STRUCTURE OF PODOPHYLLUM PELTATUM L.

by

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Maps

Histology of Podophyllum peltatum, Lin.

In the following pages, results of a microscopic examination of the rhizome and roots of Podophyllum peltatum, Lin., of the Barberry family, are given, in the hope of adding something to the recorded knowledge of this plant, which seems not to have been much studied in detail.

Literature

Some of the more important articles which have been published relating to this plant, are:

F. B. Power, Proceedings of the American Pharmaceutical Association, Vol. 25, p. 420; general article on the constituents of the plant, including a short sketch of the structure of the rhizome.

E. S. Bastin, American Journal of Pharmacy, Vol. 66, page 417; "Structure

of Podophyllum"; an eight-page article on the histology of the rhizome and roots. A general account, not going into minutiæ, but much more completely than the others noticed.

D. H. Campbell, Botanical Gazette, Vol. 14, p. 199; "Nuclear Division." A brief study of nuclear division as illustrated in stained pollen grains of Podophyllum peltatum and Allium canadense.

Literature

A. F. Foerste, Botanical Gazette, Vol. 19, p. 465; brief article on the aestivation of the flower.

Wm. A. Saunders, Proc. Amer. Pharm. Ass'n, Vol. 15, p. 379; "Relative Value of Rhizome and Roots." An account of an experiment which resulted in showing the rhizome and roots to have equal value in the

amount of resin present, provided the roots are clean.

Podophyllum peltatum has in different parts of the country various common names, of which mayapple and mandrake are the most important. The former is considered the more nearly correct, and is the synonym used in The U. S. Pharmacopoeia.

Nomenclature

According to Culbreth, the name podophyllum, from two Greek words meaning foot and leaf, derives its significance from the resemblance of the leaf to the foot of agnatic birds or domestic fowls, as ducks, while peltatum, Latin peltatus, having a pelta or light shield, refers to the manner of attachment of the petiole to the

middle of the leaf. May apple indicates the blooming of the plant in May, thus starting the fruit, which ripens late in summer.

This plant early became known for its medicinal properties, having been used and mentioned in medical literature as far back as . It was employed in the treatment of various diseases, chiefly on account of its cholagogue and cathartic properties, and as an alterative. It is still used, but to a less extent. The dried rhizome and roots are an official drug in the U.S. Pharmacopoeia, the official remedies derived from it being the solid and fluid extracts, and the resin. History.

The may apple is indigenous to and common in the northern

portion of the United States and in Canada. It flourishes in rich woodlands and thickets, the plants occurring usually in patches of more or less dense growth. This species is reported to have been found on a mountain in Japan. Habitat.

The mayapple is a perennial herb, having an underground stem, or rhizome, growing two or three inches underneath the surface to a length of several feet, the rear portion dying as the shoot advances. The rhizome consists of a nearly cylindrical series of joints, about 6 or 7 mm. in thickness and from 3 to 10 or 12 centimeters in length. The nodes are thickened to a diameter of 10 or 12 millimeters. It is found in the market in pieces from 7 to 20 cm. long. The roots, being Exterior of plant

fragile, are usually wanting in the drug. The nodes are roundish, having on the upper side circular cup-shaped depressions, the scars of former upright stems. Below and on the sides are about 8 to 12 nearly simple roots, little branched at or near the nodes, but more freely near the ends. The roots average in thickness at the rhizome 1½ to 2 mm., and are from 10 to 20 cm. long. They are light yellowish in color externally, whitish internally. The rhizome sometimes branches laterally at the nodes. Exterior of plant.

The dried rhizome is brittle, the fracture short; externally reddish brown or somewhat yellowish, smooth or somewhat wrinkled; internally white and mealy, with a shaded circle of small wood bundles; pith large. Nearly inodorous; taste sweetish, bitter, acrid.

The upright pale green stems reach a hight of about 1/3 meter, and are 5 or 6 mm. in thickness. The flowerless stems terminate in a single leaf, 7 to 9 lobed, peltate. The flowering stems are forked at the upper one-fifth, bearing on each branch one 5 or 7-parted one-sided leaves, the petiole being fixed at the inner edge. The leaf lobes are wedge-shaped, somewhat lobed and toothed at the apex. The leaves are 10 to 15 cm. in diameter. stems.

A nodding white flower appears in May, about 5 cm. across, borne in the fork of a stem. This consists (according to Gray) of 3 green bractlets, which early fall away, 6 sepals, fugacious, petals 6 to 9, obovate, and 12 to 18 stamens. Anthers linear-oblong; ovary ovoid; stigma sessile, large, thick, undulated.

Fruit ovoid, a large fleshy berry

3 to 5 cm. long, the numerous seeds covering the very large lateral placenta in many rows, each seed enclosed in a pulpy aril, all forming a mass filling the fruit cavity. Fruit ripens in July and August. It is found occasionally with 2 to 6 carpels. The fruit is slightly acid, edible. Fruit

Analyzed by John R. Lewis (U. S. D.) podophyllum pelt. yielded albumen, gum, starch, extractive, lignin, gallic acid, fixed oil, traces of volatile ~~oil~~, salts of potassa and lime, and two resinous principles, one soluble in alcohol and ether, the other in alcohol only. Both resins were found to have the active properties of the root. Percentage of resin found, 4 to 5 per cent. Analysis

The drug is stated by Cubbreth to be best collected soon after the leaves fall.

Cross sections of small and large roots and of the rhizome, and longitudinal sections from the rhizome and large roots, were examined and drawn. The specimen plants were preserved in alcohol, after immersion for about 24 hours in chrom-acetic acid fixing solution, — a water solution containing 0.7 % chromic, and 0.3 % acetic acid. Beginning with the smallest section studied, the various ones will be mentioned in the order of size. The sections drawn were stained with hæmotoxylon.

The smallest root examined was 0.4 mm. in diameter. The general appearance of its cross section is shown in Fig. 2, plate I, magnified diameters. The outer edge has a scalloped appearance, on account of the rounded epidermal cells. The parenchyma cells in- Root # 1

crease in size from the epidermis to the cylinder, which occupies from 1/4 to 1/5 of the whole diameter. The bundle cylinder is composed of cells much smaller than the cortical cells. It contains two wood rays, on opposite sides, with two corresponding phloem groups alternating in position with the wood rays. A few parenchyma cells form the pith between these groups.

Root #1

The epidermis is composed of a layer of cells of medium size, averaging in radial diameter about 20.0 μ, and 23.0 μ tangentially (μ = micromillimeter). The outer wall is thick and convex, being about 1/3 the diameter of the cell in thickness. The radial and inner walls are thin, thinner than those of the parenchyma cells. The form of the inner wall may be either rounded, flat, or angling.

Epidermis

The radial walls in some cases slightly fold upon themselves. The walls stained blue, except the thin cuticle, which appeared black, and a dark line of middle lamella. Chloriodide of zinc treatment showed the thickening of epidermal walls to be of cellulose, only the cuticle and middle lamella having the yellow color of cuticularization, this extending around some of the cells of the adjoining layer. No stratification noticed. Contents: a nucleus, usually oval, enclosing in some cases a small dark body, apparently the nucleolus; also a little of what seemed to be remains of protoplasm. Epidermis

Four or five layers of parenchyma cells occupy the space between the epidermis and the cylinder. These are comparatively large and rounded cells, increasing from dimensions of Cortex

30.0 μ by 33.0 μ in the outer row, to 50.0 by 45.0 μ in the inner row, - the radial diameter being given first. The walls are of medium thickness, consisting of cellulose. Triangular air spaces occur between most of the cells of the middle portion. Occasional simple pits are seen, the pitting being more extensive in the end walls. This seems to be the case in all parenchyma cells of the plant. Cortex

The parenchyma cells of the cortical region are five to seven sided. The lateral and outer walls of the row of cells next the epidermis are thinner than the walls of other cells, as also are the walls of the inner row of parenchyma cells. The tangential diameter the greater in most cases, except of the innermost cells. Cortical parenchyma.

These parenchyma cells contain a little

starch in small granules, about 3.0 M in average diameter; protoplasm with granular contents; and a nucleus, about 1/4 or 1/5 the diameter of the cell, - or about 12.0 M in diameter. The protoplasm of many cells was in the shape of tubular masses, or more or less rounded and elongated masses.

Cortical parenchyma.

The endodermis was strongly differentiated from the parenchyma cells. It was composed of 14 to 16 cells surrounding the cylinder in a rough circle, the cells elongated tangentially usually, with an average internal diameter of about 12.0 M by 20.0 M, radially and tangentially. The walls are of medium thickness, about the same throughout. Tests showed the radial walls to be strongly cuticularized, also the central part of tangential walls. The lateral walls slightly thinner than the radial. A few intercellular spaces

Endodermis

were to be seen between the endodermis and the cells next outside. The endodermal cells are quite variable in size and shape, the largest being about twice the size of the smallest.

Opposite the phloem groups are one or two, sometimes three, endodermal cells usually more rounded than others, with thicker and darker walls, and showing greater cuticularization. Chloriodide of zinc solution colored these walls a pronounced yellow, with a dark median line, which also shows strongly with the haemotoxylon treatment. Similar cells occur in all roots noticed. Endodermis

Cells of the endodermis contain protoplasm, nucleus. No starch found.

The layer of cells within the endodermis, the pericambrium, were much similar in size and shape to the endodermal cells, with slightly thinner walls. Pericambrium.

The bundle cylinder, as seen in plate I, Fig. 1, contained two wood rays alternating with the two phloem groups, arranged in a circle about the pith, the groups separated from each other by a row of parenchyma cells, two layers of these composing the pith portion of the cylinder. The cylinder was generally elongated parallel with the wood rays. Cylinder

Each wood ray consisted of from one to five or six wood vessels, these diminishing in size toward the outside. The vessels presented the usual characteristic appearance in cross section, with the different shadings arising from varying degrees of light refraction. The prevailing shape slightly elliptical, the sides made up of curved and straight sections, being straight where two vessels joined. The walls of medium thickness. Dimensions of the cavity measured about 9.0 by 11.0 M. Wood

Contents: none found.

The smallest cells composed the phloem groups, an average cell measuring about 5.0 μ by 7.5 μ. These are of various irregular shapes, the walls thick compared with the size of cell cavity, thus appearing prominently blue from the stain. The sieve cells could not be distinguished, only as a probability from the greater diameter of some cells. Phloem

Contents noted: Some minute starch grains, protoplasm, nuclei.

Most of the parenchyma cells between and about the wood rays and phloem groups were smaller in size than endodermal cells, averaging about 9.0 μ in diameter. These have walls of medium thickness, not differing from the cellulose walls of the remaining parenchyma. Contents also similar, but the nuclei larger in proportion to cell cavity. Pith

In the root section resin in small

amount, especially in the two outer tiers of cells, was indicated on treatment with alcanet solution. Resin Root #1

The root examined next had a diameter of 0.75 millimeter. The cross section showed a structure like the one previously described, with two wood rays and two phloem groups, the difference being a slight increase in size of the various elements and in the number of cells in the different tissues. Hence the only drawing made was that of plate II, showing the general appearance of the cross section under a magnification of Root #2.

The parenchyma tissue of cortex was seen to be increased by about two layers of cells. The peculiar cells of the endodermis showing greatest cuticularization, those opposite the phloem groups, were increased in number one or two.

Sections were next cut from a root of the diameter of 1.3 mm. A drawing was made of the cross section of bundle cylinder, plate III, with a magnification of * A parenchyma cell is shown separately, to represent the appearance of the starch grains. Root #3

The bundle is four-rayed, with four corresponding phloem groups. The pith is considerably increased in amount, being 6 or 7 cells in depth. The cortical parenchyma occupies 4/5 to 5/6 of the whole diameter. Bundle These cells are very similar those before mentioned. Occasional pitting of the walls is seen, the pitting being opposite, as usual.

As in the previous sections, the bundle cylinder appears sharply differentiated from the tissue outside it, the cells being so much smaller. The inner vessels are comparatively large, about twice the diameter of other cells of the cylinder. Two or three of such larger vessels

are to be noticed in each ray, the adjoining vessels smaller, the outermost very small.

The epidermis has here the same general appearance as in smaller roots, the cuticularization being similar.

The parenchyma cells contain more starch than those of smaller roots. The pitting is more numerous, especially in the end walls, the pits of quite varying size.

Root #3

The endodermis is composed of about 33 cells, being about twice as many as in the smallest root.

The wood rays are made up of from 6 to 8 tracheæ.

Each phloem group consists of 10 or 12 cells.

The contents appeared similar to those of the cells in smaller roots.

Four drawings were made of sections from the largest size of root, designated as size 4.

Plate IV shows a general view of a cross section in part, including the cylinder and a wedge of cortical portion and epidermis, magnified times. Root #4

Plate V represents a high power view of a part of tissue of cortex, and part of the central cylinder, including two wood rays and some cells of pith; magnified times.

A longitudinal section is drawn in plate II, beginning with the epidermis and extending into the pith; magnified times.

In plate III is shown a longitudinal section of the axial cylinder, reaching into the parenchyma on each side, magnified diameters.

The root measured 1.9 mm. in diameter.

The appearance of the cross section is essentially like that of the smaller roots, differing in the extent of the various tissues, and in the number of rays. In the specimens examined, some had five wood rays, but most had four. In the section shown in plate IV, one of the wood rays is less developed and shorter than the other four. The cylinder measures about 1/4 the diameter of the whole section. Root #4

The average dimensions of the cavities of the various cells were approximately measured, and follow, given in micromillimeters:

Epidermal cell, - radial 27.0 M., tangential 33.0 M.; these figures often reversed.

Parenchyma cell next epidermis, - 34.0 M. Dimensions.

" " , central cortex, - 60.0 M.

" " , next endodermis, - same as outer.

Endodermis, - radial 18.0 M., tangential 30.0 M.

Largest wood vessel, - 42.0 M. by 36.0 M.

Pith, - 11.0 M by 18.0 M. Starch bodies, 4.5 to 6.0.

The diameter of the root from which drawing VI was made, was 2.0 M. This longitudinal drawing shows about ½ of the root, extending from epidermis to pith. Being cut through a wood ray, no sieve cells appear. Root ✝ 4.

The epidermal cells are seen to be elongated, some being 10 times as long as the breadth. Protoplasm and nuclei noticed in these. Epidermis

The cells of the two or three layers next within the epidermis are also long, being five or six times the distance across, the general outline being oblong. The end walls are thinner than the side walls. No pits noticed in these walls. The cells contained some starch in small grains. Outer cortex

Seventeen rows of parenchyma cells compose the cortical tissue in the specimen drawn in plate VI, arranged in uniform longitudinal layers. The cells are comparatively short, averaging perhaps twice the Cortex

breadth, or nearly. The cellulose walls are of medium thickness, end and side walls about the same thickness. Most of the cross walls are at right angles to the side walls, in some cases more or less inclined. A moderate number of large and small simple pits, the end walls more extensively pitted. Root #4 Cortex

These cells are packed with starch, there being a greater amount than in smaller roots. Many of the grains are compound, of a diameter of from 4.5 to 6 μ. Starch

Occasional stellate calcium oxalate crystals are to be seen, one in a cell, these usually occurring together, but a few together, in consecutive cells. In such cases the cells are usually short, often isodiametric, as of longer cells divided, a crystal forming in each division. Calcium Oxalate

Many cells contain the yellow or yellow-brown resinous globules to be seen Resin

Root #4

throughout the plant stem and roots. Resin
These globules are generally more or less
associated with starch grains.

The endodermis is difficult to distin-
guish in most cases. It appears as a
row of long oblong cells, with nearly trans-
verse end walls, The walls thin, The outer Endodermis
and inner walls corrugated or wavy and
very thin. This is not well shown in
plate II, but is seen in number VII.
The length of a cell is 4 or 5 times the
radial diameter.

These cells appeared to have a good sup-
ply of starch in small granules, here and in
the axial cylinder The starch being in smaller
grains than in the larger parenchyma cells.

The row of cells next within the ~~epi~~ endo-
dermis, The pericambium, which in cross
section are very similar in appearance to Pericam-
bium
endodermal cells, in longitudinal sec-

Root # 4

tion are much like elongated parenchyma cells in outline, but thin walled and long, the length 3 to 4 times the breadth, the length quite variable. The cells are quite narrow. Pericambium.

The cells of the phloem groups appear in longitudinal section very long and narrow, the sieve tubes being considerably longer and larger than the accompanying companion cells. The length of the cells was not found. Phloem

The sieve tubes have thin walls, the end walls being usually much slanted, often inclined about 45°; and commonly showing in cross section a slight S form. The perforations in the end wall cause a bead-like appearance in portions of it, as of a string of beads. Sieve cells.

The tubes are considerably widened

in the vicinity of the cross walls, being widest at this point. The sieve areas are few and small in extent. These cells are in length approximately 20 to 25 times the breadth, about the same proportion as in the rhizome. Root #4

The sieve cells contained a little starch in small grains, considerable protoplasm, and lens-shaped nuclei; the long diameter of the latter being parallel with the length of the cell. The nuclei showed a granular appearance. Phloem

The wood rays seemed to be made up wholly of vessels, so far as noted. Wood

The members of the spiral vessels could not be determined, but the end walls of many large vessels were distinct, showing the large opening caused by the breaking down of the middle portion of the end wall.

The remaining portions of the end walls Root #4
were usually somewhat inclined to the side
walls, and showed pitting similar to that Wood
of side walls. The walls of vessels ap-
peared to be generally reticulately pitted,
with narrow transverse slits, irregularly placed.
The pitting of larger vessels quite uniform.

The smallest vessels are at the outer
end of the ray, next the pericambrium.
These have the spiral thickening, the
number of turns of the band in a certain
distance varying much, the band being Vessels
narrow or broad. The fewer the turns, the
narrower the band seemed to be.

The length of the large vessel mem-
bers was about 10 times the breadth.

No contents were to be seen.

The number of cells in the distance
across the pith was 8 or 10, between the

encircling phloem groups and wood rays, Root #4
these cells being narrower and longer than
the cortical cells, but larger than phloem cells.
Many measured 8 or 10 times the radial
diameter in length. The end walls are mostly
at right angles to the long way of the cell,
or nearly so. The walls are comparatively
thin. Pitting simple, not numerous, ex-
cept in end walls.

Contents: starch, protoplasm, nuclei. Contents.
The parenchyma cells well packed with starch.

In sections from some of the large roots
gathered August 15, the walls of most of the
pith parenchyma cells were very much
thickened, leaving but small cell cavities. Roots
These walls were pierced by narrow pits. got
The nature of the substance of these walls Aug. 15
was not determined.

The rhizome in cross section is represented in plate VIII, magnified times. This rough sketch illustrates the arrangement of the various tissues. Rhizome

Parenchyma tissue occupies the much larger portion of the area, the bundles, which show as the shaded spots on the white ground of parenchyma, being comparatively small. The larger bundles are in a circle about the pith or central part, midway between the center of the stem and the circumference. The arrangement of the phloem and wood is the radial one, the phloem being outside the wood, as typical of dicotyledons. General appearance.

Occasional immature and small fibro-vascular bundles are seen in the cortex; the farther out these are, the smaller and less developed the bundle.

The cortex, composed of parenchyma tissue excepting the few scattered

bundles, with the epidermis occupies nearly Rhizome
a half of the diameter of the rhizome; the bundles of the ring about 1/5, and the pith about 1/3 the diameter.

The stems examined were young ones.

The rhizome is surrounded by an epidermis Epidermis
of one row of cells, which have thin lateral walls, usually more or less folded upon themselves. The inner and outer walls are thickened, especially the outer, both being cuticularized. The cuticle, appearing as a thin, dark line, adheres closely to the outer wall.

The epidermal cells have cavities averaging in diameter about 9.0 M. radially, by 30.0 M. tangentially, with a length of about 300.0 M, thus giving a tabular form. The outer wall is thick in most cases, though in the section shown in plate XIII this wall is thinner than usual. The epidermis in young rhizomes is clearly

defined. Here the lateral walls are usually folded more or less, and with increasing age the collapsing of the wall increases, the layer of cells becoming so compressed as to be indistinguishable as such. The remaining protoplasmic contents and nuclei assist in the apparent solidification by filling the cell cavities. The layer is frequently torn off through the weakness of the lateral walls, these splitting, leaving the projecting ends of the inner half of the walls. Rhizome Epidermis

The underlying layer of cells seems adapted to supplying the place of the epidermis, owing to the rather thick outer walls and the strong cuticularization.

In the cross sections studied the formation of cork shows in arcs of the circumference, the larger part showing plainly the epidermal layer with no cork underneath.

In some places several rows of thin walled cork cells occur beneath the epidermis and the hypodermal cells, the epidermis to be seen in places still attached, but indistinct mostly. In older plants the cork growth is common, encircling most of the rhizome, the epidermis being usually more or less separated from the rhizome. Rhizome Epidermis

No drawing was made of this tissue.

The cuticularization extends along the middle lamella of the two layers next the epidermis, the part of the wall next the cavities being cellulose. The outer walls are thicker than the inner one.

The cells of the layer next the epidermis are tangentially oblong in general outline, with rounding corners and side walls. The diameter of the cavities of these cells averages about 20.0 M. radially by 30.0 M. tangentially, and they are about 75.0 M. long. The Hypodermis.

length being more variable. Rhizome

The contents appear similar to those of the epidermis.

In cross section the lateral walls of the epidermal cells do not correspond in position with those of the adjoining cells, nor do these usually with the walls of the cells next in order.

The third layer of cells from the epidermis Hypoderm-mis. is composed of cells similar to those of the layer next the epidermis. These are shown in plate XIII, the section having been treated with chlor-iodide of zinc. The epidermal cells and the radial walls of the next layer to about the middle of the cells, as indicated by the small arrow and letters br., showed a brown color. From here to another small arrow in the drawing, marked l.y., the walls were stained light yellow, indicating cuticularization to a less degree than the outer cells.

In most of the sections studied the second tier of cells from the epidermis was strongly differentiated, in cross section appearing as larger square or radially oblong cells, with thin walls in proportion to the size of cell, the walls of cellulose except the middle lamella and a thin layer next to it. The cuticularization was not noticed at a greater depth than around these cells. Rhizome Hypodermis

In some cases this layer of large cells is the third from the epidermis, as shown in drawing XIII.

The radial diameter of these large cells, when undivided, is greater than the tangential, being about 51.0 M., by 36.0 M. tangentially; length from 75.0 M. to 100.0 M.

These cells are often divided by tangential walls into 2, 3, or even 4 cells, which are then small and tangentially oblong.

These layers of cells next to the

epidermis seem to have the nature of a hypo- Rhizome
dermis. There are no intercellular spaces,
and no pitting, except occasionally in
some cells bordering on the adjoining paren-
chyma. Hypoderma

The outer cells of this hypodermis, as stated,
seem to contain only protoplasm and nuclei.
The large cells contain a little starch, also num-
erous globules of resinous matter, as indicated
by a test. In cross section these globules are
seen to be mostly in the outer part of the cavity,
adhering to the walls, but in cells where most
abundant they are also in the middle portion
of the cell along with starch grains. These
resinous globules are in the hypodermis
most abundant in the cells bordering on
the parenchyma tissue proper, and they are
also abundant in the outer parenchyma layers,
diminishing in amount toward the interior,
though a few of the globules may be seen in

most of the cells of the cortex. The amount again increases in the vicinity of the bundles, both at their outer and inner edges. Rhizome Resin

The color of the globules in untreated sections is yellow or brownish-yellow; when stained with haemotoxylon they are of a dark green to yellowish-green color. Occasional cells of cortex contain masses of globules of a bright yellow tint.

The cortex, from hypodermis to the bundle ring, is composed of parenchyma tissue, except the occasional small cortical fibro-vascular bundles. These parenchyma cells are much alike in general appearance. Those near the hypodermis are smallest, the cavity of an average cell being about 26.0 M. radially by 42.0 M. in tangential diameter; length 90.0 M. to 140.0 M. Cortex

Intercellular spaces occur between most

of the parenchyma cells, except those next the hypodermis or bundles. These spaces are generally triangular, often quite large, being 8.0 or 10.0 M. in diameter. Some of the spaces are four or five-sided, and may then be 20.0 to 30.0 M. long. In no case was any secretion or contents noticed in these spaces, nor anything resembling a gland. Rhizome Cortex Intercellular spaces.

In older plants the outer parenchyma cells take the form of collenchyma - very thick-walled at the corners, without intercellular spaces, and with wide pits in the thin portions of the walls. Toward the interior this soon merges into ordinary parenchyma, the walls becoming thinner and intercellular spaces appearing. Collenchyma.

In the outer cells of ordinary parenchyma, the shape is usually that of a tangential ellipse. The walls (cellulose) are of medium thickness, with a few simple pits, especially Parenchyma.

in the middle portion of walls. Rhizome

In thin sections the cellulose striations are seen.

The size of the parenchyma cells increases towards the interior, they becoming at the same time more rounded, being mostly isodiametric. The dimensions of cell cavities in middle of cortex averaged about 60.0 M. radially by 75.0 M. tangentially; longitudinally 100.0 to 150.0 M. The largest measured about 75.0 M. by 90.0 M., radially and tangentially. Parenchyma

The cells bordering on the bundle ring are more nearly like the outer parenchyma cells in size.

Contents: Starch, resin, nuclei.

The bundles occurring in the cortex are mostly quite small, being larger as they approach the bundle ring, those next the bundle circle being nearly the same size Bundles of Cortex.

as those of the ring. The form of these bundles is oval or rounded. The longer diameter may be either radial or tangential. Rhizome. Cortical bundle.

A cortical bundle may show from one to several wood vessels together near the center, with a hemisphere of phloem to the outside, and a smaller group of small-celled wood parenchyma at the inside. A cross section of one of these bundles is shown in plate XII, magnified times.

All of these cells are small compared with the surrounding parenchyma cells, the wood vessels of a small bundle being about 12.0 M. by 18.0 M. in size, with the other cells of about the same average.

The cells of the phloem, as well as those of the wood parenchyma, are quite variable in shape, but prismatic in outline, four or five sided usually. The phloem cells nearest the wood cells generally show an

arrangement into radial rows, arising from the pericambial layer next the vessels. The outer cells of the phloem group are more distorted in shape and lie irregularly. The walls are thin. Rhizome. Cortical bundle.

Contents: protoplasm, nuclei, some small starch grains.

The group of wood parenchyma cells consists of somewhat larger and thicker walled cells, arranged irregularly. They contain more starch grains, also some resinous globules. Wood parench.

The nuclei of the wood parenchyma cells next the vessels appeared of about the same size as those of ordinary parenchyma cells, often nearly filling the cell cavity, as seen in cross section. Other contents: starch, resin.

At the outer edge of the phloem group of some cortical bundles, are seen one or several thick walled cells of larger diameter Mechanical cells

than other cells of the bundle, arranged in a row tangentially to the bundle. These cells could not be found in longitudinal section, and the nature of the cell or cell wall was not determined. The walls were scarcely stained by the haematoxylon solution, being almost white, or a very faint blue tint. No contents observed. Rhizome. Mechanical cells.

In plate XIII, the vessels of the cortical bundle are represented as the shaded cells in the middle of the drawing, the wood parenchyma to the right, the phloem to the left. The large cells to the left of the phloem, shown in the drawing with shaded walls, are the thick-walled cells last mentioned. To the outside is seen the cortical parenchyma. Plate XIII

Starch grains are outlined in some of the cells, the accompanying shaded bodies being the yellowish resin globules.

Rhizome.

In the smallest bundles of the cortical region the differentiation of cells could not be determined with the microscope used, even with the highest power. These bundles were not studied in longitudinal section.

Bundle circle.

The fibro-vascular bundles of the ring number from 16 to as many as twice that, or even more, usually around 20. They have generally an elliptical shape, the long diameter being radial to the rhizome, - though they are often round or nearly so. The bundles may be separated by one or several layers of parenchyma cells, while in some instances no distinct medullary ray may be seen, but the bundles appear to be closely united. The two central bundles in the ring illustrated in plate IX seem to be a case of the kind just mentioned.

This drawing shows a portion of the

cross section of a rhizome, including four bun- Rhizome.
dles of the ring, and one cortical bundle.
The bundles show distinctly, on account of
the apparent shading caused by the small Bundle
size of most of the cells compared with the of
tissue surrounding, also by reason of the ring.
large vessels within the bundle.

The phloem (marked Ph. in one bundle) lies to
the outside, taking up nearly ½ of the space
of the whole bundle. Next within are the
wood vessels, the wood parenchyma occupying
the inner end of the bundle.

No special or differentiated layer of cells
surrounds the bundle.

An entire bundle is shown in greater
detail in plate XI, magnified Times.

The phloem consists of the usual sieve Phloem
tubes interspersed with companion cells. These
are all thin walled and prismatic,

narrow and long, many appearing distorted in the cross section. Rhizome.

An average sieve cell measured about 18.0 by 22.0 M., and the length, as nearly as could be found, varied from 350.0 M. to 430.0 M. The companion cells averaged about 15.0 by 18.0 M. in diameter, with an approximate length of 230.0 M. to 270.0 M., though many were considerably shorter. Phloem.

That these cells were originated by the pericambium next outside the vessel group could be shown in many bundles by the radial rows of cells starting from that layer, but this is not well shown by the drawing. Where well illustrated the radial tiers were several deep, the cells being nearly alike in size and four-sided. Beyond this these rows are broken up and the arrangement is irregular.

The cells composing the cambial layer are usually larger and irregular in shape.

and position, — as also are the outer phloem cells. These are all prismatic, 5 to 7 sided, mostly 5 sided. Rhizome

The sieve tubes have inclined end walls, often slightly S-shaped, and thickly perforated by minute holes. When this wall is cut across, the perforations give a beaded appearance to the wall. In many cases the end walls were covered by a callous growth. One end wall measured 60.0 μ. in length. Occasional small sieve plates, with minute holes, appear on the side walls, sometimes several in a group. Sieve tubes.

Figs. 1, 2, and 3, plate XI, show sieve areas and the different walls of a tube.

The sieve tubes are narrower in the middle, widening at the junctions.

Contents: Albumen (as shown by eosin test), nuclei, starch.

Rhizome bundle of rug.

The companion cells are narrow and long, but shorter than sieve tubes, and have thin walls. They contain nuclei and considerable starch. No pitting of cell walls noted.

Mechanical cells.

At the outer edge of the phloem groups of some bundles are one to several of the large thick-walled bast-fiber-like cells mentioned as occurring in cortical bundles. Some of these cells are small, but the larger have an internal diameter up to 30.0 M. The could not be found in the longitudinal sections.

The phloem cells are represented in longitudinal section in plate X, appropriately marked.

Rhizomes

The wood vessels occupy most of the inner half of the bundle. Most of the vessels are large and conspicuous, and have usually an oval shape, sometimes nearly round. The long diameter is generally radial to the stem. Most of the vessels have one or more comparatively straight sides, where they come in contact with one another. They become smaller in diameter toward the inner side of the bundle, some of the innermost being very small, especially the spiral vessels. The vessels usually occur in groups or pairs.

Vessels

In the spiral vessels, the thickening varies from a thin band with long spirals to wide bands and short turns. Where a second spiral vessel was noticed in a bundle, the one with the wider band was outside the other, or between it and the pitted vessels.

The larger vessels are more often retic-

ulately pitted, sometimes approaching a scalariform resemblance. The pits are usually narrow slits an at right angles to the length of the vessel. They are mostly slightly bordered, as indicated by the varying intensity of the light transmitted through them, - also by the outline of the pits when cut transversely. Rhizome Vessels

The walls of the large vessels measured were from 3.0 to 6.0 M. in thickness.

The members of the larger vessels measured about 40.0 M. one way by 60.0 M. the other, with a length of from 250.0 to 340.0 M., according to the size of vessel. The small vessels measured as little as 15.0 M. in internal diameter.

So far as noticed, the trachea consisted entirely of vessels. No contents to be seen.

A large vessel and a spiral one are illustrated in drawings 4 and 5, plate XV.

Rhizome. Wood parenchyma.

Wood parenchyma cells are between some of the vessels and to the inside of the vessel group. They are thin-walled and small cells, but not quite so small as most phloem cells.

Liberiform cells.

At the inner edge of the wood parenchyma of many bundles, occurring in bundles without seeming regularity, is seen a group of a few or perhaps several dozens of thick-walled cells, probably to be considered as liberiform cells, or mechanical cells, having lignified walls, evidently developed from wood parenchyma cells. One of these groups is represented in plate XV, Fig. 6, in longitudinal section, magnified times. Some of the contents are shown, a nucleus and starch in small grains.

In cross section the cavity of these cells varied between 15.0 M. and 30.0 M. in diameter, more often the latter figure.

The length averaged about 275.0 M., the thickness of wall about 3.0 M. Rhizome

The walls are provided with numerous pits, each pit of about the same diameter throughout. The pits are small and pore-like.

The end walls are more or less inclined, often considerably, giving a pointed appearance to the end of such cells. Liberiform cells.

A group of these lignified cells is shown in longitudinal section in plate X, marked l. c.

The parenchyma cells of the medullary rays are usually somewhat elongated radially, especially midway between the bundles. These cells have contents like those of other parenchyma, and intercellular spaces. Medullary rays.

The cells of the pith do not differ essentially from those of the cortical parenchyma. They are probably a little larger in size, and more rounding in outline. Rhizome Pith.

The contents are similar to those of the outer parenchyma, but with less of the yellow resinous globules present.

The abbreviations used in the drawings are given at the bottom of plate I.

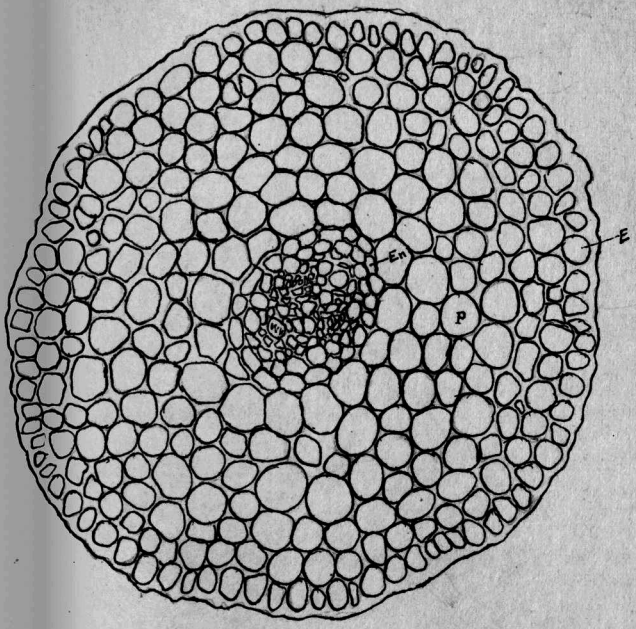
C. S. Wigdale.

The microscope used in the foregoing study was No. 22544, Bausch & Lomb.

The lenses used in magnification for the different drawings follow:

Plate I, Fig. 1 –	Eyepiece 1 in.;	objective 1/6".	Eyepiece closed.	
" I, " 2 –	" 1 in.;	" 2/3	"	"
" II,	" 1 in.	" 2/3	"	"
" III,	" 1 in.	" 1/6	"	"
" IV,	" 1 in.	" 2/3	"	"
" V,	" 1 in.	" 1/6	"	"
" VI,	" 1 in.	" 1/6	"	"
" VII,	" 2 in	" 1/6	Eyepiece pulled	
" VIII,	" 1 in.	" 2/3	out to 168.	
" IX	" 1 in.	" 2/3	Eyepiece closed.	
" X,	" 1 in.	" 2/3	"	"
" XI	" 2 in.	" 1/6	"	"
" XII,	" 1 in.	" 1/6	"	"
" XIII,	" 1 in.	" 1/6	"	"
" XIV,	" 1 in.	" 1/6	"	"
" XV,	" 1 in.	" 1/6	"	"

Plate II.

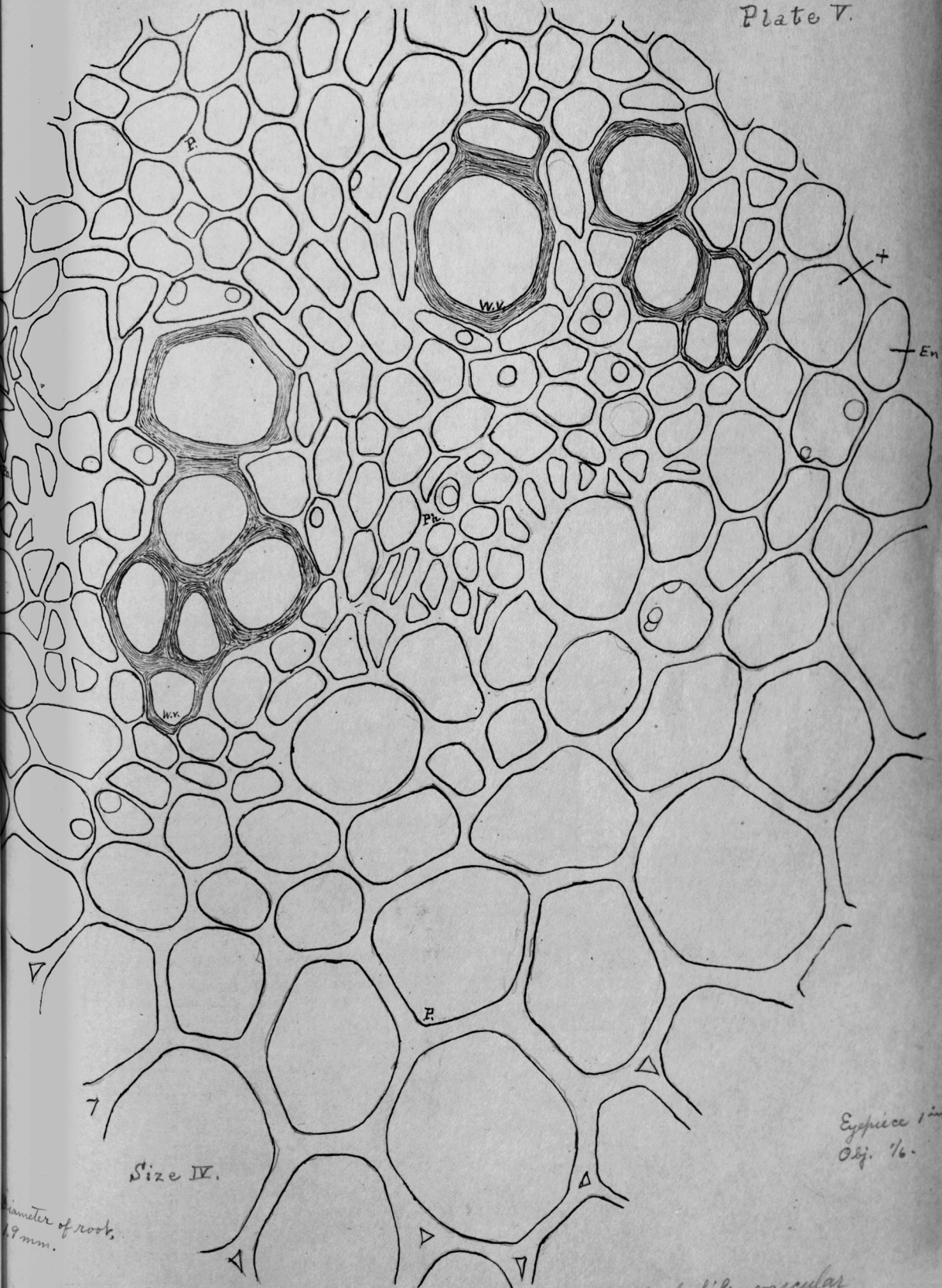


Size II.

General view of cross section
of root, size II.

Eyepiece 1 in.
Obj. 2/3.

Plate V.



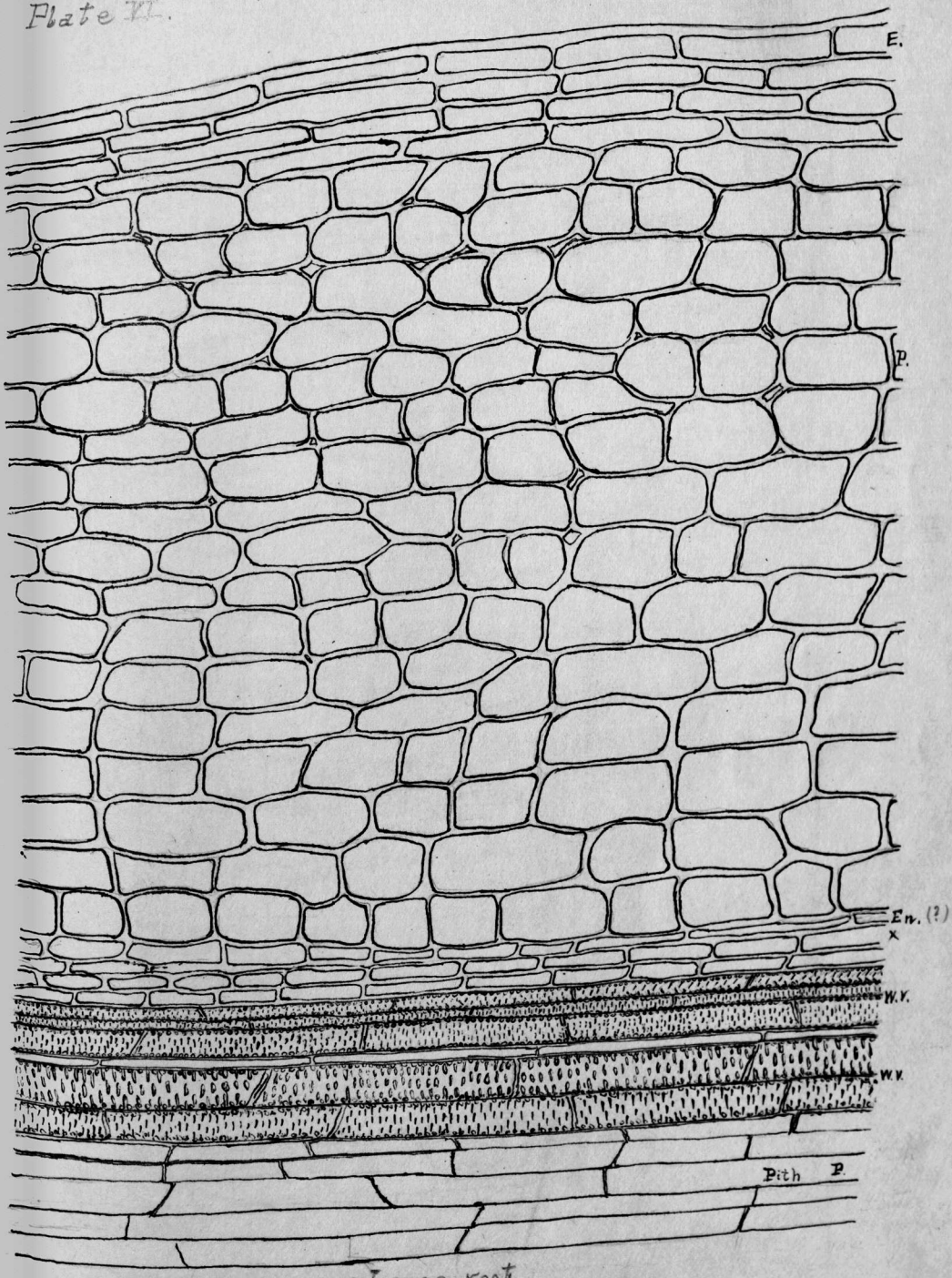
Eyepiece 1 in.
Obj. 1/6.

Size IV.

Diameter of root,
1.9 mm.

Podophyllum peltatum.— Cross section of part of fibro-vascular bundle of root, size IV, showing two wood rays.

Plate VI.

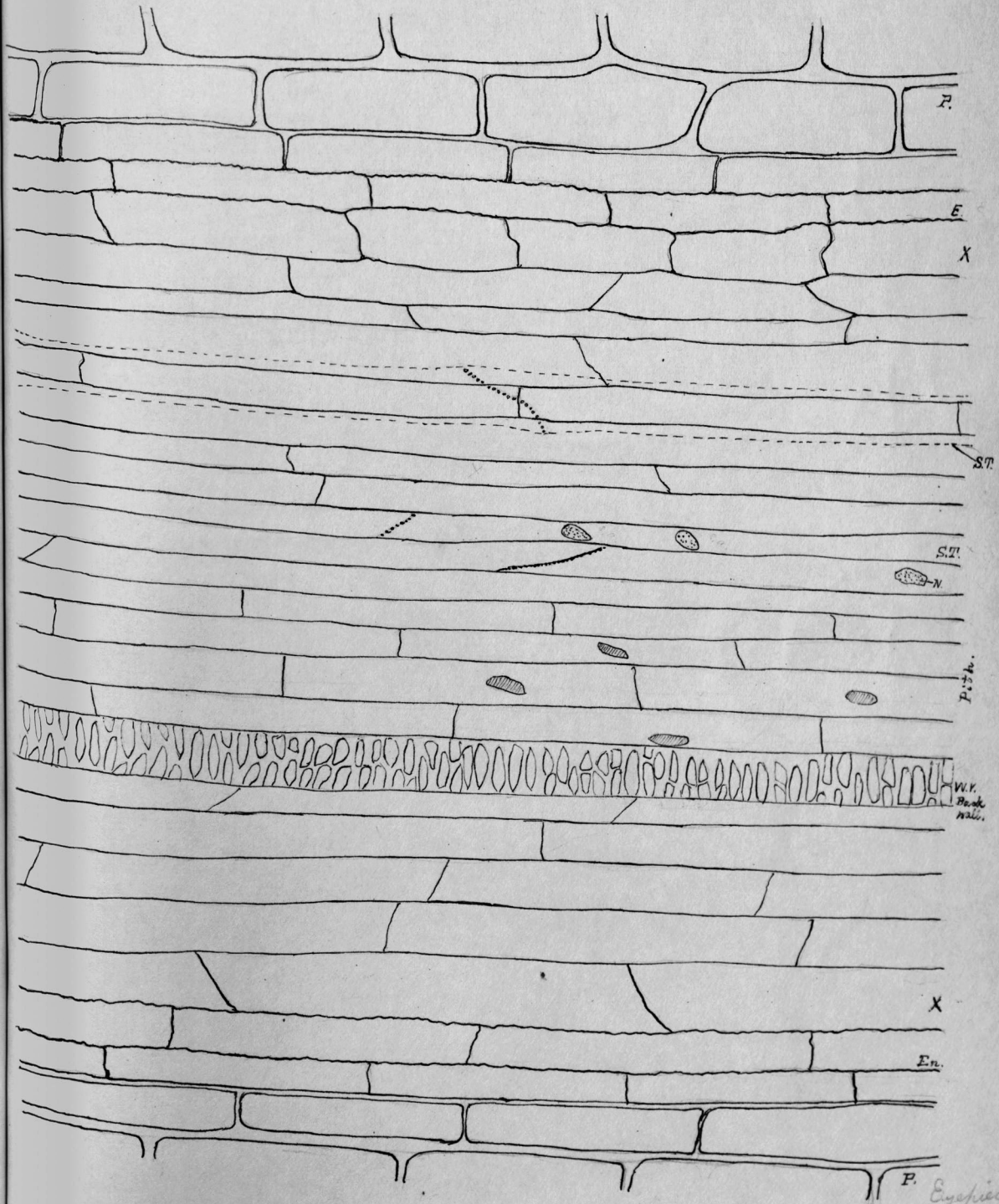


Large root.

Eyepiece 1 in. (closed)
Objective 1/6 in.
(?)

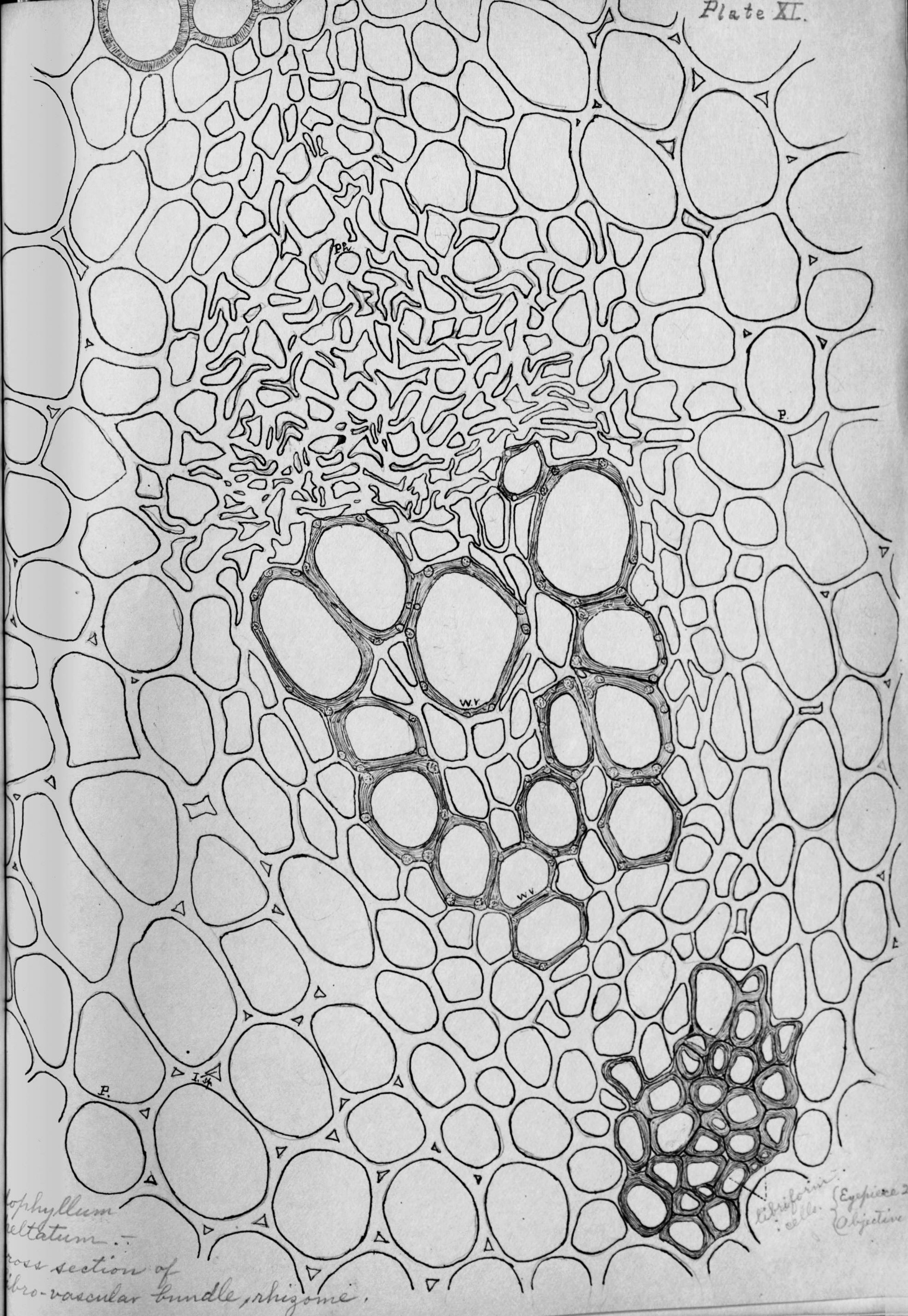
Podophyllum peltatum.— Longitudinal section of large root, to center of f.v. cylinder.

Plate VII.



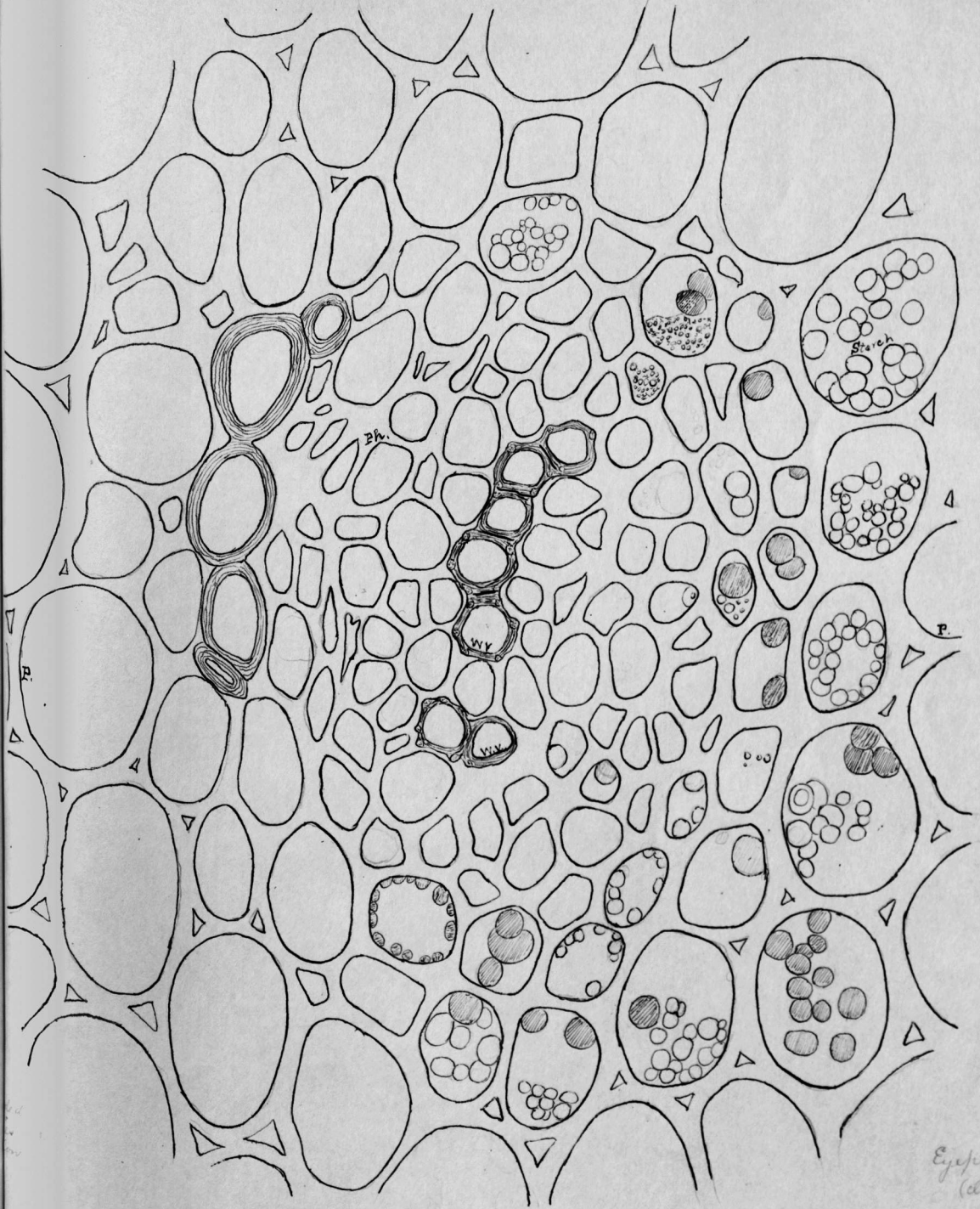
Eyepiece 2
(closed)
Objective ½

Podophyllum peltatum.— Radial longitudinal section of middle portion of large root.



...ophyllum peltatum:- Cross section of fibro-vascular bundle, rhizome.

Plate XII.



Eyepiece 1 in
(closed)
Obj. 4/6

Podophyllum peltatum. – Cross section of isolated fibro-vascular bundle in bark portion of rhizome.