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New Species of the Isolated Psaroniaceous Rachis from the Early Permian in China

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Abstract

A new kind of marattialean raches are reported from the coal balls in Coal Seam No.7 in the upper part of the Taiyuan Formation (early Early Permian) from Taiyuan, Shanxi, China and are assigned to the genus *Stipitopteris* Grand'Eury (Psaroniaceae). The present specimens are different from all six reported species of the genus, and are therefore proposed as a new species: *Stipitopteris shanxiensis*. The raches of the new species are generally dorsi-ventrally flattened. The main raches usually exhibit scales of different forms on their surface. Beneath the epidermis is a zone of parenchymatous cells, some of which contain tannin-like contents. Inside this is a zone of small sclerenchymatous cells. Inward are the ground tissue and vascular bundles. The vascular bundles are continuous and are in two circles: the outer circle assumes a transversely elliptical shape with the gap and pinna trace, and the inner circle assumes a shallow C-shape with inrolled ends. The ground tissue located at the inner side of the vascular bundle is composed of thicker-walled parenchymatous cells. The cells of the ground tissue are vertically elongated in longitudinal sections. Subordered raches are smaller and have simpler structures than the main raches. The parenchyma zone beneath the epidermis is thinner, usually one to two cells wide and the sclerenchyma zone is usually absent. The scales are poorly developed and there is only one C-shaped vascular bundle. The new species is comparable to the crosiers of Psaroniaceae of the Euramerican Flora in some aspects, for example, it has a dorsi-ventrally flattened rachis and scales on the surface of the rachis. However, the other features and the preservative conditions of the present specimens indicate that they are not crosiers, but fully developed or mature raches. The new species is the first well-studied anatomically-preserved rachis of Psaroniaceae from the Cathaysian Flora and bears significance not only in understanding the anatomy and taxonomy of Psaroniaceae in the Cathaysian Flora, but also in the relationship between the Euramerican Flora and the Cathaysian Flora.

Key words: coal ball; Early Permian; new species; Psaroniaceae; rachis; *Stipitopteris*.

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Psaroniaceae, belonging to the Marattiales, was an extinct tree fern family once predominant in the Late Carboniferous and the Permian (ca. 3.2–2.5 million years ago) of the Euramerican Flora and the Cathaysian Flora. This family also lived in some places (such as South America district) of the Gondwana Flora (Herbst 1985, 1999; Rößler 2000). Psaroniaceae was an important group of plants of the Cathaysian Flora and the Euramerican Flora. They played a considerable role in many communities and were also an important group of coal-forming plants. Therefore, studies on the Psaroniaceae have significant bearing on palaeobotany and coal geology.

Previous research on the Psaroniaceae has mainly focused on stems and fronds (including vegetative and fertile ones), but not so much attention has been paid to the petiole and rachis, especially in the Cathaysian Flora and the Gondwana Flora. Until now, there have been no formal reports on the anatomically-preserved petioles and raches of the

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Psaroniaceae in both of the above-mentioned floras. Petiole is the vital organ connecting stem and leaf and possesses the characteristics of both stems and leaves. A study on the petioles and raches of the Psaroniaceae in the Euramerican Flora shows that different kinds of stems bear different petioles and raches (Stidd 1971). Therefore, petioles and raches are also valuable in classification of the Psaroniaceae. There are plenty of stems, petioles, raches and reproductive organs of the Psaroniaceae in the coal balls in Coal Seam No.7 in the Taiyuan Formation, Xishan Coal-field, Taiyuan, Shanxi Province, and they probably belong to several different whole plants (Ma 1985; Zhao 1991; Tian and Wang 1995; Tian et al. 1996; Wang et al. 1999). However relationships among these organs, or more specifically, which kind of stem, petiole, rachis, and reproductive organ belong to the same kinds of whole plants, have remained unknown to date. Therefore, our work on petiole and rachis is an important part of the study of anatomically-preserved Psaroniaceae in the above-mentioned coal balls.

Systematic Paleobotany

Order:	Marattiales
Family:	Psaroniaceae Stenzel
Genus:	*Stipitopteris* Grand'Eury, 1877
Type Species:	*S. aequalis* Grand'Eury, 1877
	Stipitopteris shanxiensis sp.nov (Figures 1–17)

Diagnosis

Rachis dorsi-ventrally flattened with a maximal dimension of at least 1.8 cm × 0.4 cm. In larger specimens (probably main rachis) scales of different forms and sizes being on the surface. Beneath the epidermis exists a zone of parenchymatous cells and tannin-like cells that are subrotund or elliptical in shape in cross-sections and vertically elongated in shape in longitudinal sections. Next internally is a thin sclerenchyma zone. The ground tissue and two continuous vascular strands are located inside this. The outer vascular strand has a transversely-elliptical shape with pinna gaps; the inner strand has a shallow C shape with inrolled ends. The ground tissue consists of parenchymatous cells and thicker-walled parenchymatous cells with the latter mainly distributed along the adaxial side of the vascular strands. Cells of the ground tissue are subrotund in the transverse section and are vertically elongated in the longitudinal section. In smaller specimens (subordered rachis) scales are much less developed. The parenchyma zone beneath the epidermis is very thin, usually one to two cells wide, and the sclerenchyma zone is usually absent. The vascular bundle is single and C-shaped with inrolled ends.

Holotype:	Coal Ball: TN-18; Slides: W246, W247, W248.
Paratype:	Coal Ball: T_7-65, Slide: W533; Coal Ball: ST7-1000, Slide: $WP^1_1$0046.
Type locality:	Ximing Coal Mine, Taiyuan, Shanxi Province, China.
Geological horizon:	Coal Seam No.7, upper part of Taiyuan Formation.
Age:	Early Early Permian (Sakmarian).
Etymology:	Specific epithet is derived from the fossil source in Shanxi Province.

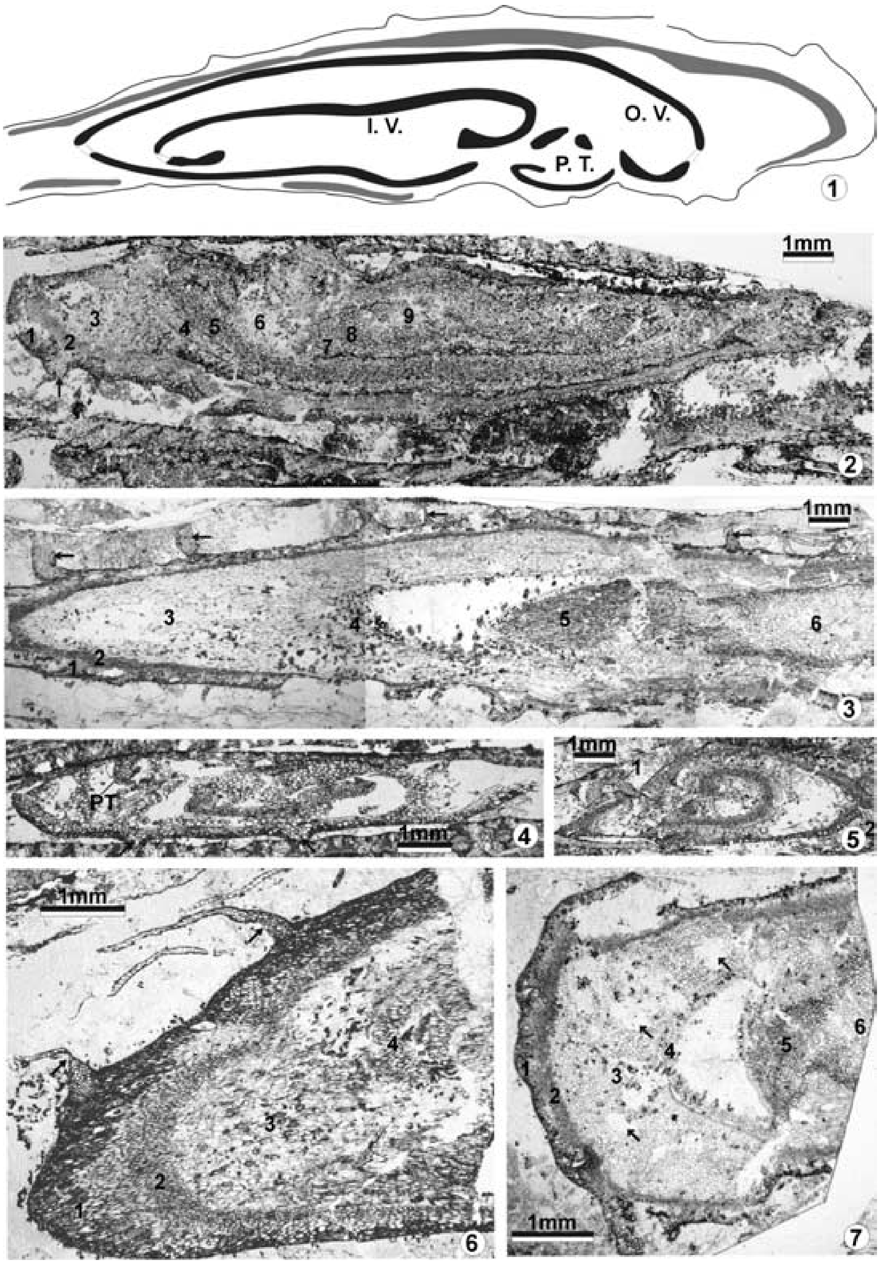
Description

There are six specimens that are assignable to this new species. Four of these are larger ones that might be the main raches, while the other two are smaller ones that might be the subordered (e.g. secondary or tertiary) raches. The four specimens of main rachis are preserved in three coal balls. In Coal Ball TN-18 the type specimen is preserved and is nearly intact. Three slightly oblique sequential cross-sections of the specimen with the slide numbers of W246, W247 and W248 (Figures 1, 2, 9) are available. Two specimens were found in Coal Ball T_7-65. One of them has been revealed as a portion of rachis in the cross-section with the slide number of W533/1 (Figures 7, 12, 14, 15) and the other one is represented by an obliquely longitudinal section with the slide number of W533/2 (Figures 3, 8, 16, 17). The fourth specimen of the main rachis is preserved in the Coal Ball ST7-1 000 and is revealed by a slightly oblique cross-section with the slide number of $WP_1{}^1$0046 (Figures 6, 10, 11, 13). Two subordered raches were found respectively in Coal Balls T_7-92E Top/3 and T_7-85B Bot/3. The first one is represented by a slightly oblique cross section with the slide number of W093 (Figure 4). The second one is a cross-section with the slide number of W098 (Figure 5).

Main rachis

The type specimen (in W246-248) is dorsi-ventrally flattened with a horizontally or transversely elliptical outline in the cross-section with a dimension of 1.8 cm × 0.35 cm (Figures 1, 2). The other two specimens (in $WP_1{}^1$0046 and W533/1) are also dorsi-ventrally flattened although they are only a small part of the main rachis (Figures 6, 7). The dimension between the dorsal and ventral surface is 0.35–0.45 cm among four specimens.

The main rachis of the present specimens consists of the following tissues inwards: the outermost epidermis, parenchyma zone, sclerenchyma zone, ground tissue and vascular bundles.



Figures 1–7. *Stipitopteris shanxiensis* sp.nov.

(**1**) Diagram of the main rachis shown in Figure 2.

Black-xylem, grey-sclerenchyma zone. I.V., inner vascular strand; O.V., outer vascular strand; P.T., pinna trace.

(**2**) Main rachis in transverse section.

Type specimen showing dorsi-ventraly flattened outline of the rachis. Slide: W246.

(**3**) Main rachis in obliquely longitudinal section, showing well-developed scales (arrowed).

Slide: W533/2.

(**4**)Subordered rachis with a pinnae trace (PT) in transverse section.

Scales (arrowed) are poorly developed. Slide: W093.

(**5**) Subordered rachis in transverse section.

Note the folded adaxial surface (1) and broken abaxial surface (2). Scales (arrowed) are poorly developed. Slide: W098.

The epidermis is a single layer of small cells. They are subrotund or tangentially elongated in cross-sections with the diameter from 20 μm × 20 μm to 8 − 30 μm × 40 μm (Figure 12). In longitudinal sections the epidermal cells are vertically elongated with the length of 40–75 μm.

An important characteristic of the present specimens is that there are scales in different developmental degrees from specimen to specimen on the surface of the main rachis. Scales on two specimens (in W533/1 and $WP_1{}^1$0046) are well developed with not only a great number, but also a complex structure. Scales consist of two parts: a triangle or conic basal part and a linear apical part. Some scales have large basal parts which might be 350 μm in diameter and 500 μm in height (Figures 8, 10) or 600 μm in diameter and 600 μm in height (Figure 9). Some scales are contracted in the basal part (Figure 3), whereas others are thin and tall (Figures 6, 11). Cells in the basal part appear as subrotund or almost isodiametrical and polygonal in all directions. The size of the cells is variable in different specimens. In the specimen in $WP_1{}^1$0046, the cells are 25–50 μm in diameter, while they are larger in the specimen in W533/2, 40–75 μm in diameter. The apical part is usually one to two cells wide and consists of polygonal cells that are larger than those of the basal part. The apical parts mostly fell off and some of them are more than 1.5 mm in length (Figure 11). The basal parts of the scales in the type specimen are low and the apical parts are absent, but there are many isolated apical parts around the basal part. In the specimen in W533/1 the scales are rare (Figure 7).

There is a parenchyma zone beneath the epidermis. The zone is three to seven cells wide and consists of two kinds of cells. One is the common parenchymatous cells, which lack cell contents and are smaller in size, usually 60–80 μm. The other ones are tannin-like cells, which contain dark contents and are larger in size; up to 170 μm × 110 μm (Figures 9, 10, 12). In the longitudinal section, cells of the zone are usually elongated vertically (Figures 8, 17).

Inside the parenchyma zone is a sclerenchyma zone, which is generally 6–10 cells wide with the width variable from specimen to specimen and from place to place in one specimen. The zone consists of sclerenchymatous cells, which are small and nearly round in the cross-section. The diameter of the cells is variable from specimen to specimen, 10–20 μm in the specimen in W533/1, 18–25 μm in the specimen in $WP_1{}^1$0046, and 15–30 μm in the type specimen. In the longitudinal section, the cells are elongated vertically with tapered ends.

In the type specimen there are two vascular bundles (Figure 1). The outer one is transversely elliptical in shape in the cross-section with the dimension of 1.15 cm in width and 2.5 mm in height. There is a gap on one side near the adaxial surface. Inside the gap there are several small fragments of vascular strands that might be the pinna trace. The inner one is C-shaped with two inrolled ends in the cross-section with its open side towards the adaxial surface. The xylem strand is generally two to three tracheids wide, but at the inrolled ends it can be up to four to five tracheids wide. Protoxylem is situated along the inner side of the xylem strand. In the longitudinal section, the tracheids of metaxylem bear scalariform thickenings.

Ground tissue consists of thinner-walled parenchymatous cells and thicker-walled parenchymatous cells. The latter are distributed along the inner side of the vascular bundle and are several cells wide (such as zone 5 in Figures 3, 7; zones 5 and 8 in Figures 2, 9). The former is distributed elsewhere (such as zones 3 and 6 in Figures 3, 7; and zones 3, 6 and 9 in Figure 9). The width of the ground tissue located between the sclerenchyma zone and the outer vascular bundle is variable and is much larger at two wings than that at the adaxial and abaxial surfaces of the rachis (Figure 2). The component of the ground tissue is variable in different specimens. Specimens in W533/1 and W533/2 possess the same ground tissue that consists of parenchymatous cells without cellular content and exhibits several air cavities with different sizes (Figures 3, 7). While in the ground tissue of specimens in W246-W248 and $WP_1{}^1$0046 no air cavities are developed and some cells with content are present (Figures 10, 13). The cells of the ground tissue, whether thinner-walled or thicker-walled, are elongated vertically in the longitudinal section with a length of 100–450 μm and horizontal end walls (Figures 16, 17).

Subordered rachis

The specimen in W093 is dorsi-ventrally flattened in the cross-section (Figure 4) with a dimension of 1.1 cm wide and only 1.5 mm high, which was probably caused by stratigraphic pressure. The other specimen in W098 is bilaterally flattened in the cross-section (Figure 5) with a dimension of 2.5 mm wide and 7.0 mm high and this might be also caused by the stratigraphic pressure because it is broken at the abaxial surface and folded at the adaxial side. It is deduced that both specimens might be also dorsi-ventrally flattened in the cross-section in natural conditions.

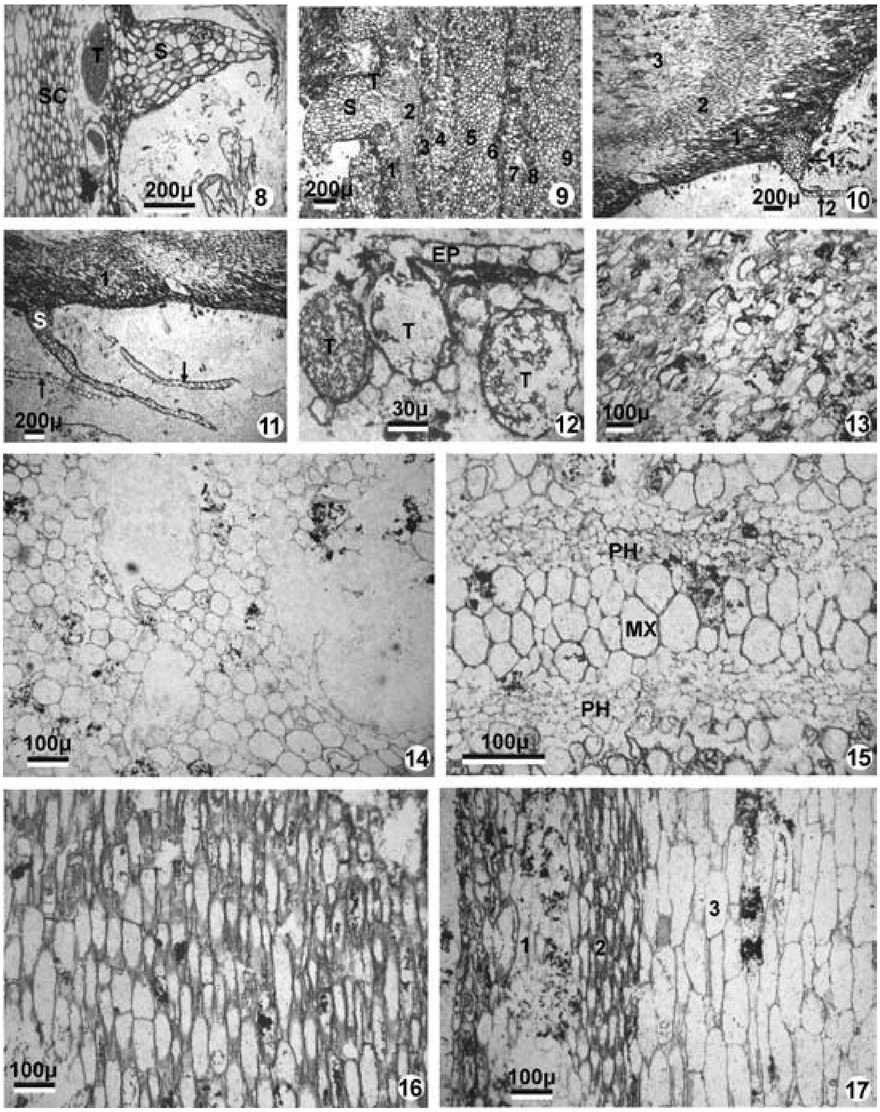
←

(**6**) Main rachis in slightly obliquely transverse section.

Note well developed scales (arrowed). Slide: $WP^1{}_1$0046.

(**7**) Main rachis in transverse section with poorly developed scales.

Note air cavities (arrowed) in ground tissue. Slide: W533/1.



Figures 8–17. *Stipitopteris shanxiensis* sp.nov.

(**8**) A portion of Figure 3, showing a scale (S), tannin-like cells (T) and sclerenchyma zone (SC).

(**9**) A portion of Figure 2. showing scales (S), tannin-like cells (T).

(**10**) A portion of Figure 6.

Arrows 1 and 2 indicate the base and tip of a scale respectively.

(**11**) Another portion of Figure 6, showing isolated scales (arrowed) and attached scales (S).

(**12**) A portion of Figure 7, showing epidermis (EP) and three tannin-like cells (T).

(**13**) A portion of Figure 6, showing ground tissue.

(**14**) A portion of Figure 7, showing air cavities in the ground tissue.

(**15**) Another portion of Figure 7, showing vascular strand.

MX, metaxylem; PH, phloem.

(**16**) A portion of Figure 3, showing the thicker-walled parenchymatous cells in obliquely longitudinal section.

(**17**) Another portion of Figure 3, showing tissues in obliquely longitudinal section.

In Figures **2–17**, tissues are numbered with arabic numerals in an inward sequence. 1, parenchyma zone containing large tannin-like cells; 2, sclerenchyma zone; 3, ground tissue; 4, outer vascular strand; 5, thicker-walled ground tissue; 6, ground tissue; 7, inner vascular strand; 8, thicker-walled ground tissue; 9, ground tissue.

The epidermal cells are difficult to recognize because of poor preservative conditions and the scales are not well developed. In both specimens, only at their abaxial surface, there are two to three short protuberances that might be the basal parts of the scales, but no apical parts are present (Figures 4, 5). The parenchyma zone beneath the epidermis is very narrow; only one to two cells wide, in which some large tannin-like cells are distributed. The width of the sclerenchyma zone is variable in a large range in the specimen in W098, from one to two cells wide in some places, from five to seven cells wide in other places. The sclerenchyma zone is not obvious in the specimen in W093. The ground tissue has been observed only near the vascular bundle, but is empty in other places. In the specimen in W098 the thinner-walled parenchymatous cells of the ground tissue outside the vascular bundle are nearly isodiametric with a diameter of 50–70 μm, whereas the thicker-walled parenchymatous cells inside the vascular bundle are nearly round in the cross-section with a diameter of 20–40 μm.

There is a single vascular bundle in the subordered rachis that is C-shaped or horseshoe-shaped with two inrolled ends in the cross-section. The metaxylem is one to two tracheids wide in the specimen in W093 and two to three tracheids wide in the specimen in W098, and is a little wider at the two inrolled ends (Figures 4, 5).

There was no pinna trace found in the specimen in W098. While in the specimen in W093, there is a small pinna trace at one side and near the adaxial surface of the rachis (PT in Figure 4). It also exhibits a C-shaped vascular bundle with the open side towards the adaxial surface of the mother rachis.

Comparison

The specimens we discussed resemble the anatomy of the main rachis of crosier of the immature frond of Psaroniaceae in the Middle and Late Pennsylvanian (Late Carboniferous) in North America, which was described in detail by Stidd (1971). Crosier is the coiled or unspread young frond of Pteropsida. The pinna rachis and pinnule might be coiled because of vernation. The basic portion of the main rachis of the crosier, which was described by Stidd (1971), is the same as the specimens discussed here in that it is also assumed to be dorsi-ventrally flattened in the cross-section, and pinna rachis of each order exhibits scales but the developmental degree decreases from the main rachis to subordered ones. The vascular configuration of the basic portion of the main rachis is also a Stipitopterid type, but is transformed into a Stewartiopterid type towards the apical portion and subordered raches. In the portion of the rachis with the Stipitopterid vascular configuration, the abaxial portion of the outer vascular strand is not continuous and consists of small and separate xylem strands, but the adxial portion and the inner vascular strand are usually continuous (Stidd 1971). The inner strand is small and assumes a shallow C-shape with the middle part arched towards the adaxial side of the rachis. In the portion of rachis with the Stewartiopterid vascular configuration, the abaxial portion of the C-, U- or horseshoe-shaped vascular strand is also not continuous, consisting of a number of small and separate xylem strands. Stidd (1971) did not give a detailed description of the tissues apart from the vascular bundle, which makes it difficult to compare his specimens with the present specimens, although it is likely that there is no parenchyma zone or sclerenchyma zone beneath the epidermis based on our observation on Stidd's (1971) illustrations.

The similarities between the specimens in this paper and the crosier described by Stidd (1971) are as follows: the dorsi-ventrally flattened main rachis in the cross-section, the presence of scales, and the shallow C-shaped inner vascular bundle. However, the differences between them are also obvious. First, in the former there are a parenchyma zone and a sclerenchyma zone beneath the epidermis, but in the latter, the epidermis directly contacts the vascular bundle. Second, the inner vascular strand in the former is large, situated at the center of the outer strand, while that in the latter is small, situated at one side where the pinna trace is departing. Third, the vascular strand in the former is continuous, while it is partially discontinuous in the latter. Furthermore, the specimens in this paper are stretched pinna rachis of fronds rather than crosier, because there are no coiled subordered pinna or pinnule, but some normal uncoiled pinnae around the specimens.

The anatomically-preserved petiole and pinna rachis of the mature frond of Psaroniaceae can be assigned into two genera according to the vascular configuration: *Stewartiopteris* Morgan et Delevoryas and *Stipitopteris* Grand'Eury. The former exhibits a single vascular strand, assuming C, U and horseshoe shapes, with two inrolled ends and the open side towards the adaxial surface of the petiole and rachis (Morgan and Delevoryas 1952a). The latter exhibits two vascular strands: an outer elliptical closed one and an inner W-shaped one (Morgan and Delevoryas 1952b). Stidd (1971) found that the vascular configuration of the two genera may present in the same species or in different petioles and raches of the same stem, which means that the vascular configuration might transform from *Stipitopteris* to *Stewartiopteris* when the petiole or pinna rachis are sectioned serially. It was thought that the boundary between the two genera was not clear, so Stidd suggested using the name of the stem to denominate the petiole or rachis that might have been relative to the stem; for example, the petiole and rachis of *Psaronius blicklei*, and use the terms of Stipitopterid and Stewartiopterid to describe the vascular configuration of the petiole and rachis. However, if the relationship between the stem and petiole or rachis is unknown, we are unable to name the petiole and rachis according to Stidd's opinion. Furthermore, not all kinds of stems possess the petiole and rachis with both types of vascular configuration. For example, the petiole and rachis of *P. blicklei* only possess Stewartiopterid, but not Stipitopterid vascular configuration (Stidd 1971). Thus, we think it is necessary to reserve the two genera to denominate the isolated petiole and rachis of Psaroniaceae. When specimens including petiole and/or main rachis and subordered raches are enough in quantity, if the petiole and main pinna rachis exhibit Stipitopterid vascular configuration, and the subordered pinna raches exhibits Stewartiopterid vascular configuration, the frond can be assigned to the genus *Stipitopteris*. If the petiole, main and subordered raches all possess the Stewartiopterid vascular configuration, they can be assigned to *Stewartiopteris*. The present specimens fall into the first condition and thus, they are *Stipitopteris*.

Grand'Eury (1877) found some carbonized or semi-mineralized petioles when he studied the plant fossils of the Stephanian stage in the Saint Etienne area, France. Associated with these petioles are the stems with *Caulopteris*-typed leaf scar and both are adjacent to each other. In the cross-section of the end adjacent to the stem there are the same vascular configurations as that in the *Caulopteris*-typed leaf scar. Thus, Grand'Eury thought that these petioles were assignable to Psaroniaceae and he erected a new genus for them, *Stipitopteris*. Grand'Eury described five species assignable to this genus: *S. aequalis*, *S. delineata*, *S. notata*, *S. punctata* and *S. verrucosa*. Andrews and Doubinger (1970) designated *S. aequalis* as the type species of the genus. Zeiller (1890) described two species, *S. reflexa* and *S. renaulti*, from the Autunian stage of the Early Permian in France, that were probably also carbonized or semi-mineralized fossils. Lenz (1942) reported the first permineralized species of *Stipitopteris*, *S. americana*. The specimens were preserved in coal balls from the Late Carboniferous in Illinois, USA. Morgan and Delevoryas (1952b) reported the second permineralized species of *Stipitopteris*; *S. gracilis*, the specimens of which came from coal balls of the Late Carboniferous in Indiana, USA. Stidd (1971) described the petioles and raches in the coal balls from the Late Carboniferous in America, which might belong to the stems *Psaronius blicklei*, *P. melandrus* and *P. chasei*. The petioles and raches of *P. melandrus* and *P. chasei* are of the Stipitopterid type.

In the above species of *Stipitopteris*, the seven species in France were difficult to compare with the specimens here, because few anatomical features were revealed. In the American species, the inner vascular bundle of *Stipitopteris americana*, *S. gracilis*, *Psaronius melandrus* and *P. chasei* was small and nearly W-shaped, situated near the adaxial side of the outer cycle. In contrast, the specimens in this paper exhibit a large and shallow C-shaped inner vascular strand, situated in the center of the outer strand. Besides the vascular configuration, the American species and the specimens in this paper are obviously different in the anatomy of other tissues. In *S. americana*, beneath the epidermis is a zone of large thin-walled parenchymatous cells, internal to which is a zone of small parenchymatous cells with cellular contents, and then vascular bundles. In *S. gracilis* and the petioles and raches of *Psaronius melandrus* and *P. chasei*, beneath the epidermis is a zone of sclerenchymatous cells, then the ground tissue, and finally the vascular bundles. However, in our specimens the anatomical structure was more complicated than that of the American species. Beneath its epidermis is the parenchyma zone, consisting of large tannin-like cells and small parenchymatous cells without cellular contents; the next is the sclerenchyma zone, followed by the ground tissue, and finally, the vascular bundles. Moreover, the cells of the ground tissue of the present specimens are vertically elongated; however there is no description about this feature in the American species , which make it difficult to compare them.

In conclusion, the present specimens are distinguished from the known species of *Stipitopteris*, thus a new species, *S. shanxiensis*, is erected.

Discussion

Until now, studies on the anatomically-preserved petiole and rachis of Psaroniaceae were mainly focused on the Euramerican Flora (Grand'Eury 1877; Zeiller 1890; Lenz 1942; Morgan and Delevoryas 1952a, b; Snigirevskaya 1967; Stidd 1971). However no studies have been conducted on the Cathaysian Flora and Gondwana Flora. This paper is the first formal report on the study of the petiole and rachis of Psaroniaceae in the Cathaysian flora.

An important aim of paleobotany is to reconstruct fossil plants, and, based on this, fossil plants are classified into natural or nearly natural taxa with biological significance. However, plant fossils are generally preserved as isolated organs, such as stems, leaves, fertile organs and so on, that are not connected with each other. In these circumstances, the first step to study the isolated organs in detail and to assign them into different organ genera and organ species is necessary. Certain isolated organs are considered to belong to the same kind of plant because they share the similar or same anatomical structures. Finally, the whole plant is reconstructed, which leads to the erection of the natural taxon. In the coal balls from Shanxi, there are different kinds of organs of Psaroniaceae and there are more than one species for each kind of organ, which means that there are more than one natural species of Psaroniaceae in Shanxi coal balls. Under these circumstances, it is appropriate to classify the isolated organs and erect the organ genus or species before the relationships between the different organs are known. The new species in this paper is the third formally reported organ species of Psaroniaceae in Shanxi coal balls. The other two formally reported organ species are all the fertile pinnules, such as *Scolecopteris sinensis* (Zhao 1991) and *S. shanxiensis* (Wang et al. 1999).

The obvious differences between the new species and the species of *Stewartiopteris* and *Stipitopteris* and the unnamed crosiers in the Euramerican Flora are as follows. In the new species a parenchyma zone is located beneath the epidermis, followed by a sclerenchyma zone, and the inner vascular bundle is larger, whereas in the Euramerican species the sclerenchyma zone or even the vascular bundle is located beneath the epidermis (except this is different in *S. americana* from the new species in that it lacks a sclerenchyma zone) and the inner vascular bundle is smaller. We can't be sure at present whether these two differences have any phylogenetic significance, thus it is necessary to study more specimens of the petioles and raches of Psaroniaceae from the Cathaysian Flora, including those from the Upper Carboniferous and the Upper Permian.

Similar to the crosiers of *Psaronius* described by Stidd (1971), the new species exhibits well-developed scales on the surface. However the scales of crosiers are better developed and much denser than those of the new species. As mentioned above, the present specimens can not be crosiers. There are two ways to explain this phenomenon. First, although the present specimens are not crosiers, they might be the raches of a young stretched frond, so it has some scales but they might disappear when the frond gets old. Second, the scales might be one of the important taxonomical features of the new species, which means that there are also scales in the mature frond. The correct explanation requires more specimens of petioles and raches of Psaroniaceae from the Cathaysian Flora to be found and studied.

Materials and Methods

Materials are permineralized plant fossils preserved in coal balls, including four specimens that might be the main raches, and two that might be the subordered raches. The mineral component of the coal balls is mainly carbonate. A peeling method (Galtier and Phillips 1999) was used to deal with the preparation of the coal balls. The coal balls were collected from an outcropt of Coal Seam No.7 near the Xindao Village that is west and ca. 4.5 km away from the the Ximing Coal Mine in Xishan Coal-field, Taiyuan, Shanxi Province. Coal Seam No.7 is located in the upper part of the Taiyuan Formation and belongs to the *Pseudoschwaggerina* zone and its age is the early Early Permian (Sakmarian). Geological information, such as the constitution of the floras of the Taiyuan Formation, the fossil plants in the coal balls and the sedimental environment of Coal Seam No.7 is detailed in the following works: Pan et al. (1985), Zhang (1987), Tian and Wang (1995), Tian et al. (1996) and is not mentioned in the present paper.

The peels containing fossils were made into transparent slides using neutral resin. Photographs were taken using microscopes with digital camera systems. Images were adjusted by using Photoshop (7.0) and were then constructed by using Corel-DRAW (v.12). The diagram of the rachis was also constructed by using Corel-DRAW (v.12).

The coal balls and slides investigated in this paper are deposited in the Paleobotanical Department of the National Herbarium, Institute of Botany, the Chinese Academy of Sciences.

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