THE USE OF STIPE CHARACTERS IN FERN TAXONOMY II

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Abstract: Based on the study of Taiwan ferns, both the external and microscopic characters of fern stipes are described and discussed. Family and genus concepts are also considered in the sense of the vascular structures which include the number and shape of bundles, and the configuration of xylem strands in the stipe.

INTRODUCTION

In our previous paper (1977) we listed some characters of fern stipes and based on these characters we presented a multiple choice key to the genera and or families of Taiwan ferns. In this paper we are giving a more detailed study of the stipe characters and listing the genera or families in which these characters are present. The names of the genera and families used in our papers follow those used in volume one of the Flora of Taiwan by Li *et al.* (1975). We have found that the stipe characters for the most part support its genera and family concepts. However in the families Dennstaedtiaceae, Pteridaceae and Adiantaceae there is some overlapping of characters. And the distinctions between the stipes of the Aspidiaceae and Dryopteridaceae are not clear.

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MATERIALS AND METHODS

The preparation of stipes for microscopic observation are identical to those given in the previous paper (Lin & DeVol, 1977). Free hand sectioning suffices for most stipes.

The following is a list of fresh specimens which were examined in this study. In addition, slides of stipe cross sections which were collected during the past years in our Department were also observed to confirm some statements.

Osmundaceae:
Osmunda banksiaefolia (Pr.) Kuhn *Liu 1546*
Osmunda japonica Thunb. *Peng 2409*

Schizaeaceae:
Lygodium japonicum (Thunb.) Sw. *NTU campus*

Gleicheniaceae:
Dicranopteris linearis (Burm. f.) Under. *Lin 32*
Diplopterygium chinensis (Rosenst.) DeVol *Peng 2221*

Dicksoniaceae:
Cibotium cumingii Kunze *Wang s. n.* Oct. '*75*

Cyatheaceae:
Alsophila denticulata Bak. *Liu 1671*
Alsophila podophylla Hook. *Lin 25, 30*

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Alsophila spinulosa (Hook.) Tryon *Liu 1801*
Sphaeropteris lepifera (Hook.) Tryon *Liu 1668*

Plagiogyriaceae:
Plagiogyria dunnii Copel. *Peng 2219*
Plagiogyria stenoptera (Hance) Diels *Peng 2408*

Onocleaceae:
Matteuccia orientalis (Hook.) Trev. *Peng 2375*

Blechnaceae:
Blechnum eburneum Christ *Liu 1545*
Blechnum melanopus Hook. *Liu 1608*
Blechnum orientale L. *Lin 31, 37; Liu 1839*
Brainea insignis Hook. *Peng 2213*
Woodwardia japonica (L. f.) Sm. *NTU shading house*
Woodwardia orientalis Sw. *Liu 1838*
Woodwardia unigemmata (Makino) Nakai *Peng 2411*

Dipteridaceae:
Dipteris conjugata Reinw. *Lin 45*

Cheiropleuriaceae:
Cheiropleuria bicuspis (Blume) Pr. *Liu 1790*

Polypodiaceae:
Arthromeris lehmanni (Mett.) Ching *Liu 1326, 1603*
Colysis elliptica (Thunb.) Ching *Liu 1669; Hsu 16857*
Colysis wrightii (Hook.) Ching *Lin 23; Hsu 16858*
Crypsinus echinosporus (Tagawa) Tagawa *Liu 1609*
Crypsinus hastatus (Thunb.) Copel. *Liu 1350*
Crypsinus quasidivaricatus (Hay.) Copel. *Liu 1326A, 1432*
Crypsinus veitchii (Bak.) Copel. *Peng 2399*
Goniophlebium argutum (Wall.) J. Sm. *Liu 1333, 1515*
Lemmaphyllum microphyllum Pr. *NTU campus*
Lepidogrammitis rostrata (Beddome) Ching *Hsu 16805*
Lepisorus megasorus (C. Chr.) Ching *Liu 1319, 1758*
Lepisorus morrisonensis (Hay.) H. Ito *Peng 2468*
Lepisorus obscure-venulosus (Hay.) Ching *Peng 2400*
Lepisorus thunbergianus (Kaulf.) Ching *Liu 1369; Peng 2463; Hsu 16947*
Lepisorus pseudo-ussuriensis Tagawa *Liu 1434*
Lepisorus tosaensis (Makino) H. Ito *Hsu 16955*
Loxogramme formosana Nakai *Hsu 16924A*
Loxogramme grammitoides (Bak.) C. Chr. *Liu 1304*
Loxogramme remote-frondigera Hay. *Hsu 16806*
Microsorium buergerianum (Miq.) Ching *Liu 1659, 1802; Hsu 16945*
Neocheiropteris ensata (Thunb.) Ching *Peng 2404; Liu 1736*
Polypodium amoenum Wall. *Peng 2415*
Polypodium atkinsoni C. Chr. *Liu 1331*
Polypodium transpiauense Yamamoto *Liu 1598*
Pseudodrynaria coronans (Mett.) Ching *Liu 1792*
Pyrrosia lingua (Thunb.) Farw. *Lin 26; Hsu 16803*

Pyrrosia polydactylis (Hance) Ching *Liu 1735*
Pyrrosia sheareri (Bak.) Ching *Peng 2403*

Dennstaedtiaceae:

Microlepia calvescens (Wall.) Pr. *Peng 2222*
Microlepia hookeriana (Wall.) Pr. *Lin 40, 27*
Microlepia marginata (Panzer) C. Chr. *Liu 1660*
Microlepia speluncae (L.) Moore *NTU campus*
Microlepia strigosa (*Thunb.*) Pr. *Liu 1678, 1739*
Microlepia tenera Christ *Liu 1762*
Monachosorum henryi Christ *Liu 1611; Hsu 16842*
Monachosorum maximowiczii (Bak.) Hay. *Hsu 16843*
Pteridium aquilinum (L.) Kuhn subsp. *latiusculum* (Desv.) Shieh *Lin 24*
Pteridium aquilinum (L.) Kuhn subsp. *wightianum* (Wall.) Shieh *Liu 1709*

Lindsaeaceae:

Lindsaea odorata Roxb. *Liu 1499*
Lindsaea orbiculata (Lam.) Mett. ex Kuhn *Lin 34*
Sphenomeris chusana (L.) Copel. *Lin 44*

Davalliaceae:

Araiostegia perdurans (Christ) Copel. *Liu 1328, 1322; Peng 2421*
Davallia mariesii Moore *Liu 1526*
Davallia solida (Forst.) Sw. *Lu s. n.* Aug. 28, '75
Humata pectinata (J. Sm.) Desv. *Lu s. n.* Aug. 28, '75
Humata trifoliata Cav. *Liu 1810*

Pteridaceae:

Cheilanthes farinosa (Forsk.) Kaulf. *Liu 1306*
Cheilanthes tenuifolia (Burm.) Sw. *Peng 2330*
Cryptogramma brunoniana Wall. *Peng 2496*
Onychium contiguum (Wall.) Hope *Liu 1438, 1488, 1523*
Onychium japonicum (Thunb.) Kunze *Liu 1680, 1682*
Pteris ensiformis Burm. *NTU campus*
Pteris excelsa Gaud. *Peng 2410*
Pteris linearis Poir. *Liu 1677*
Pteris longipinna Hay. *Liu 1757; Hsu 16006*
Pteris multifida Poir. *NTU campus*
Pteris scabristipes Tagawa *Liu 1756*
Pteris setuloso-costulata Hay. *Liu 1665, 1760*
Pteris semipinnata L. *Lin 39*
Pteris wallichiana Ag. *Liu 1411, 1747*
Pteris vittata L. *Liu 1753*

Adiantaceae:

Adiantum capillus-veneris L. *NTU campus*
Adiantum edentulum christ *Liu 1768*
Adiantum flabellulatum L. *Lin 38; Liu 1803*
Coniogramme intermedia Hieron. *Liu 1504; Peng 2417*
Gymnopteris vestita (Wall.) Underw. *Hsu 17107*
Pityrogramma calomelanos (L.) Link. *Peng 2217*

Oleandraceae:

Nephrolepis auriculata (L.) Trimen *Lin 42; NTU campus*
Nephrolepis biserrata (Sw.) Schott *NTU shading house*

Aspidiaceae:

Ctenitis apiciflora (Wall.) Ching *Hsu 16840, 16918*
Ctenitis eatoni (Bak.) Ching *Liu 1666*
Ctenitis transmorrisonensis (Hay.) Tagawa *Liu 1428*
Hemigramma decurrens (Hook.) Copel. *Lin 33; Liu 1784*
Pleocnemia winitii Holttum *Lin 43; Liu 1797, 1798, 1799*
Tectaria coadunata (J. Sm.) C. Chr. *Liu 1749*
Tectaria subtriphylla (Hook. & Arn.) Copel. *Peng 2214*

Dryopteridaceae:

Acrophorus stipellatus (Wall.) Moore *Hsu 16837; Liu 1613; Peng 2407*
Arachniodes aristata (Forst.) Tindle *Liu 1710, 1714*
Arachniodes festina (C. Chr.) Ching *Liu 1610*
Arachniodes rhomboides (Wall.) Ching *Lin 28, 35; Liu 1605*
Cyrtomium hookerianum (Pr.) C. Chr. *Peng 2393; Liu 1612*
Dryopteris atrata (Wall.) Ching *Liu 1356; Peng 2419*
Dryopteris austriaca (Jacq.) Woynar *Peng 2406*
Dryopteris barbigera (Moore) O. Ktze. *Peng 2479*
Dryopteris costalisora Tagawa *Liu 1348*
Dryopteris formosana (Christ) C. Chr. *Liu 1487, 1602, 1606; Peng 2420, 2418*
Dryopteris hypophlebia Hay. *Liu 1767*
Dryopteris paleacea (Sw.) C. Chr. *Peng 2402*
Dryopteris scottii (Beddome) Ching *Peng 2395*
Dryopteris serrato-dentata (Beddome) Hay. *Peng 2456*
Dryopteris sordidipes Tagawa *Peng 2210*
Dryopteris varia (L.) O. Ktze. *Lin 41; Liu 1308, 1318, 1800*
Dryopteris wallichiana (Spr.) Alston & Bonner *Peng 2401*
Leptorhumohra quadripinnata (Hay.) H. Ito *Liu 1436; Hsu 16841*
Peranema cyatheoides Don *Hsu 16838*
Polystichum deltodon (Bak.) Diels *Liu 1525*
Polystichum falcatipinnum Hay. *Liu 1441*
Polystichum hancockii (Hance) Diels *Liu 1599, 1615; Hsu 16844*
Polystichum lepidocaulon (Hook.) J. Sm. *Liu 1711*
Polystichum neolobatum Nakai *Liu 1713*
Polystichum stenophyllum Christ *Liu 1416; Peng 2469*

Thelypteridaceae:

Christella acuminata (Houtt.) Lév. *Liu 1535; NTU campus*
Christella dentata (Forsk.) Brownsey & Jermy *NTU campus*
Christella parasitica (L.) Lév. *NTU campus*
Chrisella subarida (Tatew. & Tagawa) Holttum *Kuo 6349*
Dictyocline griffithii Moore *Liu 1786, 1795*
Leptogramma tottoides H. Ito *Liu 1489, 1490*
Metathelypteris gracilescens (Blume) Ching *Liu 1601*
Parathelypteris beddomei (Bak.) Ching *Liu 1494*
Phegopteris decursive-pinnata (van Hall) Fée *Liu 1486*

Pneumatopteris truncata (Poir.) Holttum *Peng 2216*
Pronephrium triphyllum (Sw.) Holttum *Liu 1787*
Pseudophegopteris hirtirachis (C. Chr.) Holttum *Liu 1498*
Pseudocyclosorus esquirolii (Christ) Ching *Liu 1501, 1503, 1507*
Sphaerostephanos taiwanensis (C. Chr.) Holttum *Liu 1804*

Athyriaceae:
Athyriopsis japonica (Thunb.) Ching *Liu 1530; Peng 2212*
Athyrium anisopterum Christ *Liu 1321*
Athyrium arisanense (Hay.) Tagawa *Liu 1316, 1421, 1422, 1493*
Athyrium cryptogrammoides Hay. *Liu 1418*
Athyrium nakanoi Makino *Liu 1614*
Athyrium oppositipinnum Hay. *Liu 1437*
Athyrium tozanense Hay. *Liu 1420, 1440*
Cornopteris fluvialis (Hay.) Tagawa *Liu 1512; Peng 2422*
Cystopteris tenuisecta (Blume) Mett. *Liu 1419*
Dictyodroma formosana (Rosenst.) Ching *Liu 1617*
Diplaziopsis javanica (Blume) C. Chr. *Hsu 16927*
Diplazium dilatatum Blume *Lin 29*
Diplazium donianum (Mett.) Tard.-Blot. *Lin 21; Liu 1791*
Diplazium kawakamii Hay. *Liu 1492*
Diplazium megaphyllum (Bak.) Christ *Peng 2215*
Diplazium pseudo-doederleinii Hay. *Peng 2423*
Diplazium subsinuatum (Wall. ex Hook. & Grev.) Tagawa *Liu 1781, 1796*
Diplazium wichurae (Mett.) Diels *Peng 2413*
Lunathyrium pycnosorum (Christ) Koidz. *Peng 2401A*
Pseudocystopteris atkinsoni (Beddome) Ching *Liu 1414*
Woodsia polystichoides Eaton *Liu 1347*

Aspleniaceae:
Asplenium ensiforme Wall. ex Hook. & Grev. *Hsu 16924*
Asplenium cuneatum Lam. *Liu 1793*
Asplenium laciniatum Don *Liu 1737; Hsu 16935*
Asplenium nidus L. *Liu 1789*
Asplenium normale Don *Hsu 16807, 16932*
Asplenium trichomanes L. *Liu 1305*
Asplenium varians Wall. ex Hook. & Grev. *Liu 1346A*
Asplenium wilfordii Mett. ex Kuhn *Liu 1616; Peng 2416*
Asplenium wrightii Eaton *Liu 1748*

OBSERVATIONS AND DISCUSSION

A character is considered to be good if it is both convenient to use and significant. Some characters such as spores and karyotypes are not easily observed but are so meaningful that they are worth the effort expended to prepare them. In our study of ferns, the abundance of stipe materials and the ease with which they can be prepared for study have been the chief motivating factors in our selecting of this organ for research. We began with characters which were easily observed and clear-cut, and thereafter found that many of them were significant both for identification and classification.

The external features of the stipe (Table I) are generally not so readily distinguishable as

Table 1. External characters of fern stipes

Character / Family	Color			Groove	Wing	Aerating structure				Articulation	
	green	Ad-green Ab-purple	purple			stoma	aerophore		lateral line	stipe base	pinna base
							globose	linear			
Osmundaceae	+				*	+					+
Schizaeaceae	+				+						
Gleicheniaceae	÷		+	+							
Dicksoniaceae	+	+		+				+			
Cyatheaceae	+	+	+	+				+			
Plagiogyriaceae	+				+		+				
Onocleaceae	+			+					+		
Blechnaceae	+	+		+					+		
Dipteridaceae			+	+							
Cheiropleuriaceae	+				+						
Polypodiaceae	+	+	+		**					+	+
Dennstaedtiaceae	+	+	+	+	+				+		
Lindsaeaceae	+			+	+						
Davalliaceae	+				+				+	+	
Pteridaceae	+	+	+	+	+				+		
Adiantaceae	+	+	+	+					+		
Oleandraceae	+			+					+	+	+
Aspidiaceae	+	+	+	+					+		
Dryopteridaceae	+	+	+	+					+		
Thelypteridaceae	+			+			+		+		
Athyriaceae	+	+	+	+					+	***	
Aspleniaceae	+	+	+	+	+				+		

Ab=abaxial side, Ad=adaxial side.
* Wings are stipular-like and occur only at the base.
** Decurrent leaf bases.
*** Only found in *Woodsia*. See the context.

the internal anatomical constituents and therefore not so easily used in taxonomy.

COLOR—Green stipes appear in nearly all the families, which may have brown streaks or brown bases and usually turn brown with age.

The purple stipe which may or may not be polished is found in *Dicranopteris linearis*, *Diplopterygium chinensis*, *Dipteris conjugata*, *Pityrogramma calomelanos*, *Monachosorum maximowiczii*, and in most species of *Adiantum* and *Cheilanthes*, together with some species of *Alsophila*, *Crypsinus*, *Loxogramme*, *Pteris*, *Polystichum*, *Hemigramma*, *Athyrium*, and *Asplenium*.

Stipes which are green on the adaxial side and purple on the abaxial side are found in species of *Alsophila*, *Blechnum*, *Goniophlebium*, *Polypodium*, *Microlepia*, *Pteris*, *Coniogramme*, *Arachniodes*, *Cyrtomium*, *Dryopteris*, *Pleocnemia*, *Polystichum*, *Diplazium*, and *Asplenium*.

AERATING STRUCTURES—The occurrence of a lateral continuous aeration line on the sides of a stipe is a common condition in the Blechnaceae, Aspidiaceae, Dryopteridaceae, Thelypteridaceae, Athyriaceae, *Matteuccia* and *Nephrolepis*. In the Dennstaedtiaceae, Pteridaceae,

Adiantaceae and Aspleniaceae, the aeration lines appear on the green stipes, but not on the purple or winged stipes. In the Davalliaceae, the wings of the same species are either parenchymatous or sclerotic, those that are sclerotic often have a region of parenchyma tissue on the lateral sides which appear as pale lines externally. The parenchymatous epidermis and wings are thought to have an aerating function. But an aerating system in ferns having purple stipes or having sclerified wings has not been observed.

Stomata are scattered on the epidermis of the stipes of *Osmunda* (Ogura, 1972). Globose aerophores are present on *Plagiogyria*, and patch-like aerophores which occur in a long broken lateral line are found on the stipe of the Cyatheaceae and *Cibotium*.

Globose or elongated aerophores at the pinna base are seen in *Pneumatopteris*, *Sphaerostephanos* and *Cyclogramma* (Holttum, 1971), strictly speaking these are not stipe characters, but are mentioned here since they occur as aerating structures.

ARTICULATION—A clear-cut articulation at the stipe base is not usual but it is found in the Davalliaceae, *Woodsia*, and many species of the Polypodiaceae. In the Davalliaceae and most species of *Arthromeris*, *Crypsinus*, *Goniophlebium*, *Lemmaphyllum*, *Lepidogrammitis*, *Lepisorus*, *Microsorium*, *Neocheiropteris*, *Polypodium*, *Pyrrosia*, and some species of *Colysis* (e. g. *C. elliptica*) and *Loxogramme* (e. g. *L. remote-frondigera*), stipes articulate to a phyllopodium but not directly to the rhizome.

Stipes of *Woodsia* may or may not have articulations and which occur at various positions, depending on the species. Diversities in the articulation and stipe color have been used as criteria for recognizing sections in this genus (Ching, 1932). The only species in Taiwan, *Woodsia polystichoides*, is articulated near the top of the stipe.

Pinna bases are articulated to the rachis in *Arthromeris*, *Nephrolepis* and *Osmunda*, this character is also found in *Arthropteris* (DeVol & Kuo, 1975). In many species of *Adiantum*, the pinna stalk is left on the rachis when the pinna blade falls. It is possible that the change in texture from the stiff, wiry pinna stalk to the herbaceous blade is the cause for the pinna blade falling at this junction, and this may not be a true articulation. The same situation is seen in species of *Asplenium* which have dark purple stipes.

VASCULAR STRUCTURE—The number of vascular bundles is a constant character in the cross section of stipes. According to the number of bundles, ferns can be divided into five categories (Table 2). The shape of the bundle and the configuration of xylem strands further distinguish the members in each grouping.

i. Stipes with one vascular bundle at base and more bundles above

Dipteris and *Cheiropleuria* differ from all other ferns in having more bundles and a much more complicated vascular structure in the upper portion of the stipe than in the lower. The single bundle at the stipe base of these two genera divides a number of times and all these resulting bundles project into the leaf blade. In other words, they lack a midrib which is common in most other ferns. But they are different from each other in several respects.

The stipes of *Dipteris* are very stiff being full of sclerenchyma. They are grooved on their adaxial sides, and have narrow dark stiff scales at the base. In the cross section, the basal part of the stipe has only a single vascular bundle which is a curve and opens towards the adaxial side with inrolled ends (Fig. 1). The bundle becomes lobed and then divides into two curved bundles which are the mirror images of each other as it approaches the upper section of the stipe (Fig. 2-3). Since this lobe-dividing process occurs several times, there are two series of four bundles (Fig. 4-6) at top of the stipe and each series runs into one of the equal divisions of the leaf blade.

The stipe of *Cheiropleuria* is brownish, glossy and slightly winged. Multicellular yellow hairs are present on the base. The cross section is terete at the base and becomes smaller,

Table 2. Number of vascular bundles in fern stipes

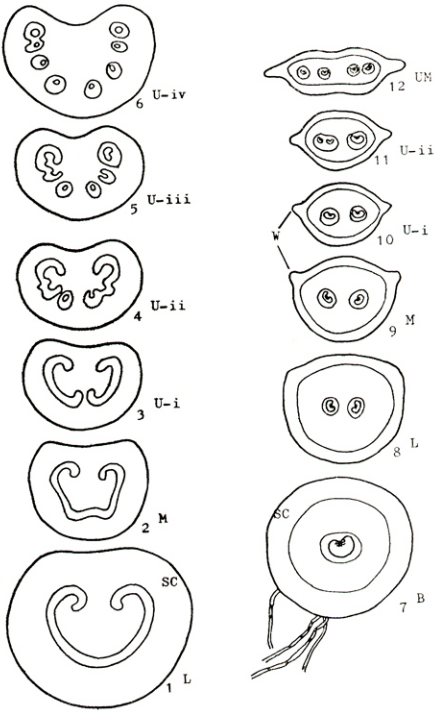
Number of bundles			
upper: several base: 1	1 throughout	upper: 1 base: 2	3 or more
Dipteridaceae	Osmundaceae		Cyatheaceae
Cheiropleuriaceae	Gleicheniaceae		Dicksoniaceae
	Plagiogyriaceae		
	Schizaeaceae		
	Lindsaeaceae	Lindsaeaceae	
	Adiantaceae	Adiantaceae	
	Dennstaedtiaceae	Dennstaedtiaceae	Dennstaedtiaceae (*Pteridium*)
	Pteridaceae	Pteridaceae	
		Onocleaceae	
		Blechnaceae	.....
		Athyriaceae	Athyriaceae
		Thelypteridaceae	Dryopteridaceae
			Aspidiaceae
		(hippocampus)	
		.....	
		(non-hippocampus)	
		Polypodiaceae	Polypodiaceae
		Davalliaceae	Davalliaceae
		Aspleniaceae	Oleandraceae

flattened and winged (Fig. 7–12). The only vascular bundle at the stipe base is terete with a reniform xylem strand which soon divides into two terete bundles with a banded xylem strand in each. These two bundles run through the major length of the stipe until very near the blade, where they divide again into four terete bundles. Each of these terete bundles has a banded xylem strand with only one protoxylem group which is on the middle of the adaxial side. The cell walls of outer cortex and the outer tangential walls of endodermis are thickened and lignified.

ii. Stipes with numerous bundles in diverse patterns (Cyatheaceae and *Cibotium*)

Since tree ferns form a very interesting group of ferns, the anatomy of the Cyatheaceae has received more attention and for a longer time than most other ferns. (Ogura, 1927; Holttum & Sen, 1961; Sen, 1964; Lucansky, 1974a, b, 1976; Lucansky and White, 1974, 1976). The vascular structure as well as many other aspects of these ferns is quite unique in the fern world. Vascular bundles in the stipe are usually numerous, arranged in three or four wavy series, one or two on the adaxial side and two on the abaxial side. In some of the young plants of *Alsophila*, there are only three or four terete bundles which are about equal in size and each has a wavy xylem strand.

Both the external and internal microscopic characters of the *Cibotium* stipes are similar to those of the Cyatheaceae. The stipe bases of *Cibotium* are covered with a mass of very long, multicellular, yellow hairs. Scales which are so plentiful and constitute such an important character in the Cyatheaceae are not found on *Cibotium*. In *Cibotium*, the three series of bundles usually unite into a single continuous wavy curved line from the middle stipe upwards. And this condition can usually be found in the upper stipe or rachis of the Cyatheaceae.



Key to labeling: AL-aeration line, B-basal part, L-lower part, M-middle part, PA-parenchyma, PT-pinna trace, SC-sclerenchyma, U-upper part, UM-uppermost part, W-wing.

Fig. 1-12. Cross section of stipes, showing the dividing process of a vascular bundle. 1-6. **Dipteris conjugata** ×8.5, 7-12. **Cheiropleuria bicuspis** ×19. Dots indicate the location of protoxylem groups.

iii. Stipes with one vascular bundle traversing the entire length of the stipe

The cross sections of *Osmunda* stipes show a curved bundle which opens towards the adaxial surface of stipe and curls inwards at its ends (Bertrand & Cornaille, 1902). Tannin-filled cells are scattered in the phloem and pericycle (Lin & DeVol, 1977. Fig. 10). Sclerenchyma is found in the outer cortex and sometimes along the inner side of the bundle.

In the Gleicheniaceae, the shape of the bundle is similar to that of *Osmunda* but joins at its adaxial ends very often as illustrated by Bower (1923-1928, Vol. 1. Fig. 164). Sclerenchyma occupies a large portion of the cortex except at the stipe base where it only surrounds the bundle. Tannin-filled cells are not seen, but the cell walls in the cortex usually contain tannin.

The Taiwan species of *Plagiogyria* can be distinguished by their stipe characters (DeVol, 1972). The cross sections of the stipes show several patterns that are not usually seen in other fern families. The cross sections may be triangular, tetragonal or oval. The vascular bundle varies from V-shaped to U-shaped with extended ends. These features are usually different in the lower stipe from the upper portions of a stipe. The metaxylem is usually of a single cell layer, and the protoxylem is grouped in clusters. The endodermis and cortical parenchyma usually contain dark-stained cell contents. The epidermis is parenchymatous or slightly lignified. Sclerenchyma in the outer cotex is next to the epidermis or separated from it by two to six layers of parenchyma. Around the bundles the sclerenchyma is especially thickened in the central concavity on the adaxial side.

The stipe characters of the Osmundaceae, Gleicheniaceae and Plagiogyriaceae are distinctive and coincide with their other characters to give the concept that they are primitive and natrual families (Bower, 1923-28; Copeland, 1947).

Lygodium japonicum, a common fern in Taiwan, shows a terete cross section with raised wings from the adaxial side. The cortex is filled with sclerenchyma. A rounded or angular xylem core occupies the major portion of the single terete vascular bundle. Ogura (1972) described all the four genera of the Schizaeaceae as having a single bundle in the stipe but they vary greatly in shape. *Anemia* and *Mohria* have a U-or C-shaped bundle. Bundles are terete in *Schizaea* but the xylem strand is a curved band in *S. digitata* and is T-shaped in some other species. Stipe characters as well as the other characters reveal great diversity in this family.

The stipe anatomy of the Lindsaeaceae shows uniformity. Sclerenchyma fills the basal part of the stipe but gradually becomes concentrated in the outer cortex and wings in the upper stipe. Parenchyma tissue with dense cytoplasmic contents surround the bundle like a band, which is narrow at the base and broadens upwards (Fig. 15-18). The vascular bundle is terete or heart-shaped. The xylem strand is mostly V-shaped and hooked at the adaxial ends, which may break at the middle into two hippocampus-shaped strands. The cross sections of three species are oval at the base but are tetragonal in *Lindsaea orbiculata* (Lin & DeVol, 1977. Fig. 7), rounded-triangular in *Lindsaea odorata* (Fig. 17), and oval in *Sphenomeris chusana* (Fig. 16). Some stipes of *Lindsaea odorata* have two oval bundles at the base, and these contain a hippocampus-shaped xylem strand in each (Fig. 18).

The Adiantaceae, Dennstaedtiaceae and Pteridaceae show great similarity in respect to their stipe characters (Table 3). Purple stipes are more abundant in this group than in other groups of ferns. The cross sections of the stipes are often terete. The xylem strands are usually hippocampus-shaped. Some stipes have a single bundle, and others have two bundles in the lower stipe which unite in the upper portion of the stipe or in the rachis. The shape of a single bundle or the united upper one varies greatly, but is usually constant for a genus. However in *Pteris*, it is a species character, where various types of bundles are found (Fig. 22-26, 28-29).

Table 3. Stipe characters in the Adiantaceae, Dennstaedtiaceae, and Pteridaceae

Character / Genus	Color			Groove	Wing	Scale	Hair	Shape of vascular bundle				
	green	Ad-green Ab-purple	purple					∂	U	V	X	terete or lobed
Adiantum			+	+		+					+	+
Cheilanthes			+	+		+				+		+
Coniogramme	+	+		+		+		+				
Cryptogramma			+	+		+						+
Gymnopteris			+				+					+
Microlepia	+	+		+			+		+	+		
Monachosorum	+		+		+	+			+	+		
Onychium	+			+	+	+						+
Pityrogramma			+	+		+			+			
Pteris	+	+	+	+	+	+	+	+	+	+		

Ab=abaxial side, Ad=adaxial side.

Pteridium aquilinum shows a rather diversified pattern of vascular arrangement. There are more than twenty bundles in the cross section of the stipe. They differ in size and shape, and may be round, linear, V-shaped or irregularly branched (Fig. 27). Tracing these bundles up into the rachilla, we find their arrangement becomes simpler, and forms a discontinous curve with about seven bundles. This curve is smaller but is similar in form to the bundle shape of the large species of *Pteris*, such as *Pteris wallichiana* (Fig. 28-29).

The boundaries between the stipe characters for the above three families are not striking, yet most of their genera can be identified by their external and anatomical characters (Lin & DeVol, 1977).

iv. Stipes with two vascular bundles at the base and one in the upper part

In addition to the Adiantaceae, Dennstaedtiaceae and Pteridaceae, there are ferns of seven families in this group (Table 2), which are distinguishable by stipe characters (Lin & DeVol, 1977). The cross sections are usually terete. The vascular bundles are oblong, with their long axis parallel to the lateral side (Fig. 30, 32), or are terete (Fig. 45) in the lower stipe, and unite upwards.

Matteuccia, *Blechnum*, *Woodwardia*, the Athyriaceae and the Thelypteridaceae have hippocampus-shaped xylem strands. The upper united bundle is U- or V-shaped (Fig. 31, 33). The non-hippocampus strands of xylem occur in the Polypodiaceae, Davalliaceae, and Aspleniaceae. Their upper united bundle is V-shaped, X-shaped, terete, or lobed (Fig. 51, 52, 55).

In *Asplenium*, stipe characters show great diversity. The stipe may be winged or not. Cross sections may be terete or triangular. Vascular bundles are terete or oblong in the lower portions of stipe. The oblong or longer bundles usually unite into an X-shaped bundle in the upper portions of stipe (Lin & DeVol, 1977, Fig. 8-9), and the terete or shorter ones usually unite to form a rounded or somewhat lobed bundle (Fig. 44-45). The only common feature is the non-hippocampus configuration of the xylem strand, which forms an X-shaped or four-armed figure as they unite.

v. Stipes with three or more vascular bundles forming an arc

These ferns contain a network of vascular bundles throughout their stipes. In the cross sections, there are two larger adaxial bundles with one or more smaller bundles lying between.

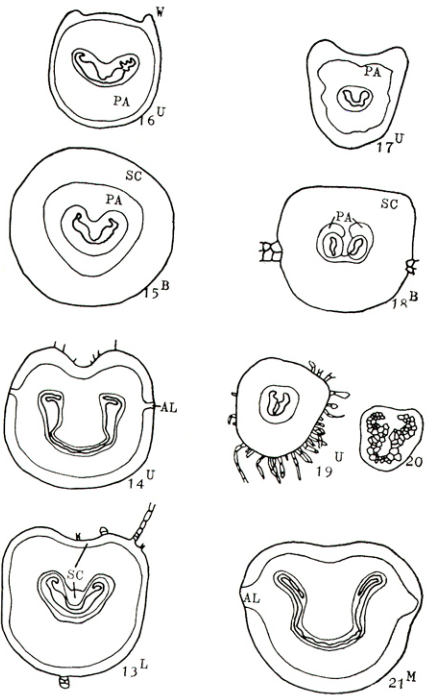


Fig. 13-21. Cross section of stipes. 13. **Microlepia hookeriana** with a V-shaped bundle, ×27; 14. **Microlepia speluncae** with a U-shaped bundle, ×10; 15-18. differences in cortex components between lower aud upper stipes of Lindsaeaceae; 15-16. **Sphenomeris chusana** with heart-shaped bundle, ×17; 17-18. **Lindsaea odorata** with terete bundle, ×41; 19-20. **Gymnopteris vestita**, 19. ×32, 20. terete bundle of 19. showing the details of xylem, ×48; 21. **Coniogramme intermedia**, curved bundle with extended ends, ×11.

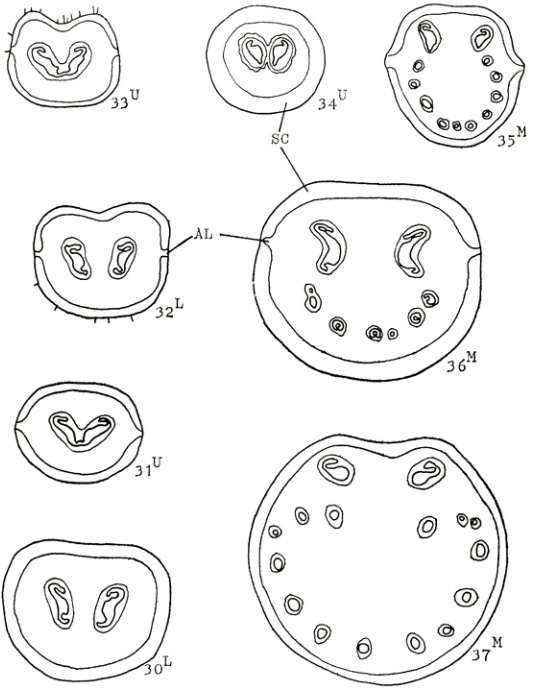


Fig. 22-29. Cross section of stipes. 22. **Pteris vittata** with U-shaped bundle and hippocampus xylem configuration, ×13; 23-24. **Pteris semipinnata**, U-shaped bundle with extended ends, ×18; 25-26. **Pteris multifida** ×18; 27. **Pteridium aquilinum latiusculum** ×7.5; 28-29. **Pteris wallichiana**, curved bundle with extended ends, ×6.

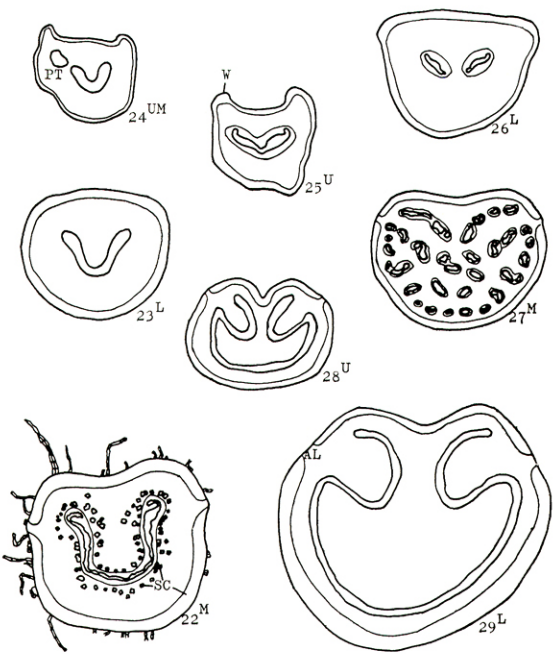


Fig. 30-37. Cross section of stipes, showing hippocampus-shaped xylem configuration and diversities of vascular structure. 30-31. **Woodwardia japonica** ×20, 32-33. **Christella acuminata** ×13, 34. **Blechnum eburneum** ×28, 35. **Brainea insignis** 36. **Woodwardia orientalis** 37. **Blechnum orientale**, 35-37. ×6.

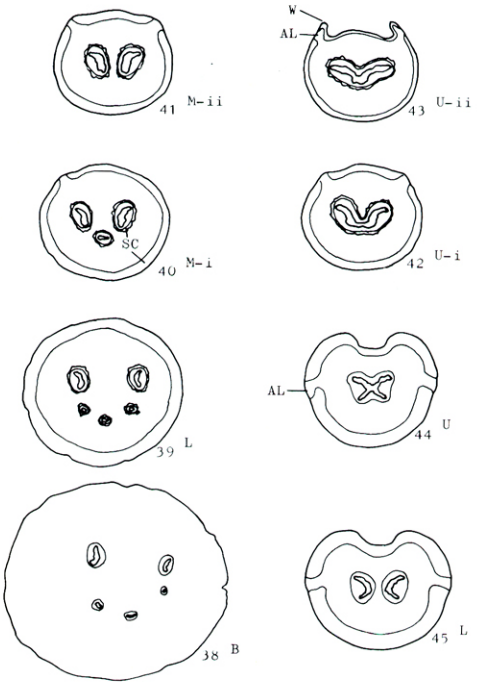


Fig. 38-45. Cross section of stipes, with non-hippocampus xylem configuration. 38-43. serial changes of vascular structure in **Davallia mariesii** ×13. 44-45. **Asplenium wilfordii** ×19. 44. with lobed bundle. 45. with terete bundles.

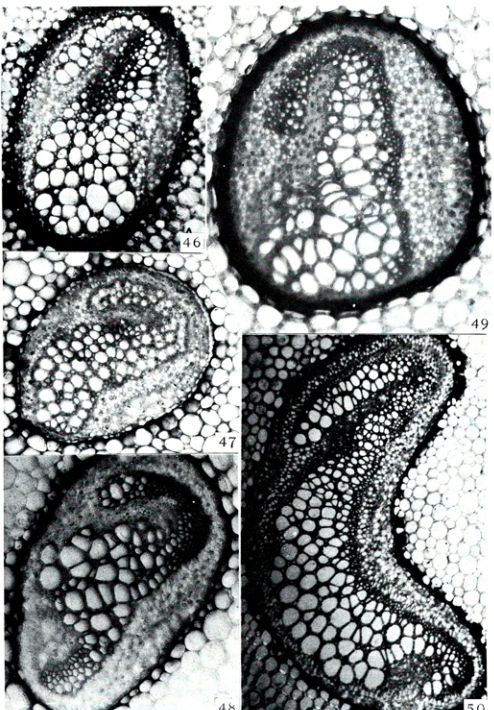


Fig. 46-50. Hippocampus xylem configuration in adaxial bundle. 46. **Blechnum orientale** ×60, 47. **Pleocnemia winitii** ×50, 48. **Blechnum melanopus** ×130, 49. **Arachniodes rhomboides** ×150, 50. **Woodwardia orientalis** ×60.

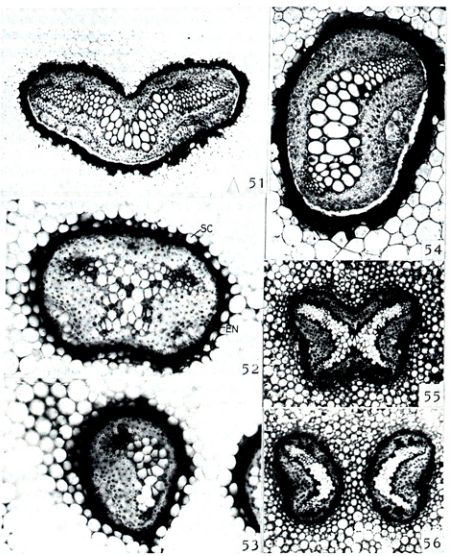


Fig. 51-56. Non-hippocampus xylem configuration. 51, 54. **Davallia mariesii**, 51. ×45, 54. ×80; 52-53. **Crypsinus echinosporus** ×90; 55-56. **Asplenium wilfordii** ×100.
Two bundles in lower (53, 56) or middle (54, of the two bundles) stipe unite in the upper portion (51, 52, 55) to form a V-shaped (51), terete (52), or lobed (55) bundle with V-shape (51) or 4-armed (52, 55) xylem strand.

The use of the number of bundles meets its limitation in these ferns. Different number of bundles are found in stipes of different species, size, and even on the same plant. There are usually more bundles in the lower stipe than in the upper portions. The shape of the arc is not identical but the differences can hardly be recognized. Their most distinguishable feature is the configuration of xylem strands in the larger adaxial vascular bundles. The Blechnaceae, Athyriaceae (in *Diplazium pseudodoederleinii*), Dryopteridaceae and Aspidiaceae have hippocampus-shaped xylem strands, with hooked ends on their adaxial side (Fig. 46–49) and rarely on the abaxial end (Fig. 50). This group of ferns are not easily separated on the basis of stipe characters. Whereas in the Polypodiaceae, Davalliaceae, and *Nephrolepis*, the xylem strands are not hippocampus-shaped, and are more or less curved towards the lateral sides and may unite to form a V- or X-shaped entity (Fig. 51–56).

Among the non-hippocampus ferns, a close relationship between the Davalliaceae and *Nephrolepis* has been proposed in many systems (Ching, 1940; Copeland, 1947; Alston, 1956; Pichi Sermolli, 1958; Holttum, 1973; Crabbe et al., 1975). The Polypodiaceae and Davalliaceae differ in many aspects of their reproductive and vegetative structures, but they are similar in their stipe characters which distinguish them from other ferns. In addition to the xylem configuration, they are common in having an articulation between the stipe base and phyllopodium or rhizome, and in having non-lignified epidermal cells. An articulation at the pinna base is found in the Oleandraceae as well as in some of the Polypodiaceae. *Asplenium* has been proposed to be related to the Athyrioid ferns (Christensen, 1938; Ching, 1940; Pichi Sermolli, 1958; Crabbe et al., 1975), but has not been accepted and placed close to the Blechnaceae instead (Copeland, 1947). Alston (1956) has noticed the similarity in spores, sporangia and stipe anatomy between the Polypodiaceae and Davalliaceae. And we find no pteridologist except Holttum (1949, 1973, and in recent personal communication) that considers the Polypodiaceae, Davalliaceae and Aspleniaceae to be allied.

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