 3. No. HEP4912.
8, 8a. One row of synangia at each side of the midrib. 8a, X 3. No. HEP4383

PLATE 2

Syntypes—The specimens in Pl. 1, fig. 1; Pl. 2, figs 1, 4, 7; Pl. 3. figs 1, 2.

Type locality—Pingdingshan Coalfield (Henan).

Horizon—Xiaofengkou Formation (late Middle Permian)

Etymology—*Cathay*, an ancient name of China.

Scolecopteris sinensis Yang et Sheng (sp. nov.)
Pl. 3, figs 6-13

Description—Fronds of unknown shape. Ultimate pinna linear. Pinnules linear, generally 15 x 3 mm in size; midrib strong and slightly decurrent. Lateral veins bifurcating once very near the midrib, with the anterior branch bifurcating once more (Pl. 3, figs 6, 6a); fertile and vegetative pinnules uniform, attached to the adaxial side of rachis. Fertile pinnules generally 10-23 x 2-3.5 mm in size (Pl. 3, figs 6-10). Synangia (Pl. 3, figs 7a, 7b, 10a, 10b, 11-13) 10-16, arranged in a single row on each side of midrib, each composed of four sporangia. Sporangium round-square or squarish as viewed vertically or tubiform viewed laterally (Pl. 3, figs 10a, 10b, 7b). Spores *in situ* trilete, spherial. Exine rugose or granular. The trilete sutures are not distinct under SEM because they are often covered by rugae or granules (Pl. 3, figs 11, 12) under SEM, but they are distinct under microscope (Pl. 3, fig. 13).

Syntypes—Specimens in Pl. 3, figs 6, 7, 10, 12.

Type locality—Pingdingshan Coalfield (Henan).

Horizon—Shenhou Formation (early Middle Permian).

Etymology—*Sinae*, a Latin name of China.

Scolecopteris unifercata (Yang et Chen) emend. Yang
Pl. 4, figs 1-5

1979 *Acitheca (Pecopteris) unifercata* Yang et Chen, pp.116-118, pls XXV. XXVI. XXVII XVIII.

1980 *Bifariuotheca qinglongensis* Zhao, p. 81, pl. XII. figs 5, 6, 5a.

1990 *Acitheca (Pecopteris) unifercata*, Zhu, p. 94, pl. 32, fig. 6.

Description—Vegetative fronds of unknown shape (Pl. 4, figs 1, 1a), bipinnate. Linear ultimate pinna attached to the adaxial side of rachis, 16 cm or more in length. Pinnules large, elliptical or elongately elliptical, with obtuse ends, generally 9-16 x 3.5-5 mm in size, with length 2.5-3 times the breadth. Midrib coarse, slightly decurrent. Lateral veins extending from the midrib in acute angles and bifurcating once very near the midrib.

Fertile fronds incomplete (Pl. 4, figs 2-5). Fertile pinnules being narrower and longer as compared with vegetative ones, with margins turned down, generally 9-13 x 2-2.5 mm in size. Ultimate pinna attached to the adaxial side of rachis (Pl. 4, fig. 2); synangium composed of four sporangia arranged in a single row on each side of the midrib (Pl. 4, fig. 3a). Sporangium round-square or round (Pl. 4, fig. 4b) as viewed vertically and spindle-shaped (Pl. 4, fig. 3b) laterally, generally 1.2 mm in length and 0.2 mm in breadth, connected with their bases to the sporangiophore (Pl. 4, fig. 3c) while the other one-third or one-half separated. Spores not obtained.

Syntypes—Specimens in Pl. 4, figs 1, 2, 3, 4.

Type locality—Renhua County (Guangdong).

Horizon—Longtan Formation (early Late Permian).

Etymology—The species is named for the lateral unifercating vein of pinnule.

PLATE 3

1-5. *Scolecopteris cathaysicus* Yang et Wang sp. nov.

1, 1a. Showing two rows of synangia attached to one fertile pinnule, at least six synangia in a single row. 1, X 12. Nos. HEP5602, Z89339. 1a, X 18. Two synangia at left in fig.1 enlarged to show that one synangium is composed of four sporangia. No. : HEP5602, Z89400.

2, 2a. Showing one synangium composed of four sporangia. 2, X 18. Z86888; 2a, X 26. Showing exine cells of sporangium. Z89889.

3-5. Spores *in situ*. 3, X 600, Z86905. 4, X 720, Z86905. Spherical monolete spores, exine smooth; 5, X 400, Z86906. Monolete spores with a third arm (pseudotrilete).

6-13. *Scolecopteris sinensis* Yang et Sheng (sp. nov)

6, 6a. Fragment of ultimate vegetative pinna; 6a, X 3. Showing venation. No. HEP4008.

7-10. Fragments of ultimate fertile pinnae. 7a, X 3. 7b, X 10. No. : HEP4005. Showing lateral view of synangia and sporangia; 10a, X 3. 10b, X10. No. HEP4006. Showing vertical view of synangia and sporangia; 11, X 820. Z80157. 12, X 1300. Z80159. SEM photos of spores *in situ*, spherical and warty; 13, X 1600. Spores *in situ* trilete; Slide No. 20.

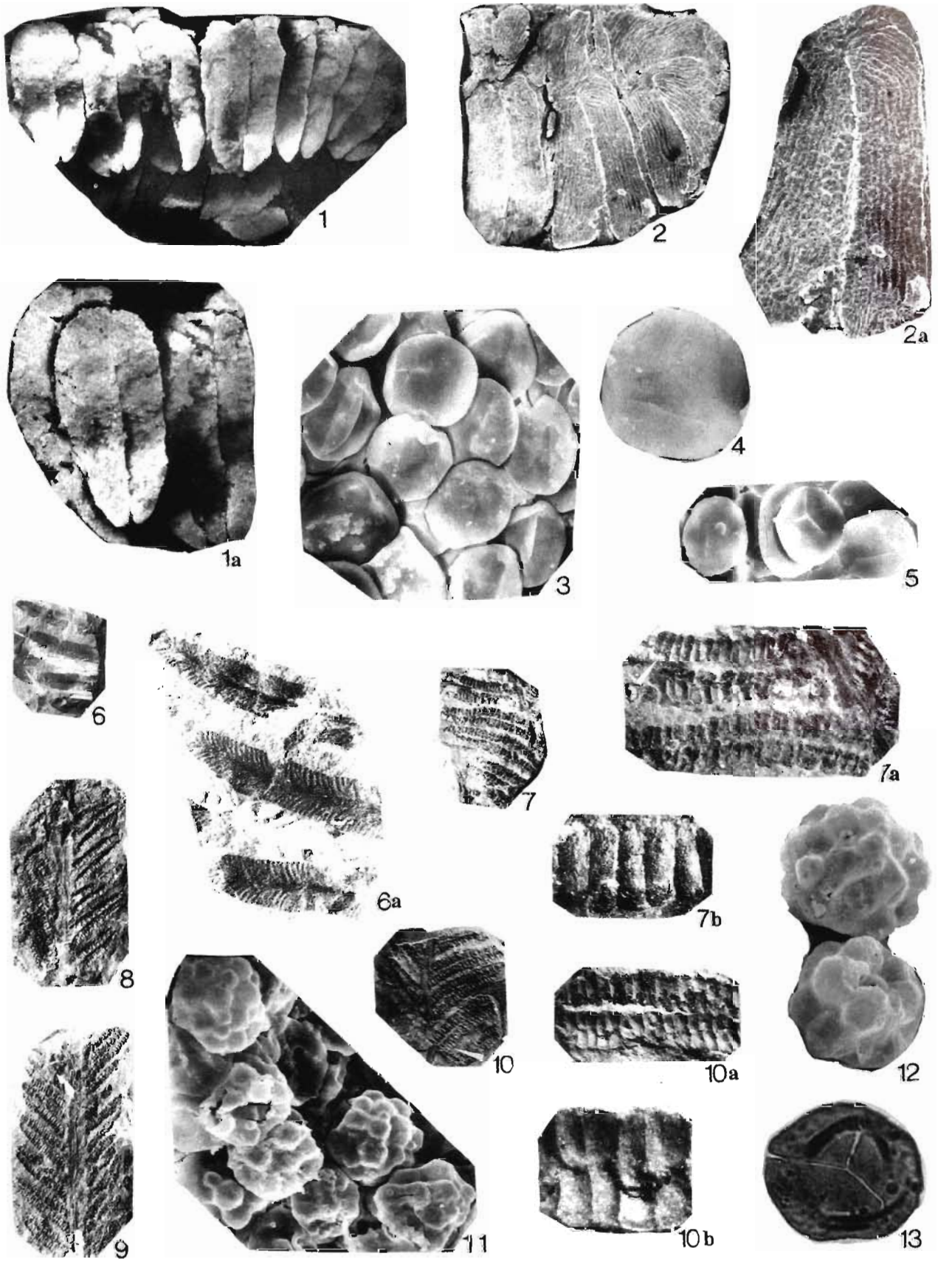


PLATE 3

COMPARISON AND DISCUSSION

Table 1—Differences among *S. cathaysicus, S. sinensis* and *S.*

	S. unifercata	*S. sinensis*	*S. cathaysicus*
Morphology and size of vegetative pinnule	Elliptical or elongately elliptical; 9—16mm × 3. 5—5mm Length 2. 5—3 times breadth; lateral veins bifurcating once.	Long lingulate; 10—23mm × 2—3. 5mm, length about 5 times breadth; lateral veins bigurcating twice.	Lingulate, long lingulate; 3—15mm × 1. 5—4. 5mm, lenth 2—5 times breadth; lateral veins bifurcating twice.
Fertile pinnules compared with vegetative ones	different narrower and longer	uniform	different, shorter and broader.
With or without sporangiophore	with	not clear	without
Number of synangia in each row.	10—12	10—16	6—9
Size of sporangia (Lateral view)	1. 2×0. 2mm acute or obtuse at the end.	0. 9×0. 3mm obtuse at the end	2. 2—1. 8 × 0. 65—0. 35mm obtuse or acute at the end.
Characters of spores in situ	unknown	Spherical, trilete, rugose 24—35μm × 26—36μm	Spherical, monolete, smooth. 30μm

As mentioned above, around 20 species of *Scolecopteris* from Euramerica have been described (Millay, 1979, 1980). Apart from a few species (Stidd, 1971), most are pinnules of fertile fronds preserved in coal balls. Though fertile pinnules, synangia, sporangia, spores and even their anatomy have been described in detail; little is known about the vegetative fronds and the relationship between vegetative and fertile fronds. This makes it rather difficult for us to compare the three species with those from Euramerica. Comparisons can be made only based on the characters (especially size) of fertile pinnules, synangia and *in situ* spores. The largest fertile pinnules of *Scolecopteris* from Euramerica are those of *S. majopsis* (7.4 x 2.8 mm). It is much smaller than that of *S. sinensis* (10-23 x 2-3.5 mm) and *S. unifercata* (9-13 x 2-2.5 mm). In addition, *in situ* spores of *S. sinensis* are triletes with rugose rugate exine. According to these characters, *S. sinensis* and *S. unifercata* can be distinguished from those species of *Scolecopteris* from Euramerica. The fertile pinnule of *S. cathaysicus* is similar to that of some *Scolecopteris* from Euramerica in size (4-10 x 3-5 mm), but its sporangium is larger (1.8-2.2 x 0.35-0.65 mm). It is somewhat similar in size to the sporangium of *S. monothrix* (1.8 mm in length), but the sporangia of all other species are not more than 1.4 mm long. The spherical monolete *in situ* spores with smooth exine of *S. cathaysicus* is also similar to those of *S. monothrix*, but spore of the former is generally 30 μm in diameter, while those of the latter are 12 x 9 μm. Based on the size of fertile pinnules and sporangia and spores, it is easy to distinguish *S. cathaysicus* from the Euramerican species of *Scolecopteris*.

There are diverse opinions about the distinctions between *Scolecopteris* and *Asterotheca* (Stur, 1883; Hirmer, 1927; Radforth, 1942; Millay, 1979, etc.). Having examined two species of *Asterotheca*, e.g., *Pecopteris (Asterotheca) orientalis* and *P. (A.) arborescens* (to be described in detail in another paper) collected from the same horizon as *S. cathaysicus* in the Pingdingshan Coalfield of Henan Province, China, we found that, as compared with the three species of *Scolecopteris*, the vegetative and fertile pinnules of *P. (A.) orientalis* and *P. (A.) arborescens* are uniform and rather small in size, and their synangia are also rather small. So we think that *Scolecopteris* and *Asterotheca* are different both in foliage form and characters of reproductive organs *in situ*.

PALAEOECOLOGY OF *SCOLECOPTERIS*

The present three species are characterized by having their fertile pinnules or fertile pinnae of different orders attached to the abaxial side of the rachis, in a wide "V" shape. Such type of attachment is found similar to that of *Weichselia* of Weichseliaceae in the Lower Cretaceous. Alvin (1971) considered that *Weichselia* was a xerophyte, adapted to the dune by river bank, whereas *Scolecopteris* is a frond of tree fern *Psaronius*, adapted to a tropical warm and humid environment. Nevertheless, the gigantic frond at the top may also receive direct sunlight, so the

PLATE 4

1-5. *Scolecopteris unifercata* (Yang et Chen) Yang emend.

1, 1a. Vegetative fronds, at least bipinnate; 1a, X3. Showing lateral veins bifurcating once. No. K-0352 (Syntype specimen).

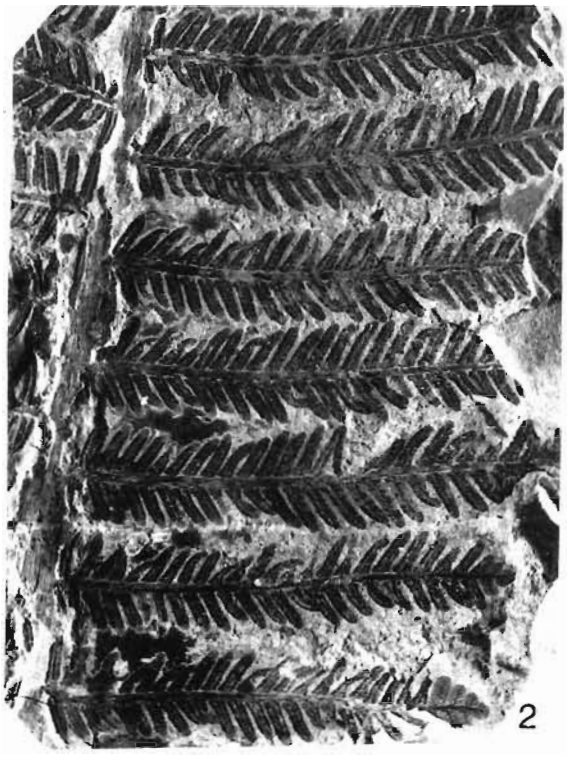
2, 2a. Fertile fronds, bipinnate; 2a, X 2.5. Showing ultimate fertile pinna

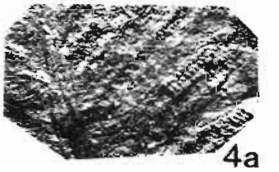
2b. 2c. and vegetative pinnules at its end; 2b, X 6. 2c, X 10. Showing slantwise preserved synangia on each side of the midrib. No. K-0358 (Syntype specimen).

3, 3a, 3b, 3c. Fertile pinna; 3a, X 5. Showing laterally preserved synangia on each side of the midrib (at least 16 synangia in each row); 3b, X 15. Lateral view of synangia; 3c, X 10. Sporangia connected at the base. No. K-0359 (Syntype specimen).

4, 4a, 4b. Fertile pinna; 4a, X 3. 4b, X 6. Vertical view of synangia. No. K-0356 (Syntype specimen).

5. Fragment of fertile pinna. No. K-0360.





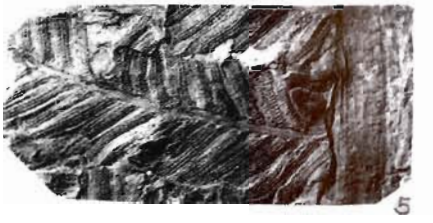


PLATE 4

frond needs to possess some functional xerophytic structures, which can withstand strong sunlight and reduce evaporation. In addition, this type of attachment is common in other species of different genera in the South China subprovince of the Cathaysian Province, e.g., *Pecopteris (Asterotheca) crassinervis, Pecopteris renhuaensis* (Yang, 1979) and *Pecopteris (Asterotheca) guizhouensis* (Zhao, 1980). This indicates that other genera of Psaroniaceae may also possess the same ecological habit as *Scolecopteris.*

The fertile pinnule margins of most species of *Scolecopteris* from both China and North America are more or less recurved such as *Scolecopteris minor* (Millay, 1979) and *S. unifercata.* In other species, e.g., *S. latigolia* and *S. caticifolia* (Millay, 1979), the fertile pinnules have their fibrous and downturned margins enclosing the synangia laterally. In addition, the pinnules of most species are small and veins are coarse. Still in some other species such as *Pecopteris renhuaensis* (Yang, 1979) and *Pecopteris (Asterotheca) guizhouensis* (Zhao, 1980), etc. from South China, the pinnules are small and thick, especially at the margin with hairs on the pinnule surface. All these characters indicate that some of the fronds of *Psaronius* living in the warm and humid environment may possess functional xerophytic structures.

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