PSILOTUM

Taxonomic position

Division : Psilophyta
Class: Psilotopsida
Order: Psilotales
Family: Psilotaceae
Genus: Psilotum

Occurrence

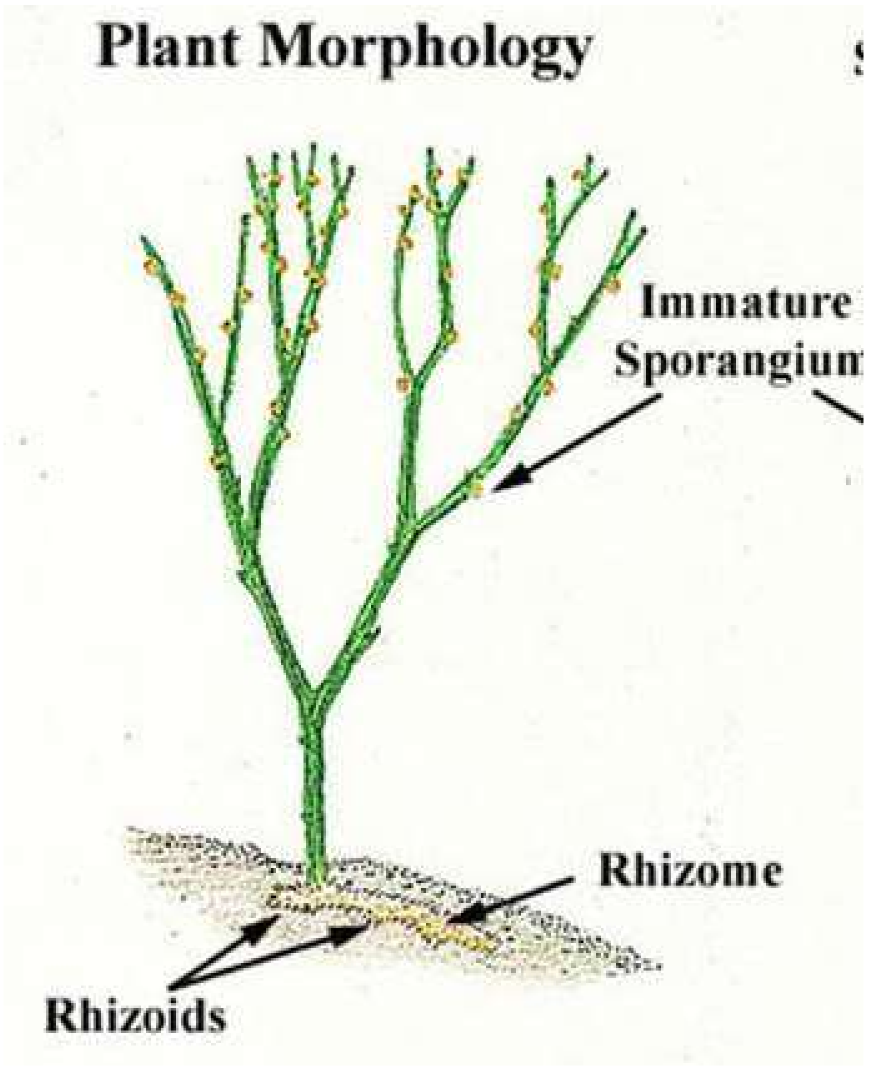
- It is commonly called as whisk fern (because it is a fern without leaves and so the stem performs all function)
- Found in humus rich soil , in tropical and sub tropical regions.
- Some species grows as epiphytes (tree trunk)

Vegetative morphology

Plant Body:

It is sporophyte and contains following parts

1. Rhizome
2. Aerial branch
3. Sporangia

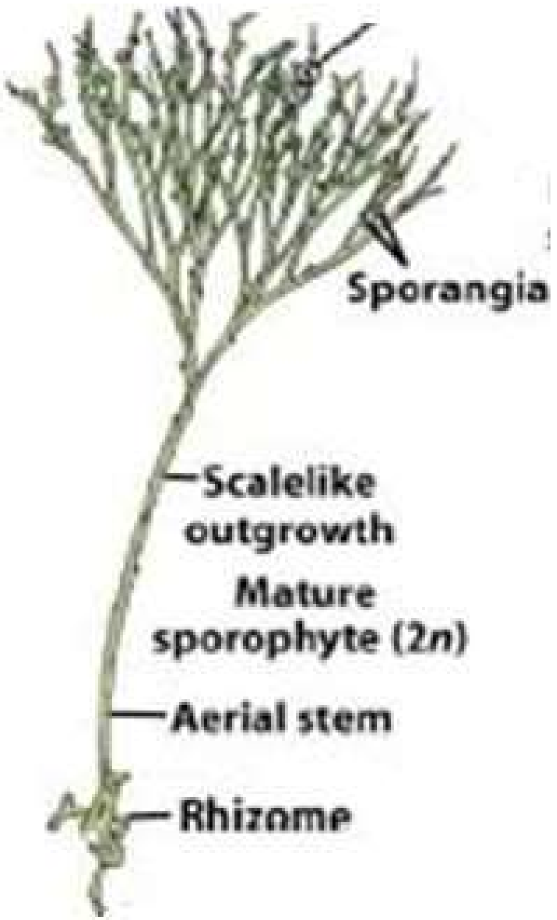


Rhizome

- The horizontal portion is rhizome
- Buried in soil or humus.
- Dichotomously branched
- 2 celled rhizoids are present near the apices of the younger branches
- These rhizoids absorb water and nutrients from soil for aerial branches

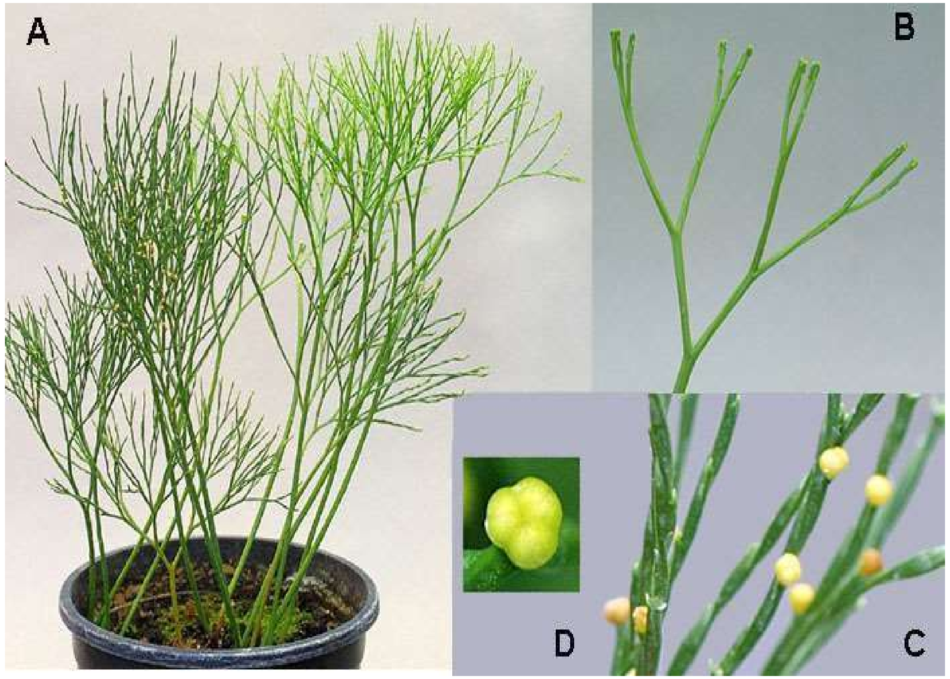
Aerial branch

- Rhizome bears aerial branches
- The branches are green, cylindrical and dichotomously branched
- The leaves are small, scale like and are scattered over these branches.



Sporangia

- The sporangia are borne in triads.
- They have very short stalks.
- They are borne in the axils of small bifid leaves on the aerial branches.
- This triad of sporangia is called a **synangium**.
- The two lobes of the leaf are closely united with the synangium.





Stem Anatomy

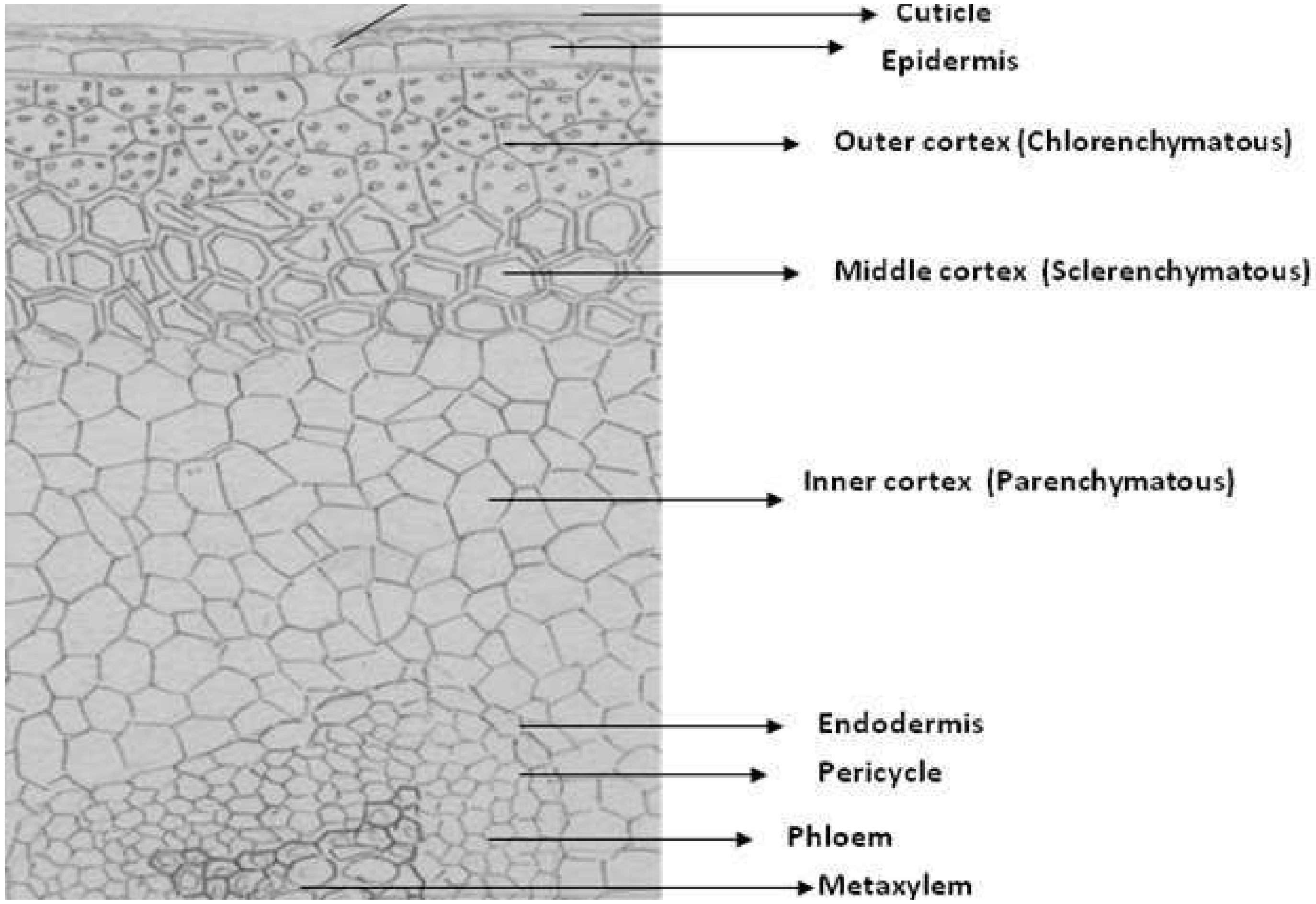
It is circular in outline from base, pentagonal near the first dichotomy and triangular between successive dichotomies .

It has following parts.

1.Epidermis

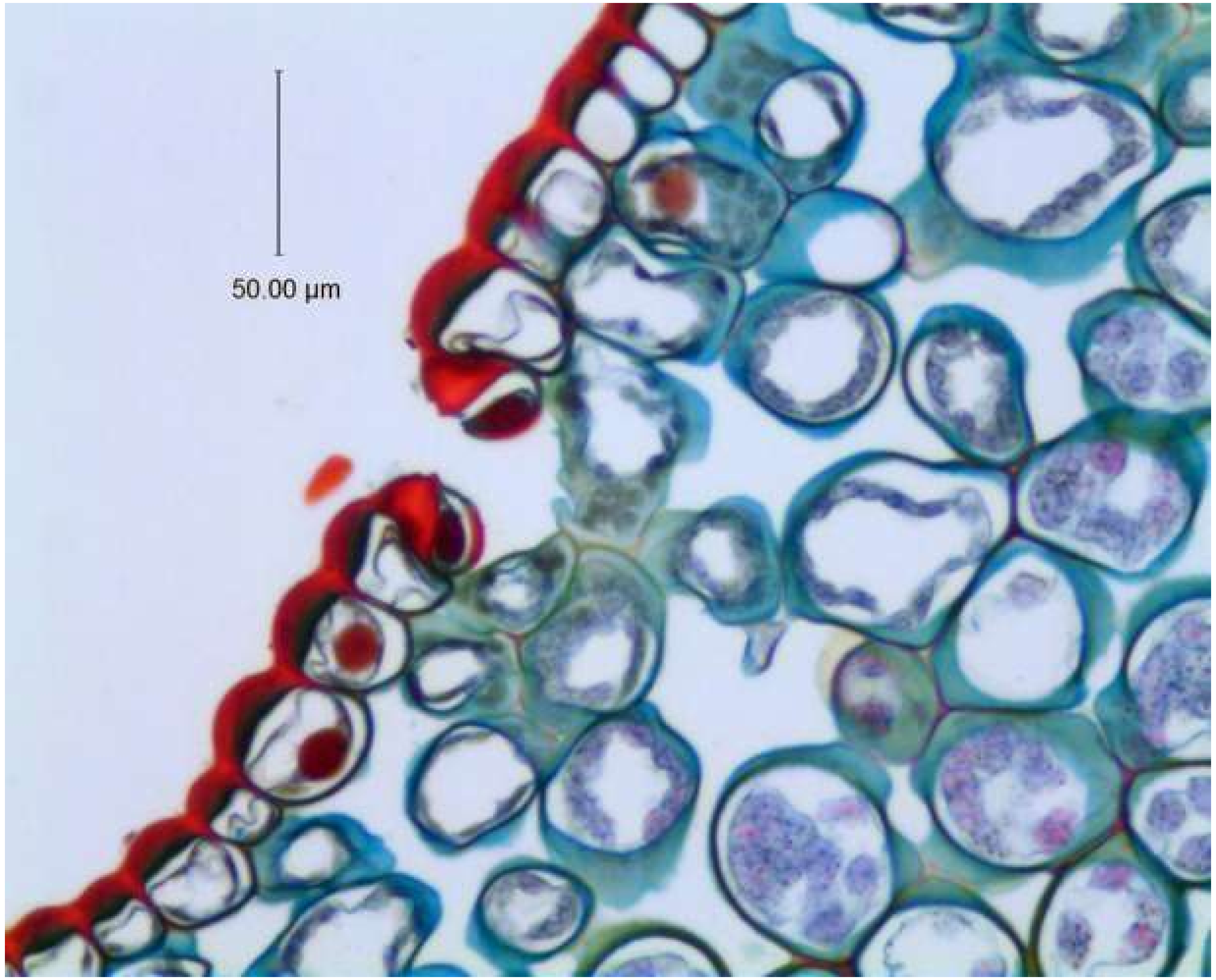
2.Cortex

3.Steler system



1: Epidermis

- There is a single layer of epidermis present outside
- It is heavily cutinized
- Stomata are also present on epidermis , situated at the grooves



2: Cortex

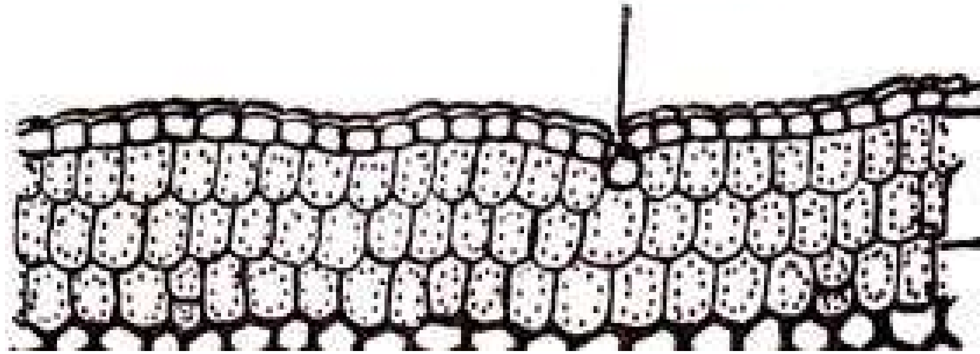
Cortex of Psilotum is divided into following parts.

a) Chlorenchymatous cortex

It is the outermost part of cortex and has 2 to
5 layers of cells.

The cells are thin walled and are parenchymatous .

They are photosynthetic as they contained chloroplast.

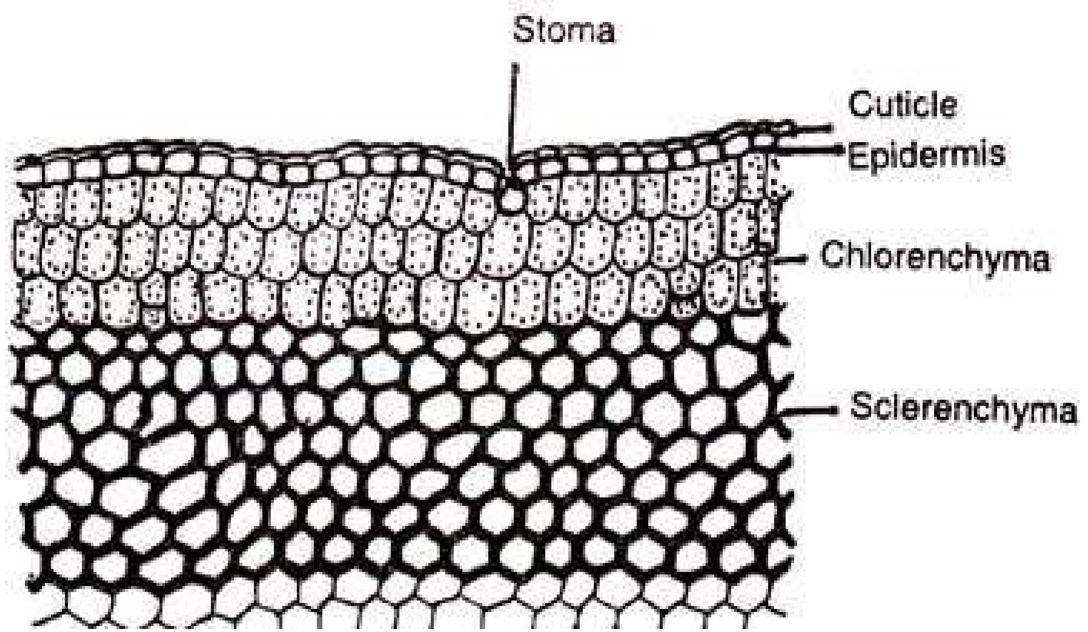


Cortex

b) Seclerenchymatous cortex

Below the parenchymatous cells there are 2-
4 layers of sclerenchymatous cells .

The cells are thick walled and provide support

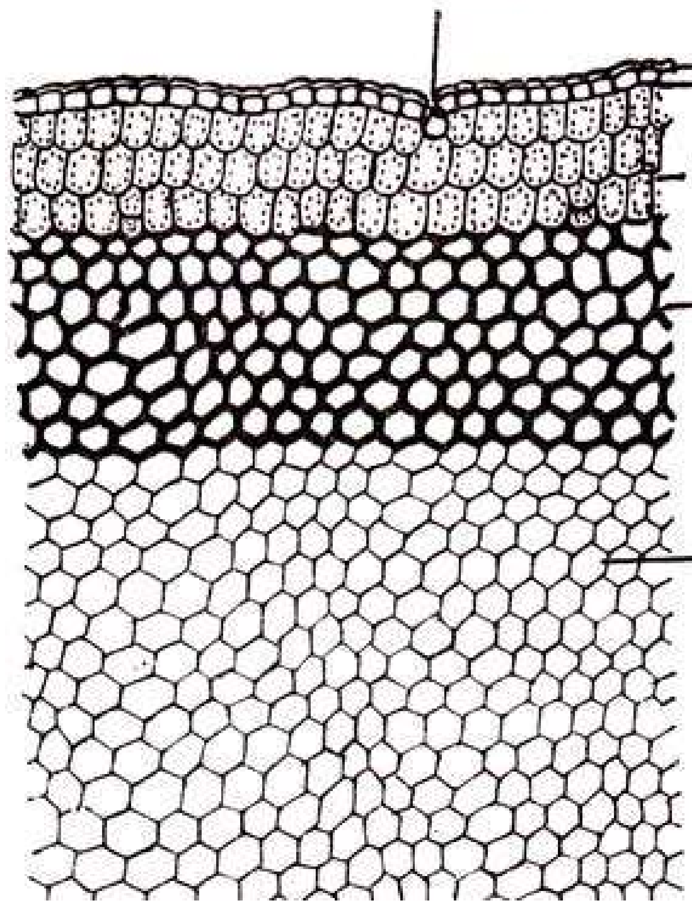


Cortex

c) Parenchymatous

They form the major portion of the stem.

The cells are thin walled and no inter cellular spaces in them



Steler system

The stele of Psilotum consists of following parts a, while pericycle and pith are usually absent.

1. Endodermis

There is well developed endodermis between the stele and the cortex. These cells has casparian bands on their radial walls

2: Xylem :

The xylem is actinostelic and radial in outside in 6 rays, the protoxylem is located at the tip of the rays. In the center the metaxylem xore is present

The cells of xylem are thick walled and their main function is transport of nutrients

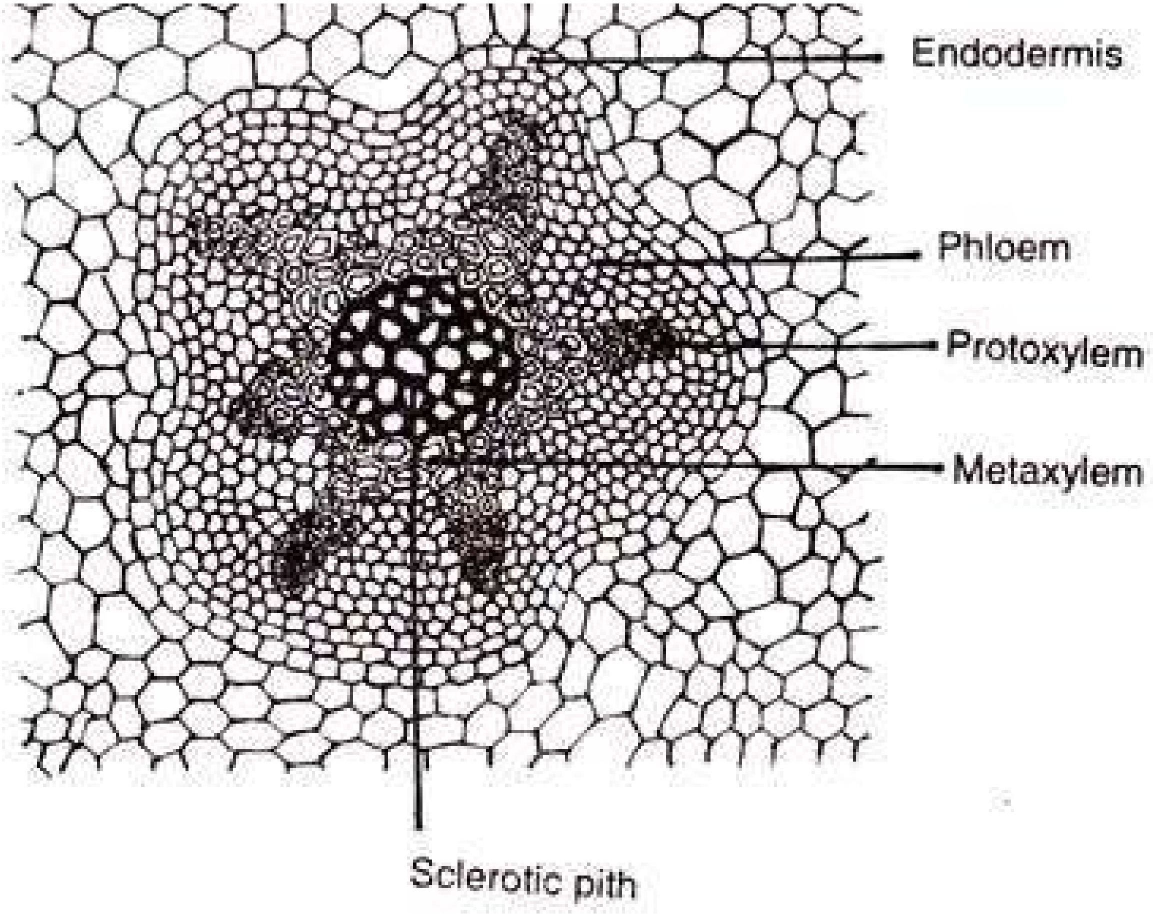


Fig. 21. *Psilotum* : T.S. of Aerial Shoot (a sector enlarged)

Steler system

4: Phloem

Between the endodermis and the xylem there is phloem.

It is of thin walled cells

It consist of sieve cells and sieve areas in their oblique end walls. Nuclei disintegrate at maturity

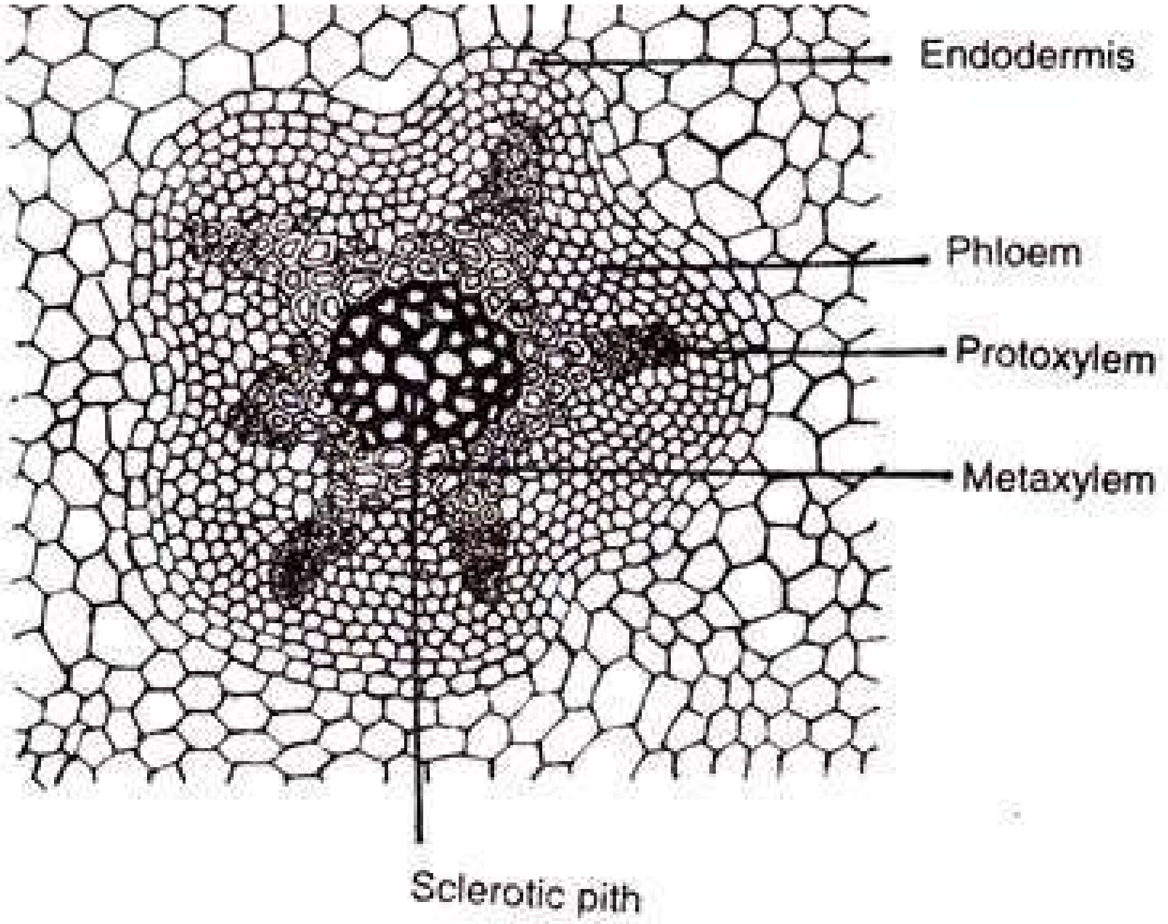


Fig. 21. *Psilotum* : T.S. of Aerial Shoot (a sector enlarged)

Anatomy of rhizome

In rhizome the epidermis is inconspicuous and all the cells of outermost layer of cortex extend into rhizoids.

The cortex is thin walled and cells contain fungus

The endodermis is conspicuous

The stele in rhizome is protostele (xylem is surrounded by phloem)

The pith is absent

And xylem occupies center of the axis and surrounded by the phloem

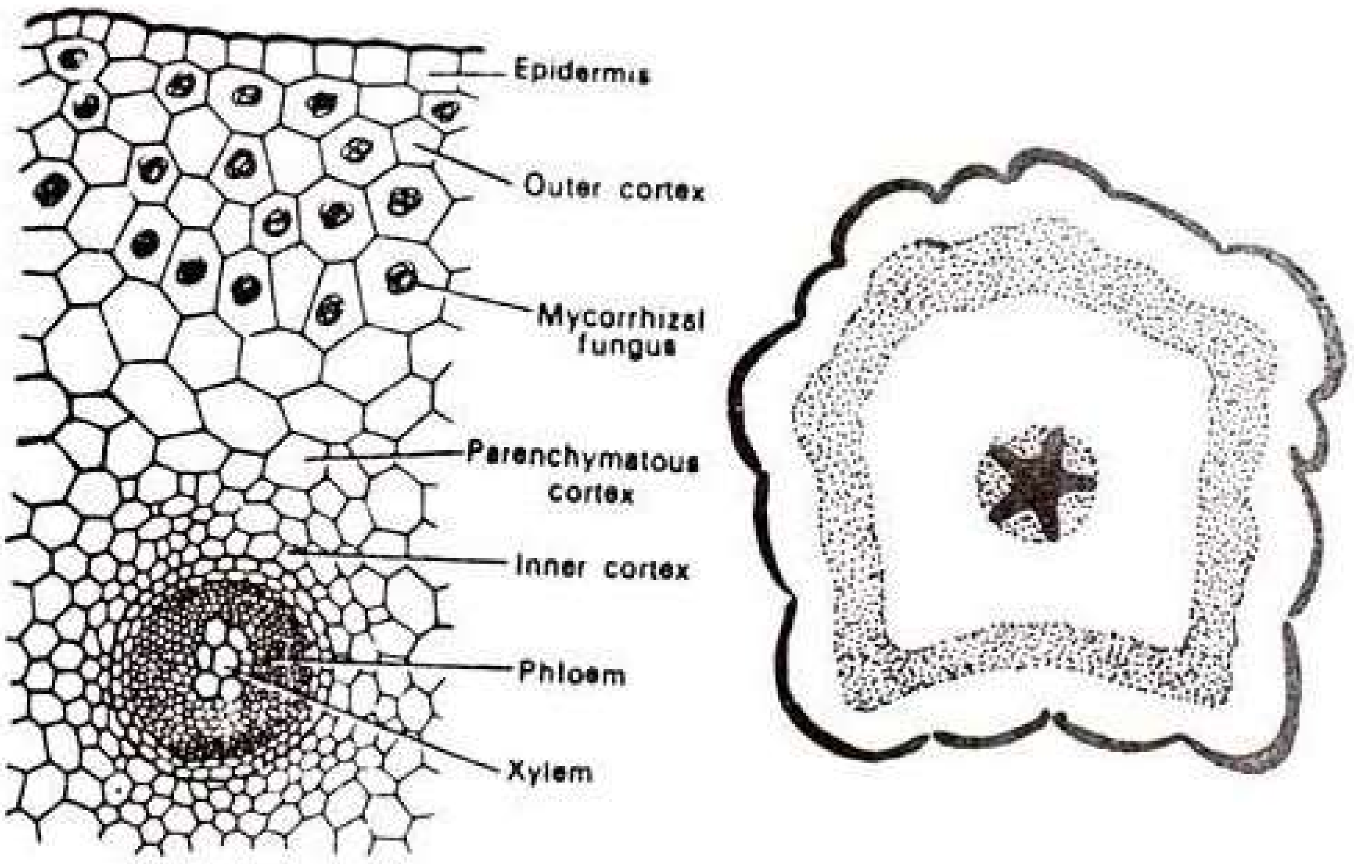


Fig. 20. *Psilotum* : T.S. of Rhizome.
A. Sector Enlarged, B. Ground Plan.

Reproduction

- It is characterized by alternation of
generation
- Both spore producing and gamete producing regeneration are independent
- Sporophyte reproduces by asexual
reproduction
- Gametophyte reproduces by sexual reproduction

Asexual reproduction (the sporophyte)

Sporophytes reproduces by formation of asexual reproductive units ,

Called as spores , produced in complex
trilobed structure synangium

Structure of synangium

Each synangium is trilobed , stalked structure borne at the apex of short lateral branch .

A bilobed appendage is present at the base of each synangium that curve and surround the stalk of synangium

Nature of synangium

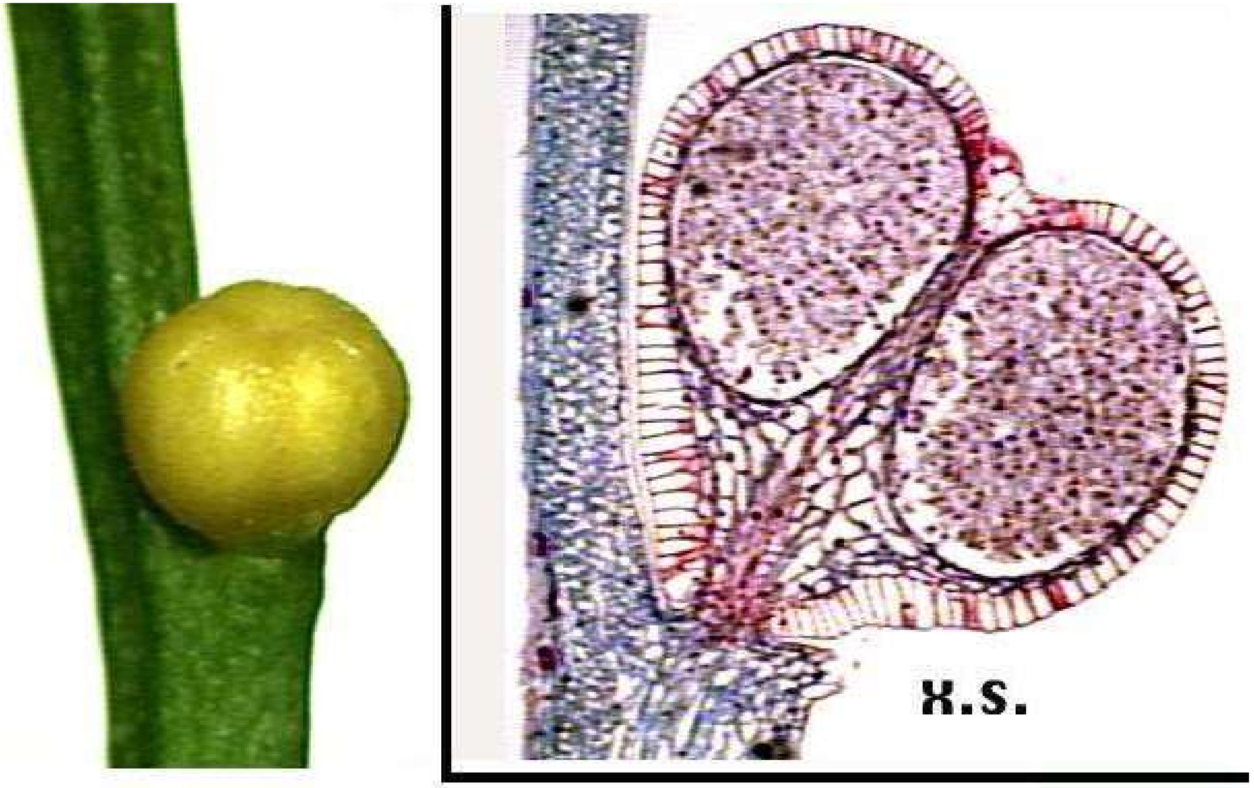
There are different views

1.The trilobed synangium is formed by fusion of two or more sporangia

2.One sporangium with 3 chambers (trilocular sporangium)

3.Synanium is cauline (developed at the apex of stem) in nature and it is actually modified trilocular sporangium present on lateral branches

4.This concept was suggested by Bierhorst (1956) according to him each unit in synangium represents a condensed fertile axis. The synangium in Psilotum can be considered as homologus to fertile portion of (Rhynia) where one arm is fertile and other is sterile . The condensation of fertile arm is modified into synangium .the bract modified to surround the synangium



Psilotum
Sporangium

Structure of synangium

It consist if three chambers or locules.

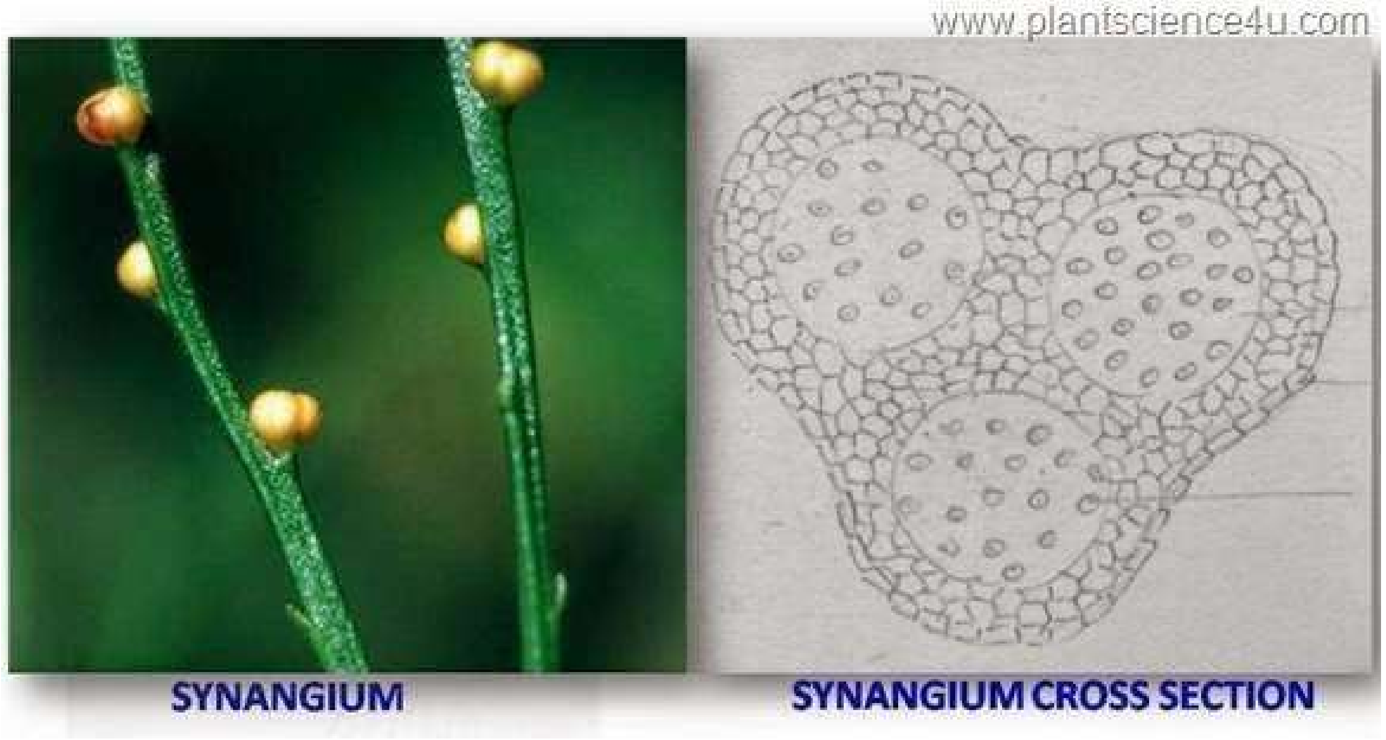
1.Wall of synangium is 3 – 4 layers

2.Thick outer wall forms the epidermis

3.Inner wall separates the three locules

4.Each locule is filled up with large number of spore. And these are homosporous in nature

5.Synangium splits up from 3 lines along the epidermis and dehiscence occurs.



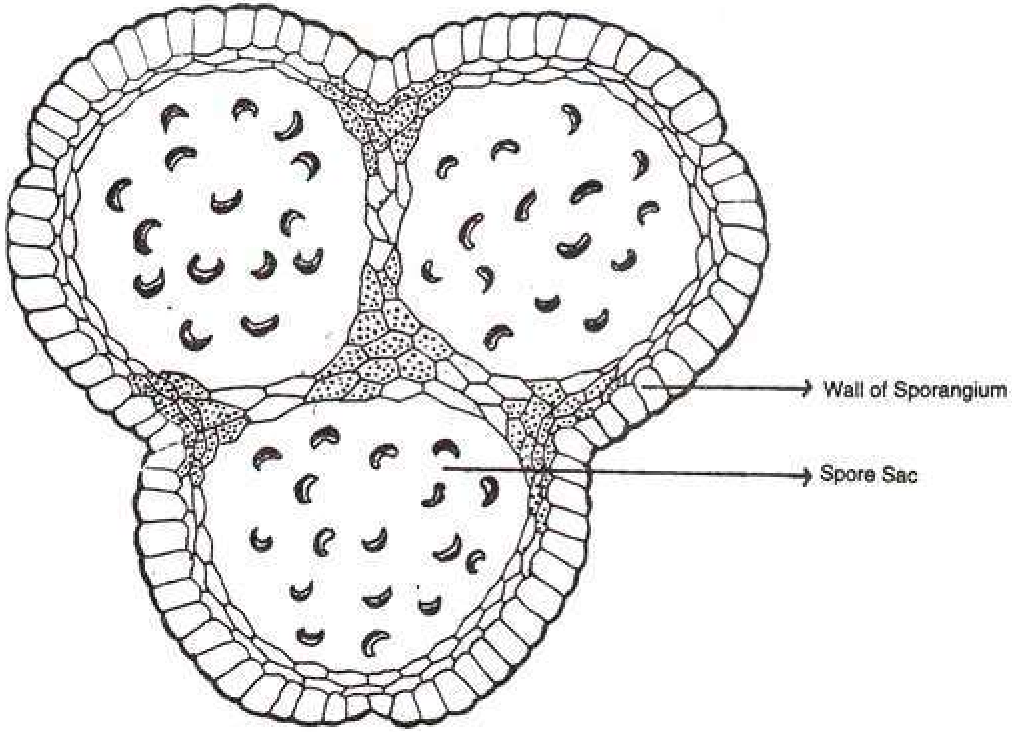
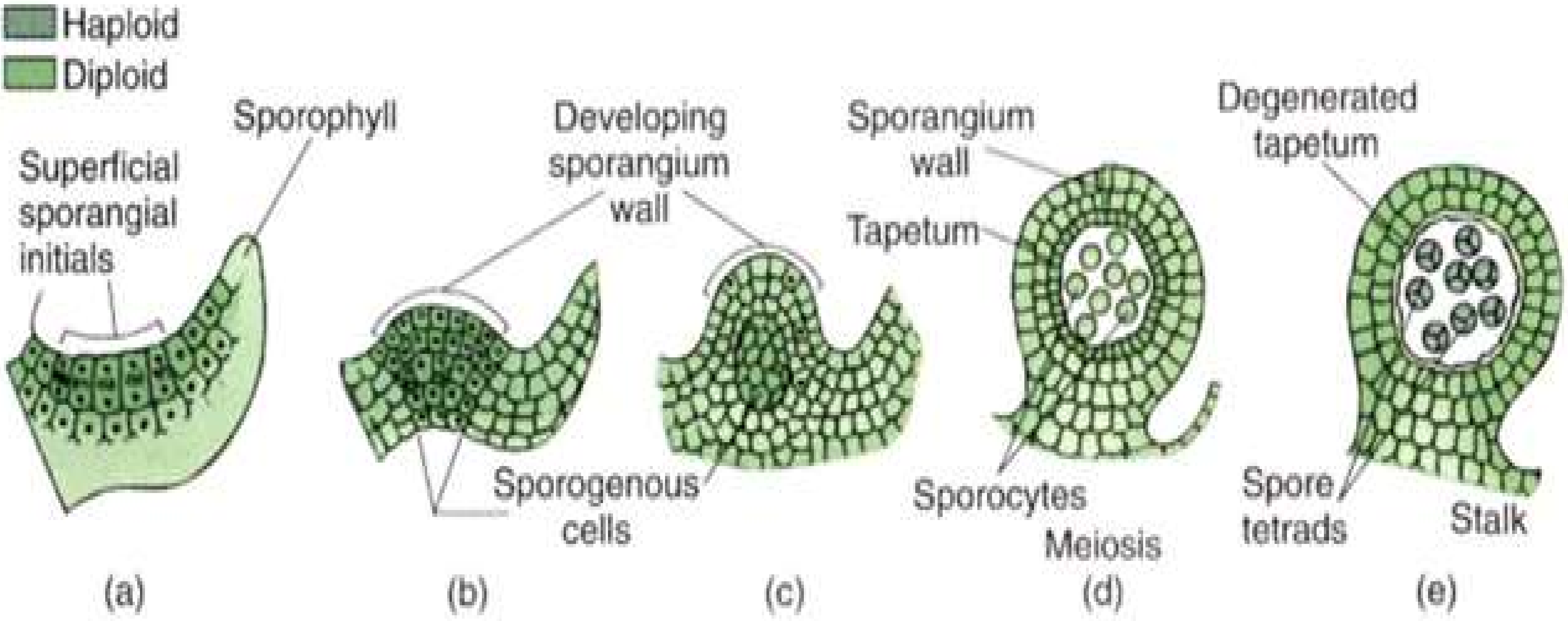


Fig. 24. *Psilotum*, T.S. of Mature Synangium with Spores



Development of eusporangia. (a) Surface cells undergo divisions and the inner daughter cells become sporogenous. (b to e) Further divisions result in a large number of spores and a thick sporangium wall.

Sexual reproduction (gametophyte)

The **gametophyte** lives underground as a saprophyte, sometimes in a mycorrhizal association. When the **gametophyte** is mature, it produces both egg and sperm cells. ... The **gametophyte of Psilotum** is unusual in that it branches dichotomously, lives underground and possesses vascular tissue.

The gametophyte of Psilotum is called as Prothallus .

It contains parenchyma cells and there is strand of tracheids extending back from the apex.

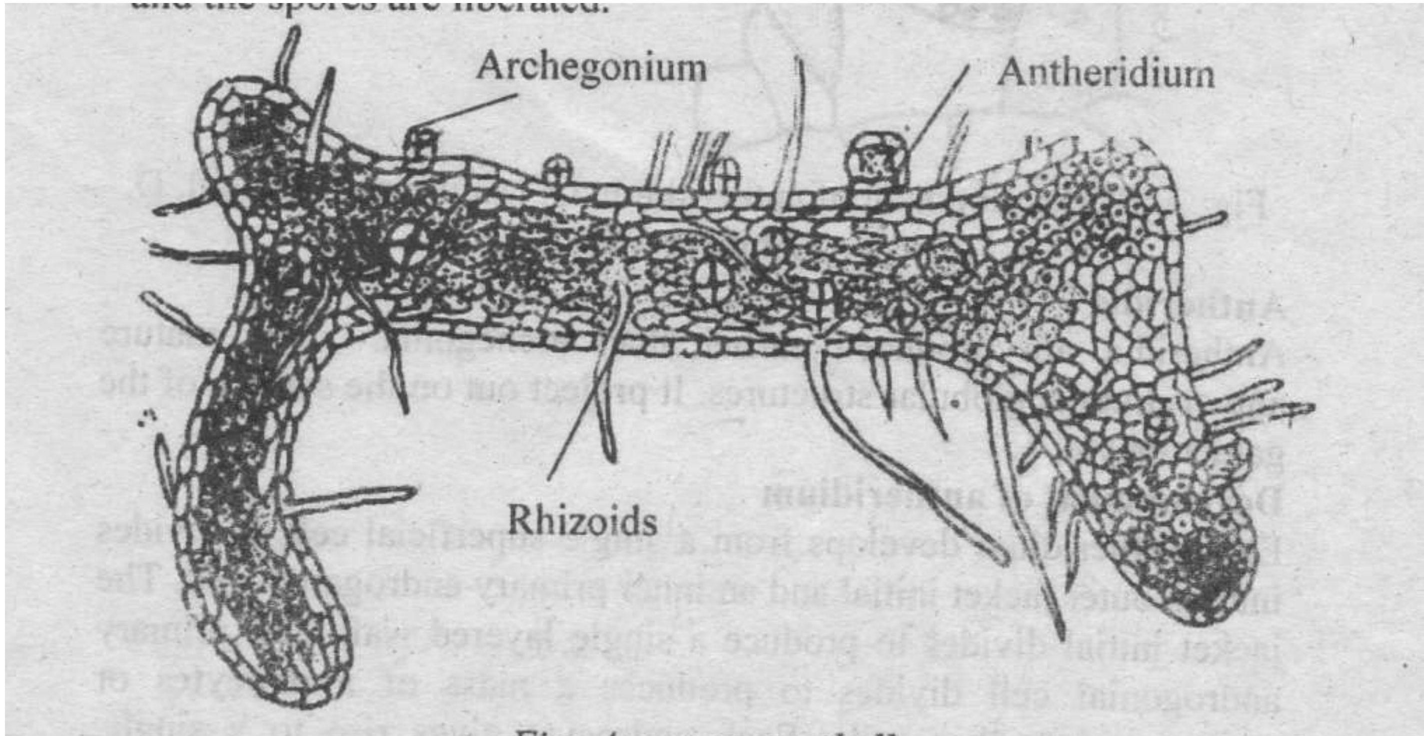


Fig: A mature prothellus

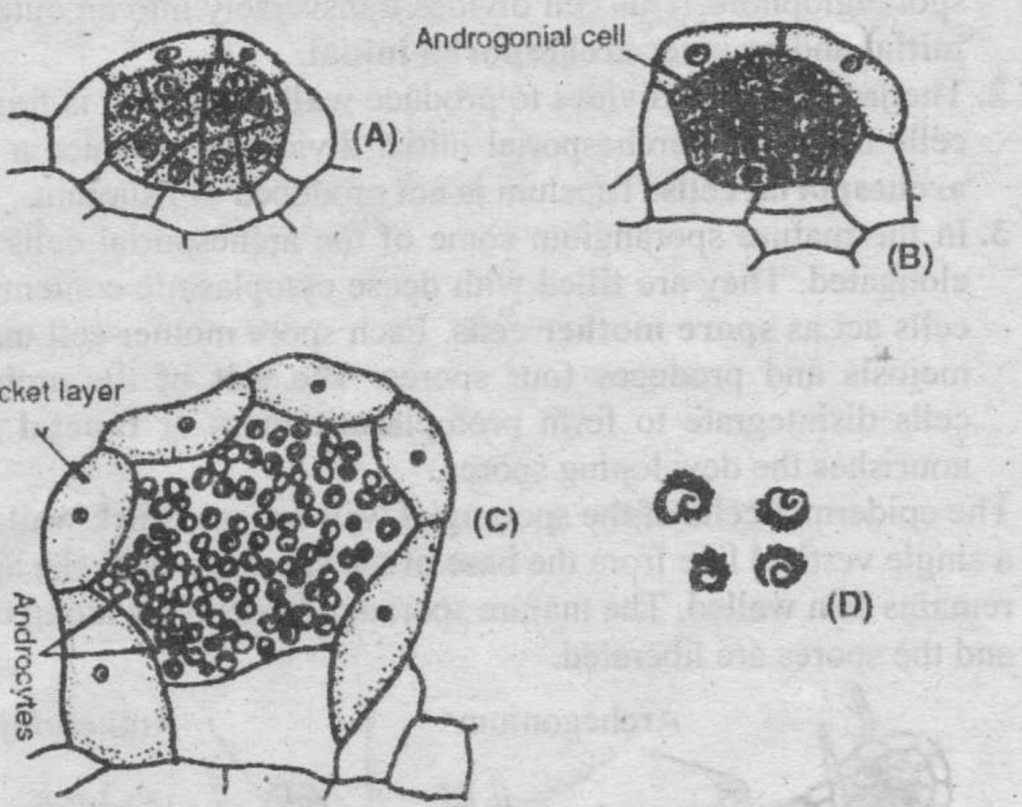
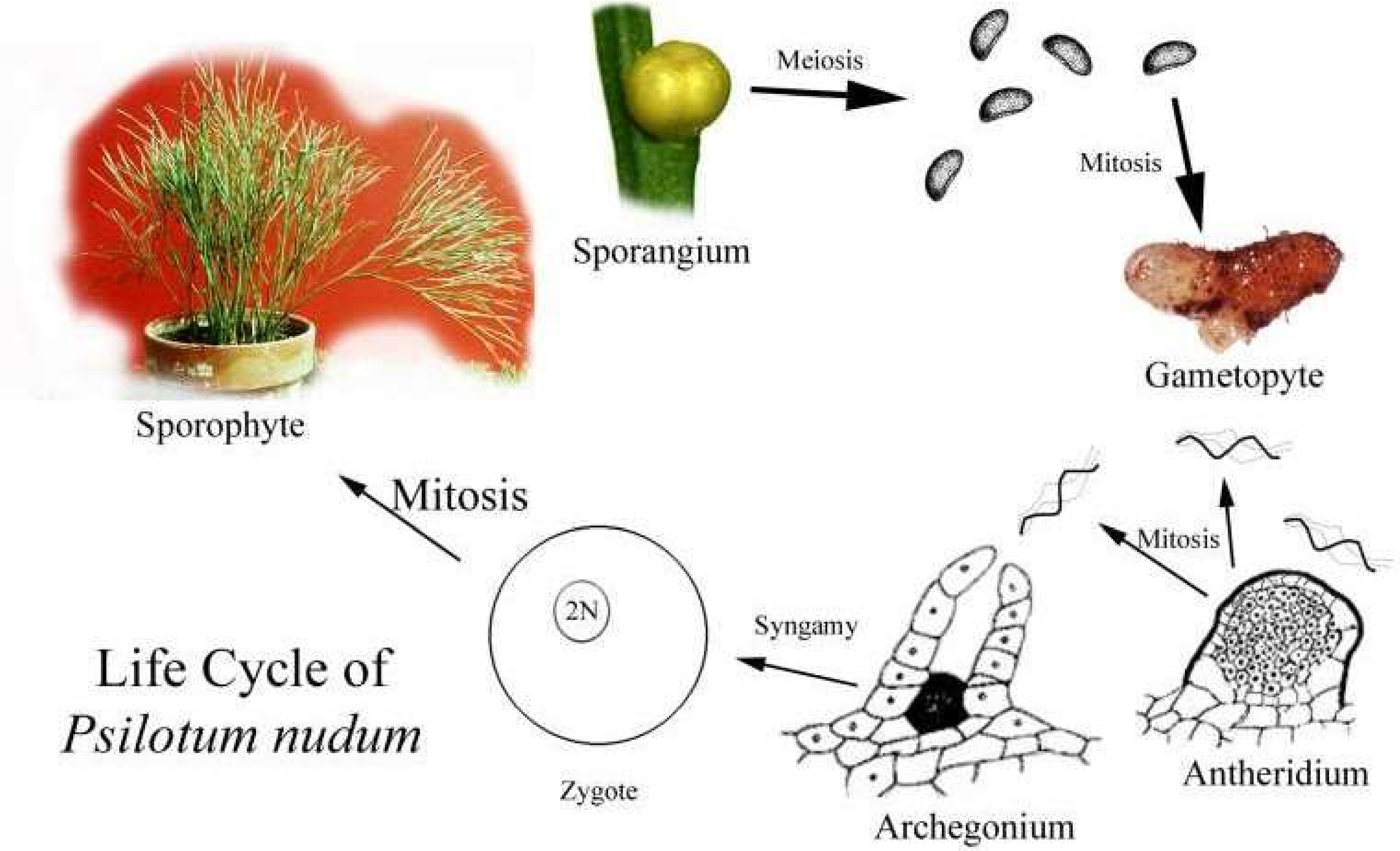


Fig: A-B: Development of antheridium, C: Mature antheridium, D. Antherozoid



Sporangium
Meiosis
Mitosis
Gametopyte
Sporophyte
Mitosis
Mitosis
2N
Syngamy
Life Cycle of
Psilotum nudum
Zygote
Archegonium
Antheridium

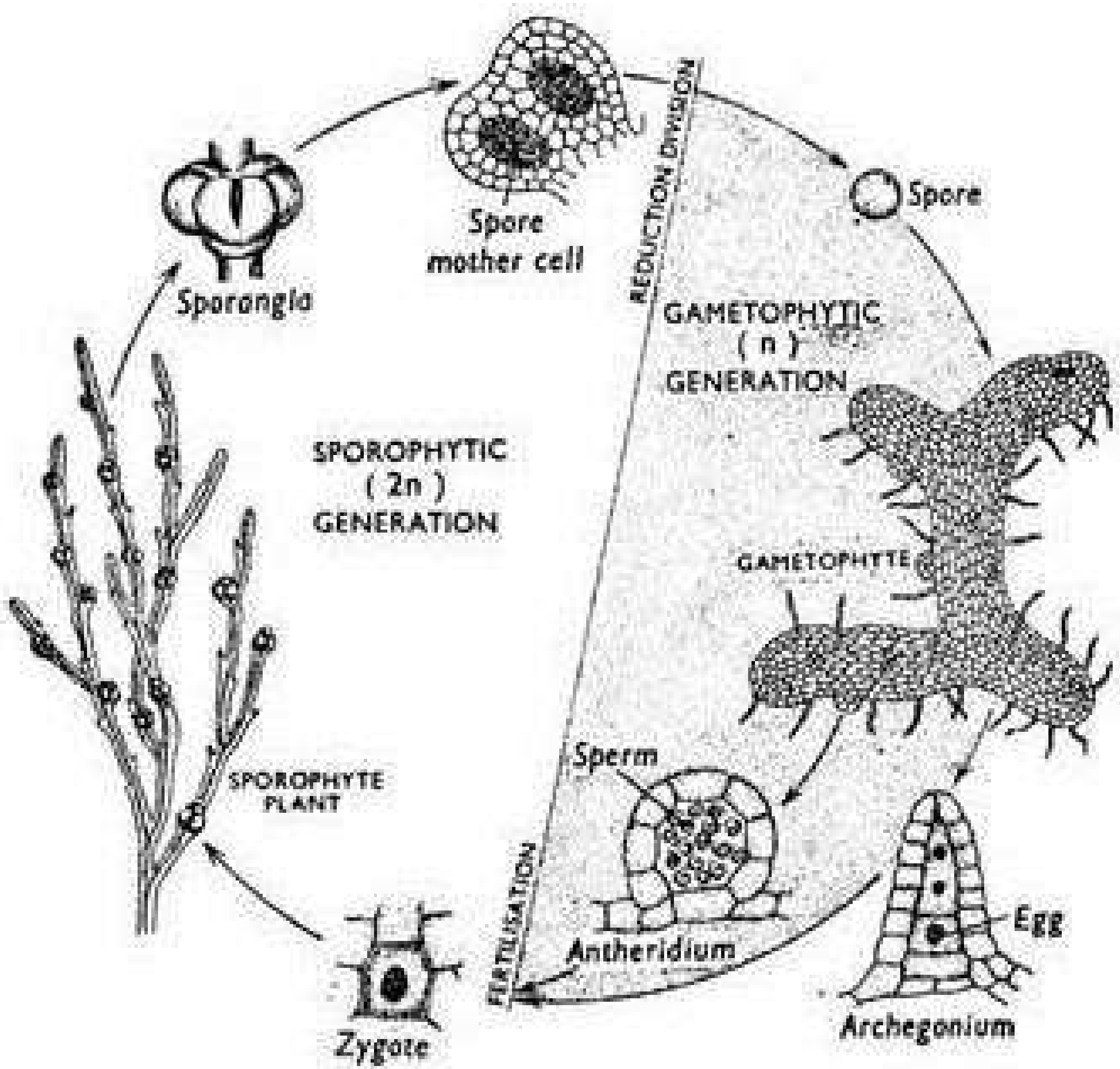


Fig. 7.22 : Life cycle of *Psilotum*

LYCOPODIUM

- **Division** : Lycophyta
- **Class** : Eligulopsida
- **Order** : Lycopodiales
- **Family** : Lycopodiaceae
- **Genus** : Lycopodium

There are about 180 species in this genus.

- The living Lycopodiales are the representatives of a group which, during the Carboniferous period, formed the chief vegetation.

Many of the types then growing,e.g., Lepidodendron, were large trees.

- The modern representatives are small and herbaceous sporophytes
- The leaves are small and simple. Each leaf possesses an unbranched midrib.
- The leaves have no ligules. There are no leaf gaps in the stele of the stem.
- The sporophylls may or may not be restricted to the terminal.
- The sporophylls and simple vegetative leaves may be similar or dissimilar. They possess homosporous sporangia, i.e., all the spores of one kind only.
- The gametophytes are wholly or partly subterranean. The antheridia remain embedded in the tissue of the prothallus. The antherozoids are biflagellate.

Distribution and Habitat

The species of Lycopodium are world-wide ir distribution.

They are mainly found in tropical and sub-tropica forests. In India they are found in the hills o Eastern Himalayas.

- The plants are commonly known as ‘ground pines’, ‘club mosses’ and ‘trailing evergreens’ many species occur in the tropics as hanging epiphytes (e.g., Lycopodium.
- These species are:
- Lycopodium clavatum, L. cernuum
- L. heamiltonii, L. setaceum
- L. phlegmaria, L. wightianum
- L. serratum, L. phyllanthum
- The most common species is L . clavatum

Sporophyte - Habit:

All species possess small, herbaceous or shrubby sporophytes.

The stem in almost all the species is delicate and weak.

Some species are epiphytic and with erect or pendant sporophytes while other species are terrestrial and have a trailing habit.(vines)

The stem and its branches are densely covered with small leaves.

Stem:

Species referred to the sub-genus Urostachya possess branched or unbranched stems that are erect or pendant but never creeping. This subgenus includes the species, eg., *L. selago*, *L. lucidulum*, *L. phlegmaria* and others.

If the stem is branched, the branching is always dichotomous. Usually the successive dichotomies are found at right angles to one another.

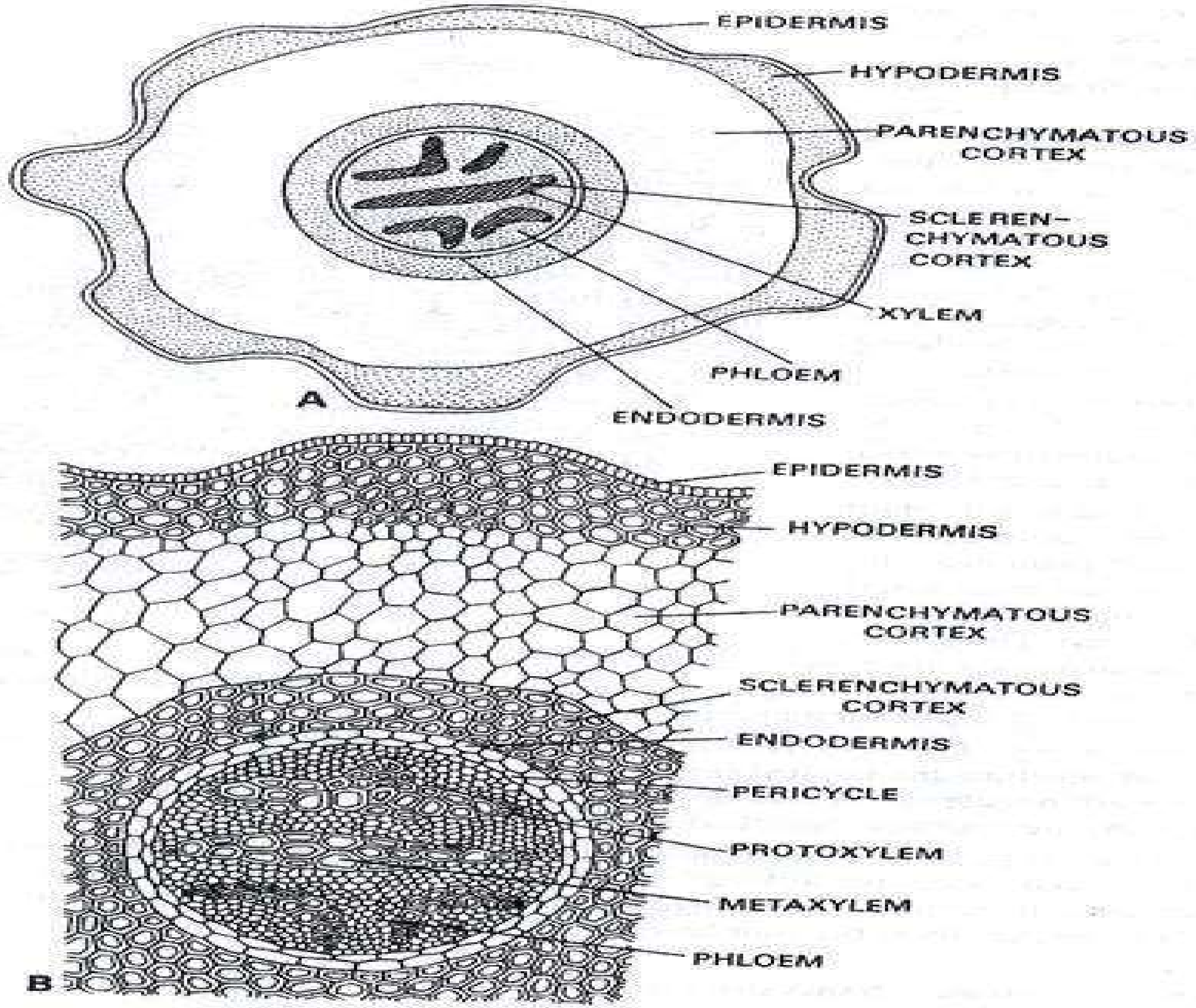


Fig. 27.3. *Lycopodium* sp. A, transverse section of stem (diagrammatic); B, transverse section of stem (detailed).

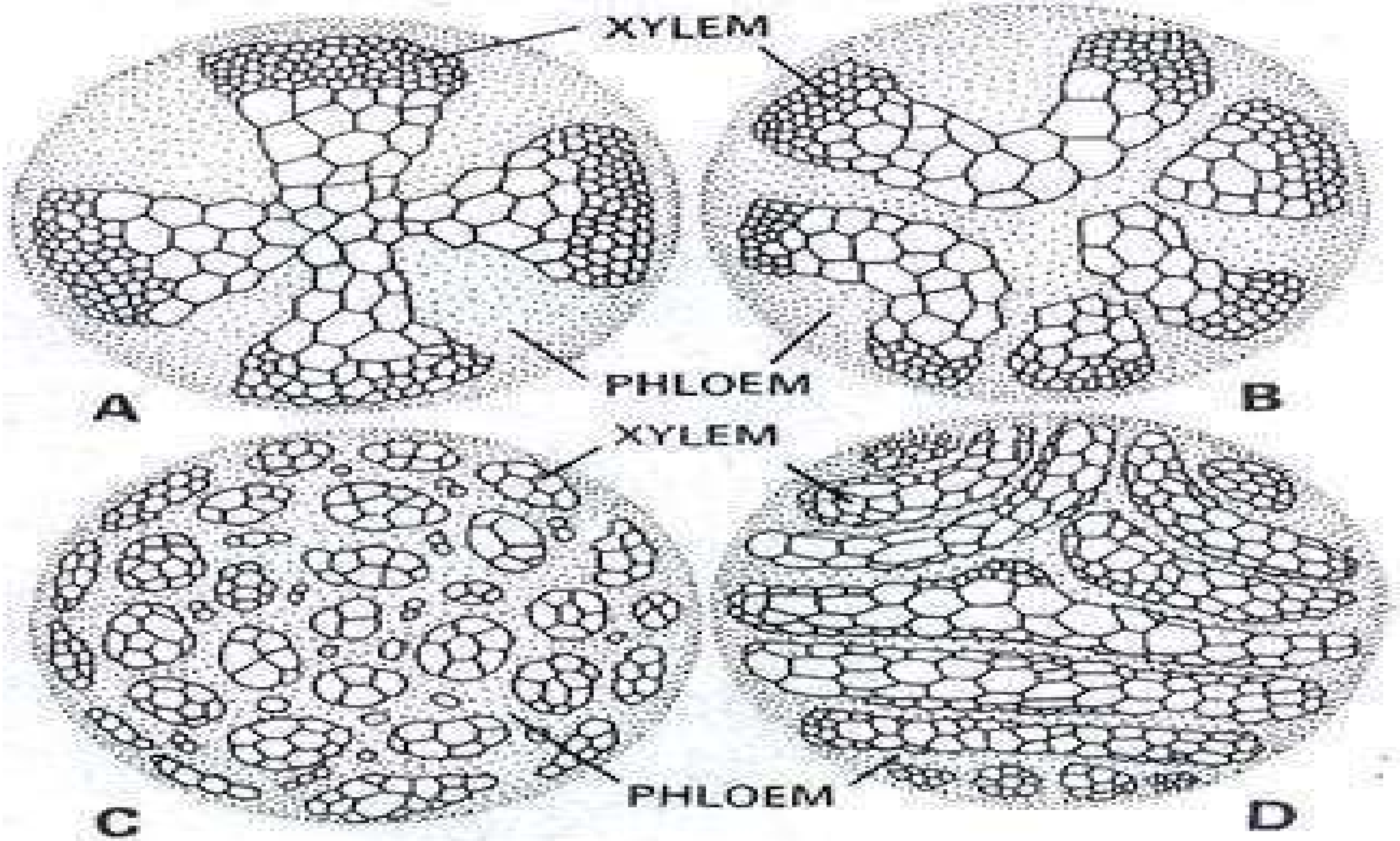


Fig. 27.4. *Lycopodium* sp. Transverse section of steles of various species of *Lycopodium*-A, *L. serratum*; B, *L. annotinum*; C, *L. cernuum*; D, *L. volubile*.

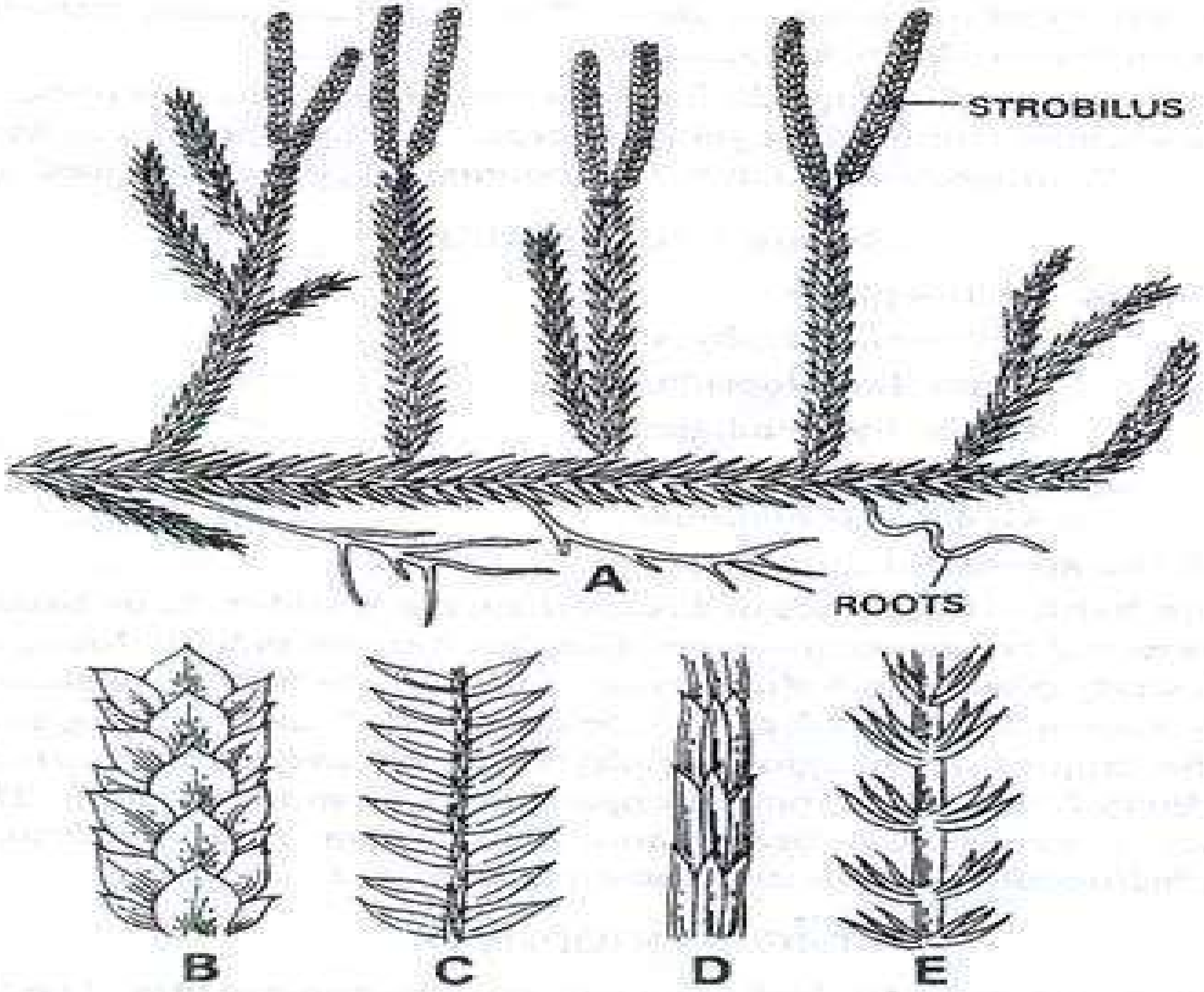


Fig. 27.1. *Lycopodium*. A, part of a plant of *L. clavatum* showing strobili; B-E, leaf form and arrangement in *Lycopodium*; B, *L. refescens*; C, *L. volubile*; D, *L. complanatum*; E, *L. cernuum*.

Leaves:

The leaves are small, simple, sessile, numerous and cover the axis closely.

Typically the leaves are 2 to 10 mm long. Usually the leaves are arranged in closed spirals (e.g., in *L. clavatum* and *L. annotinum*) while in other cases they are arranged in whorls (e.g., in *L. verticillatum* and *L. cernuum*).

In some species the leaves are found to be arranged in opposite pairs (e.g., *L. alpimum*); in others they are irregularly arranged. Usually the leaves are lanceolate (pointed)

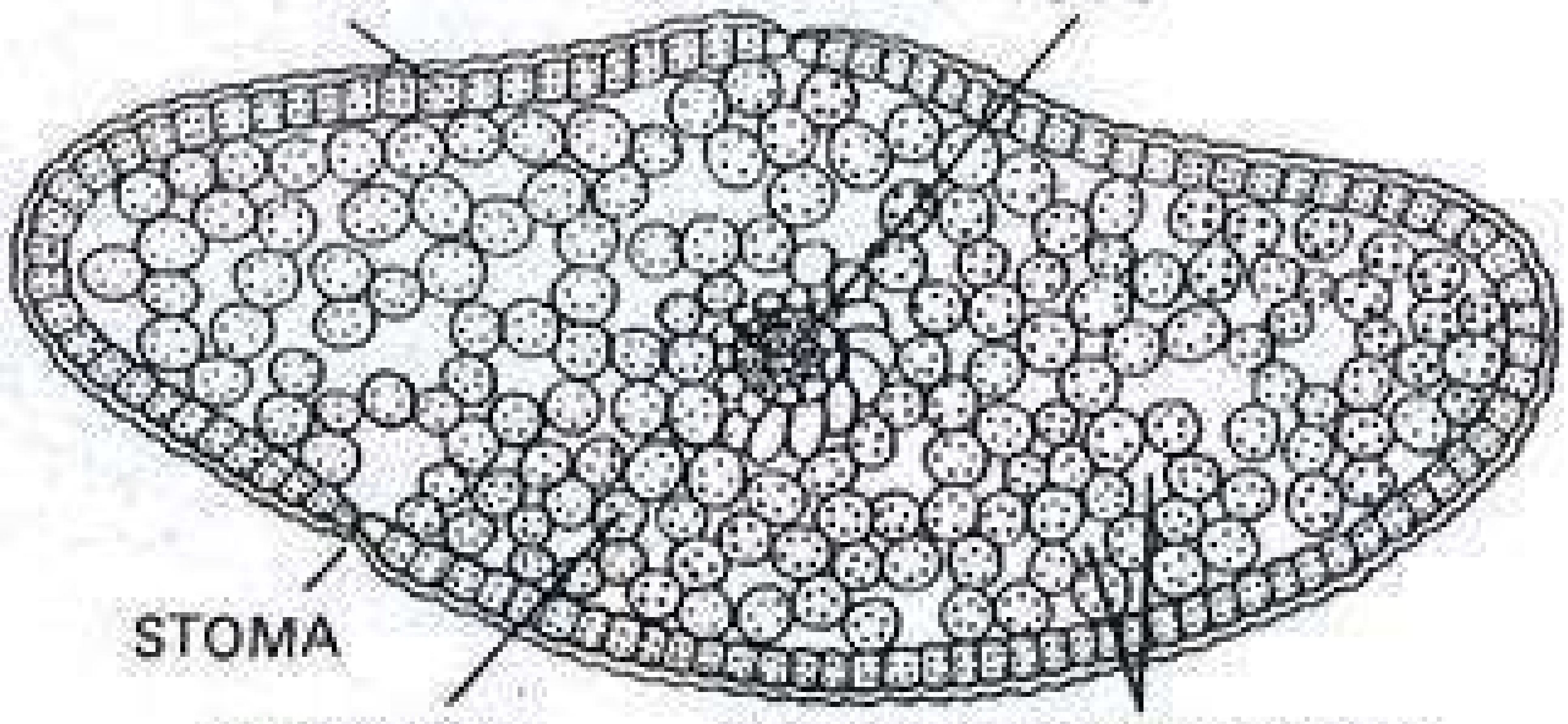


Fig. 27.5. *Lycopodium clavatum*. Transverse section of leaf.

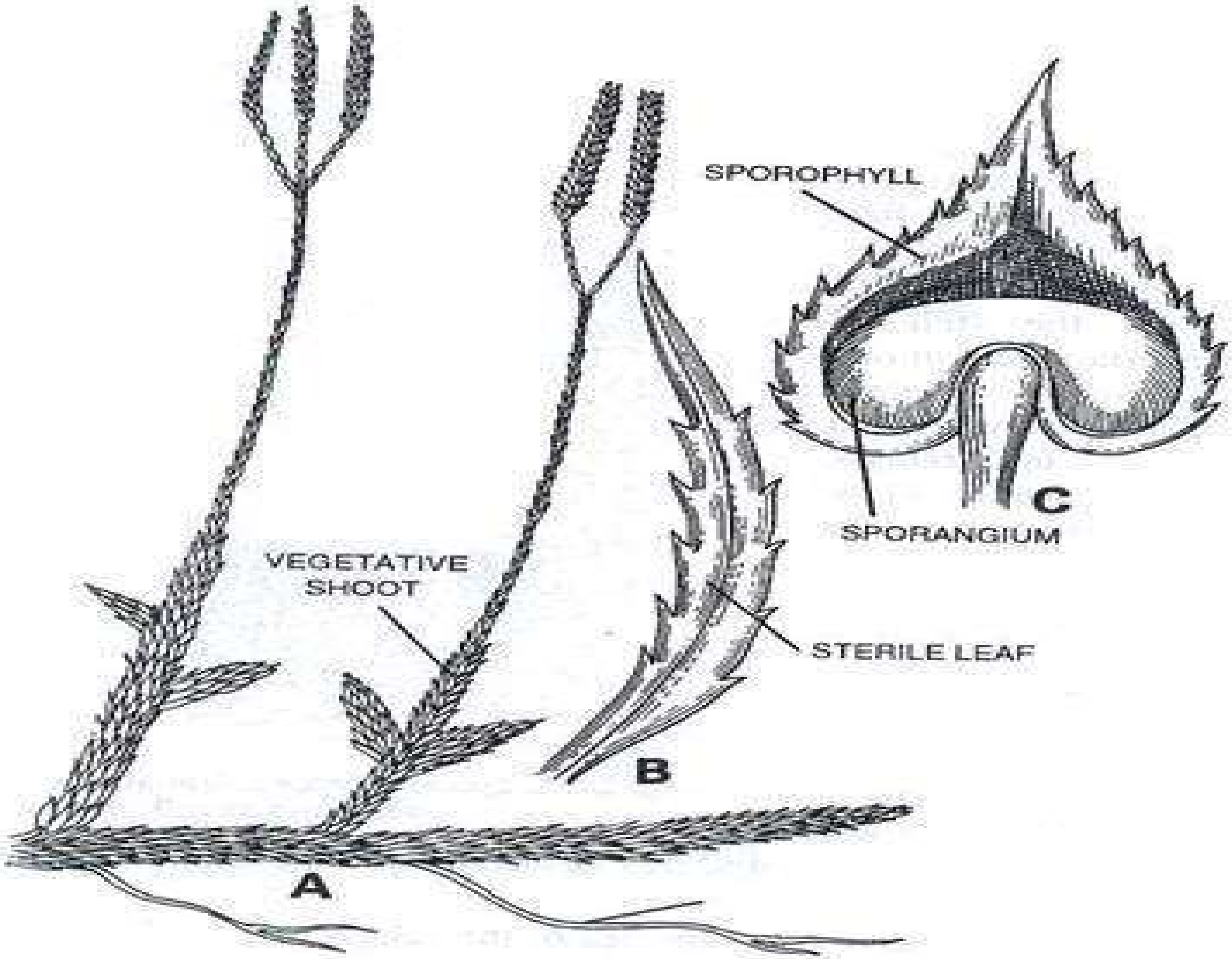
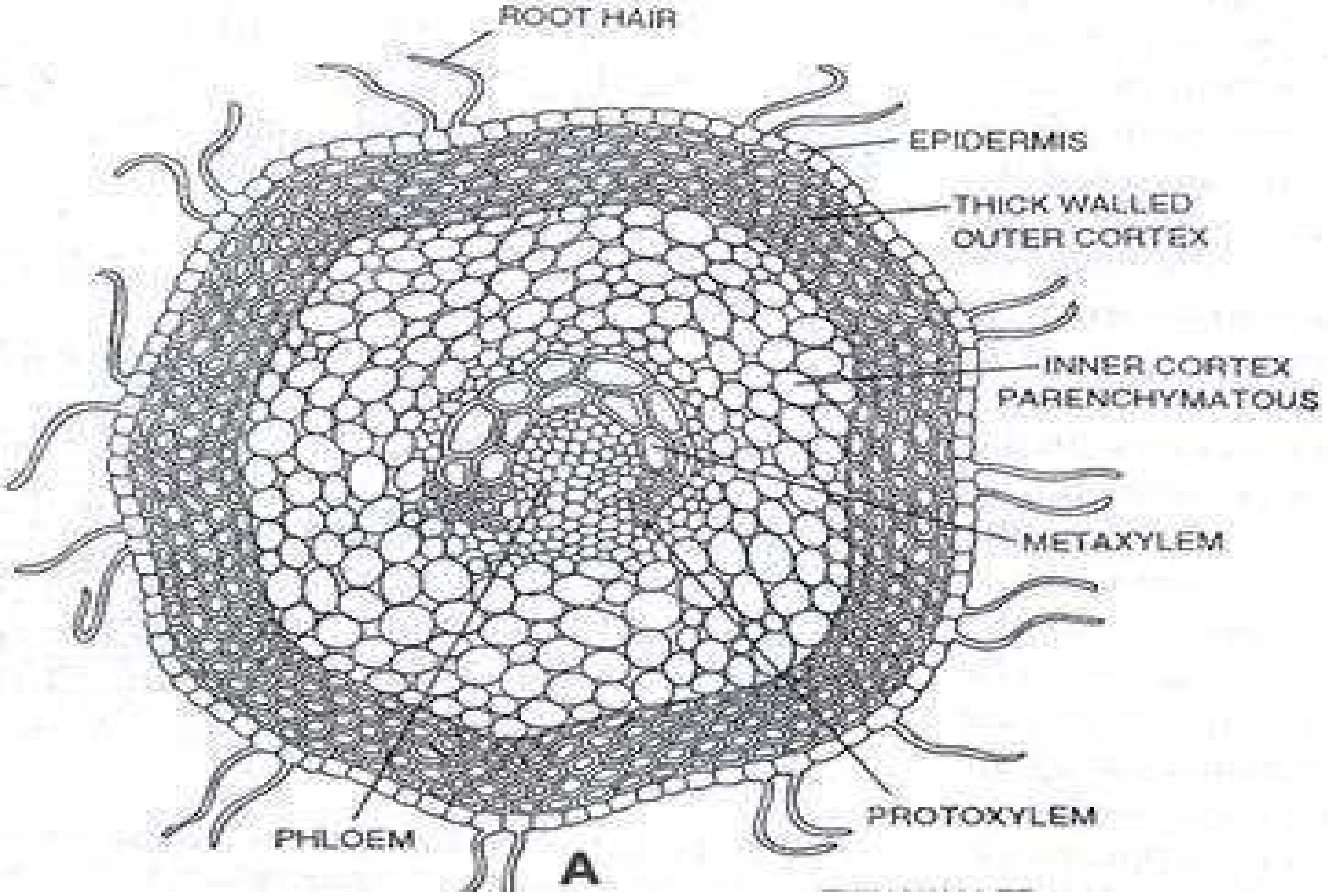


Fig. 27.8. *Lycopodium* spp. A, shoot bearing strobili; B, sterile leaf; C, sporophyll with sporangium.

ROOTS:

The roots that arise on the outside of the stele do not penetrate the cortical region of the stem at once. These roots turn downward and penetrate the soft middle cortex making canals through it, and ultimately they emerge only at the stem. Such roots are known as ‘cortical roots’


ROOT HAIR
EPIDERMIS
THICK WALLED
OUTER CORTEX
INNER CORTEX
PARENCHYMATOUS
METAXYLEM
PROTOXYLEM
PHLOEM
A

Apical growth: The apical growth of the shoot takes place by means of an apical meristem which consists of a group of apical cells.

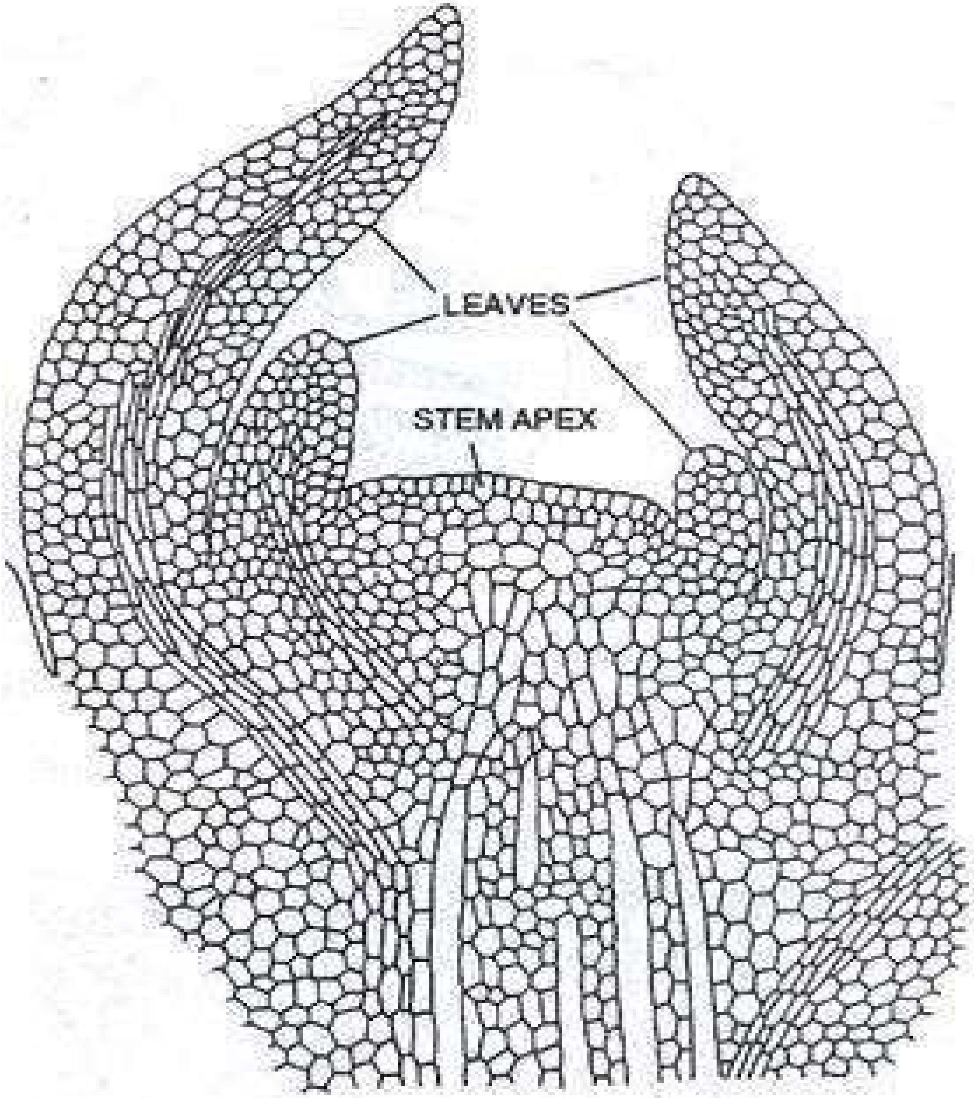


Fig 27.2. *Lycopodium* spp. L.S. of stem apex.

Vegetative propagation of the sporophyte

The new plants may be developed from

(a) vegetative propagation of the gametophyte,

(b) vegetative propagation of the juvenile stage of the sporophyte,

(c) gemmae produced from the cortical cells of the root,

(d) tubers developed at the apices of roots.

Development of sporangium

The sporangia begin to develop at a time when the sporophyll is composed of embryonic cells.

The development is of eusporangiate type.

These superficial cells are called sporangial initials These cells divide by periclinal divisions forming an outer and inner layer of cells.

The outer cells divide periclinally and anticlinally forming three celled thick wall of the sporangium

The inner daughter cells formed by this periclinal division give rise to the stalk and the basal portion of a sporangium.

The outer daughter cells contribute to the formation to the bulk of the sporangium.

The outer cells again divide periclinally forming an outer layer, the jacket initials; and an inner layer, the archesporial cells.

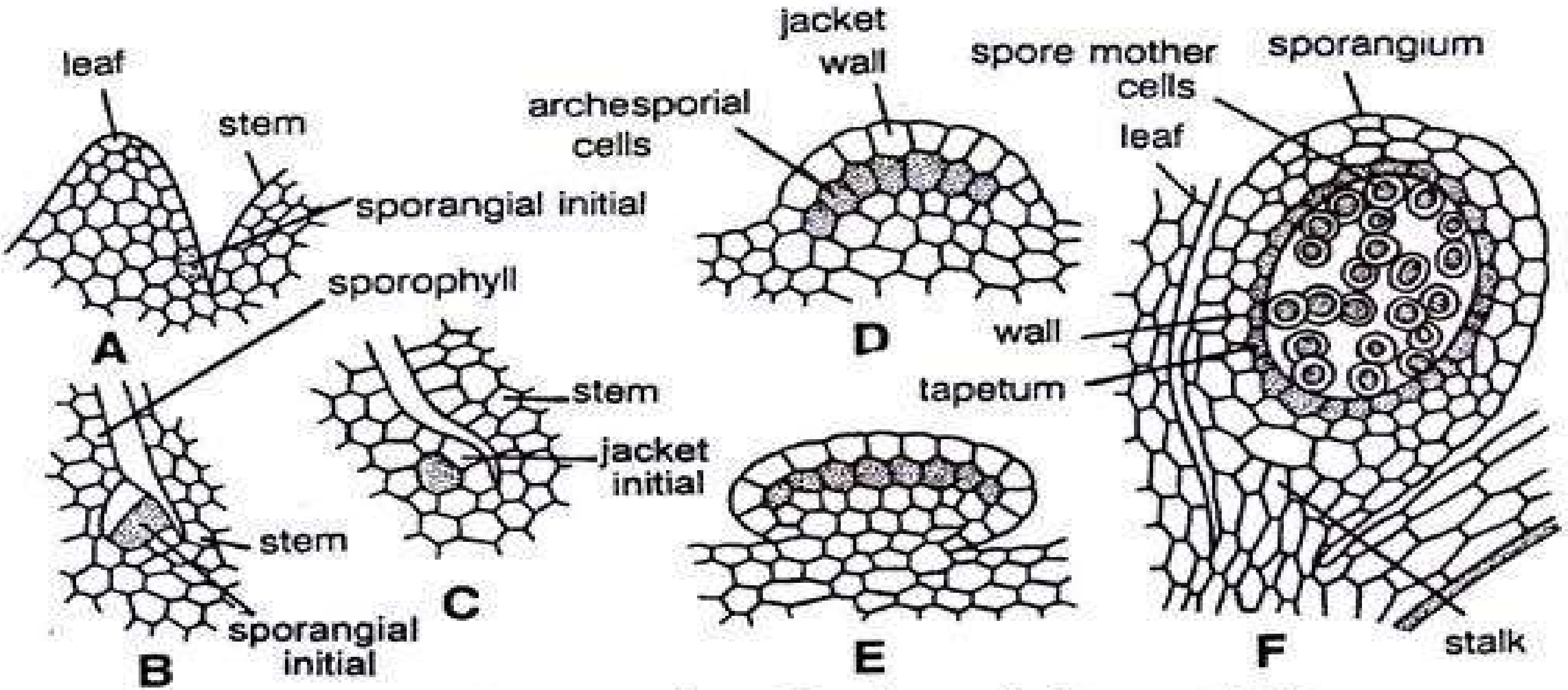


Fig. 9 (A–F). *Lycopodium* : Development of sporangium

- The archesporial cells divide periclinally and anticlinally forming a massive sporogenous tissue.
- The cells of the last generation of the sporogenous tissue act as spore mother cells.
- They become rounded and are being separated from one another.
- Now these spore mother cells float about in a viscous liquid and divide meiotically into tetrads of spores

- The jacket initials, which are found external to the sporogenous tissue divide repeatedly forming a jacket layer of three or more cells, in thickness.

- Shortly before the development of the spore mother cells a nutritive tapetal layer is formed around the This layer is partly formed from the inner-most layer of jacket cells and partly from sporangial cells found just beneath the sporogenous tissue.

- As found in most other pteridophytes, in Lycopodium there is no disintegration of the Tapetum during spore formation.

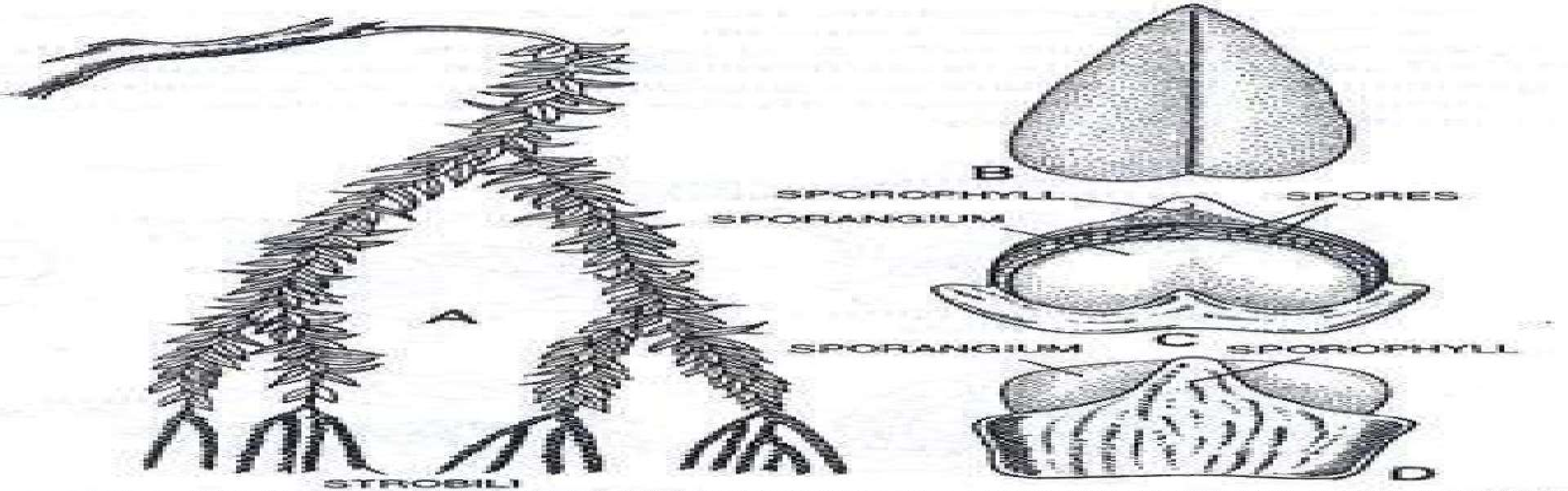


Fig. 27.9. *Lycopodium phlegmaria*. A, drooping plant with strobili

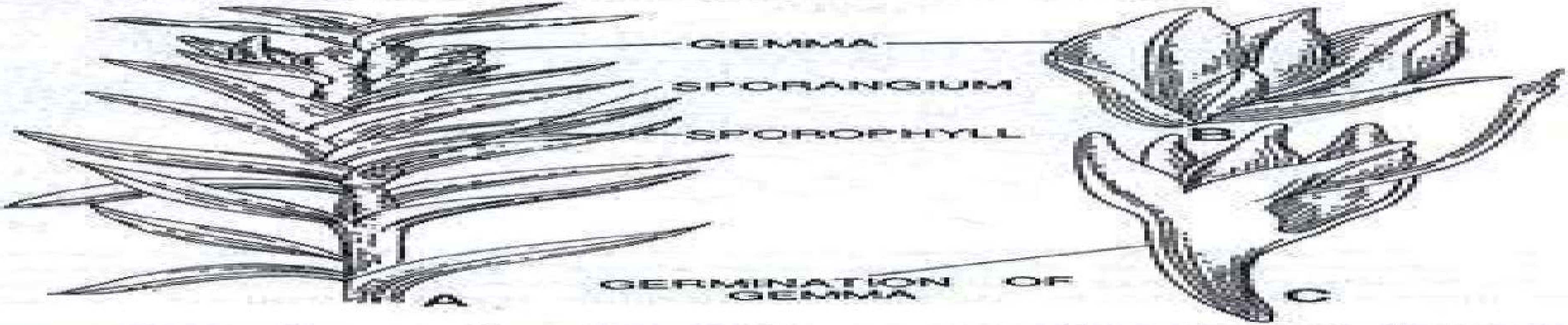


Fig. 27.10. *Lycopodium*. Vegetative reproduction. A, part of stem o
Lycopodium lucidulum bearing gemmae; B, single gemma; C,
germinating gemma of *L. selago*.

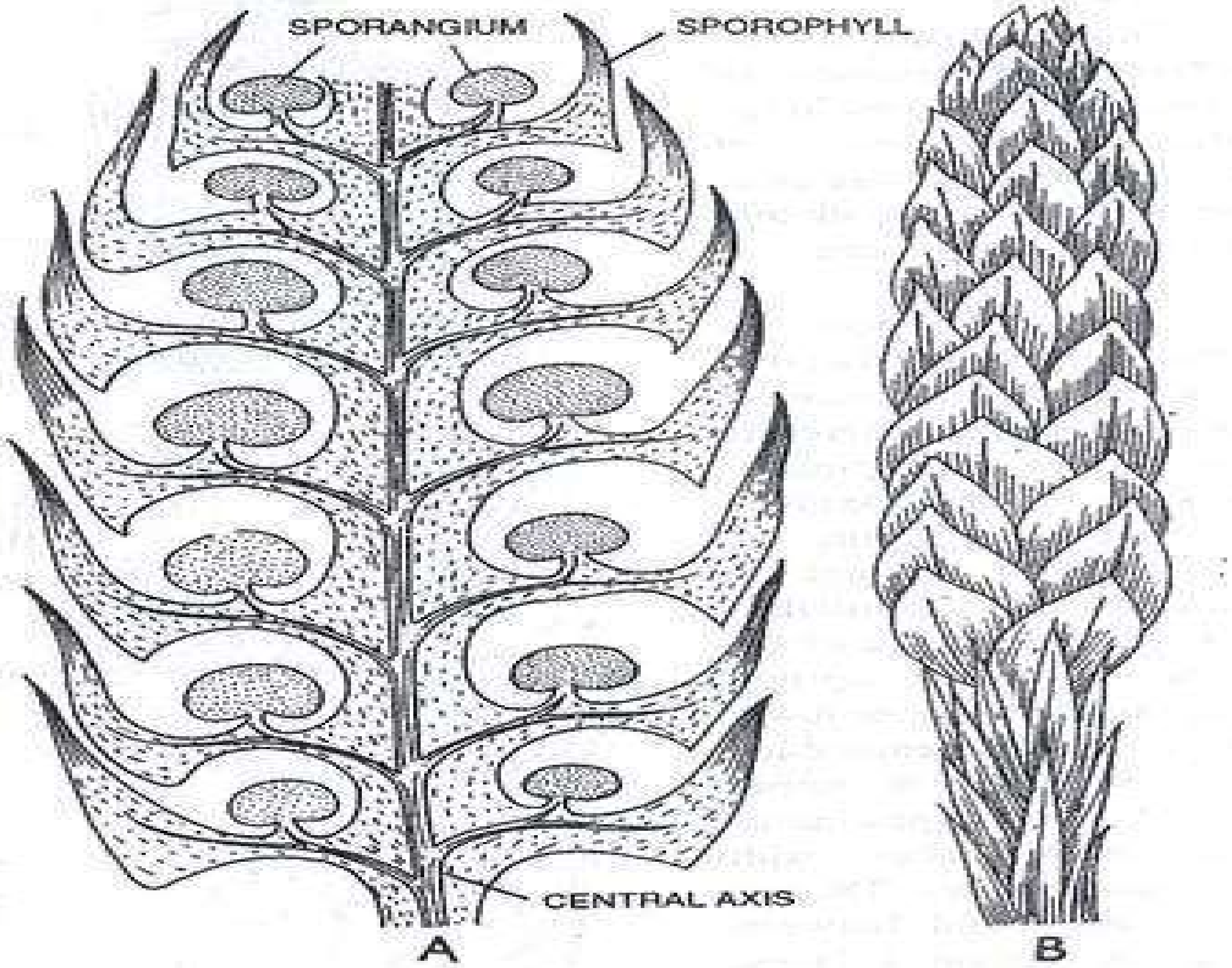


Fig. 27.12. *Lycopodium clavatum*. A, L.S. of strobilus bearing sporophylls and sporangia; B, a strobilus.

Dehiscence of sporangium

- The mature sporangium is about 2 mm across and kidney-shaped.
- On the maturity of the sporangium narrow transverse strip of cells, the stomium is formed across the apical portion of the outermost jacket layer.
- The cell walls of the stomial portion become thickened and may easily be differentiated from those of other cells present in the jacket layer of the sporangium.
- The mature sporangium ruptures by a transverse slit at its apex along the line of the stomium.
- The sporangium divides into two valves which remain united at the base and dehiscing the yellow spores.

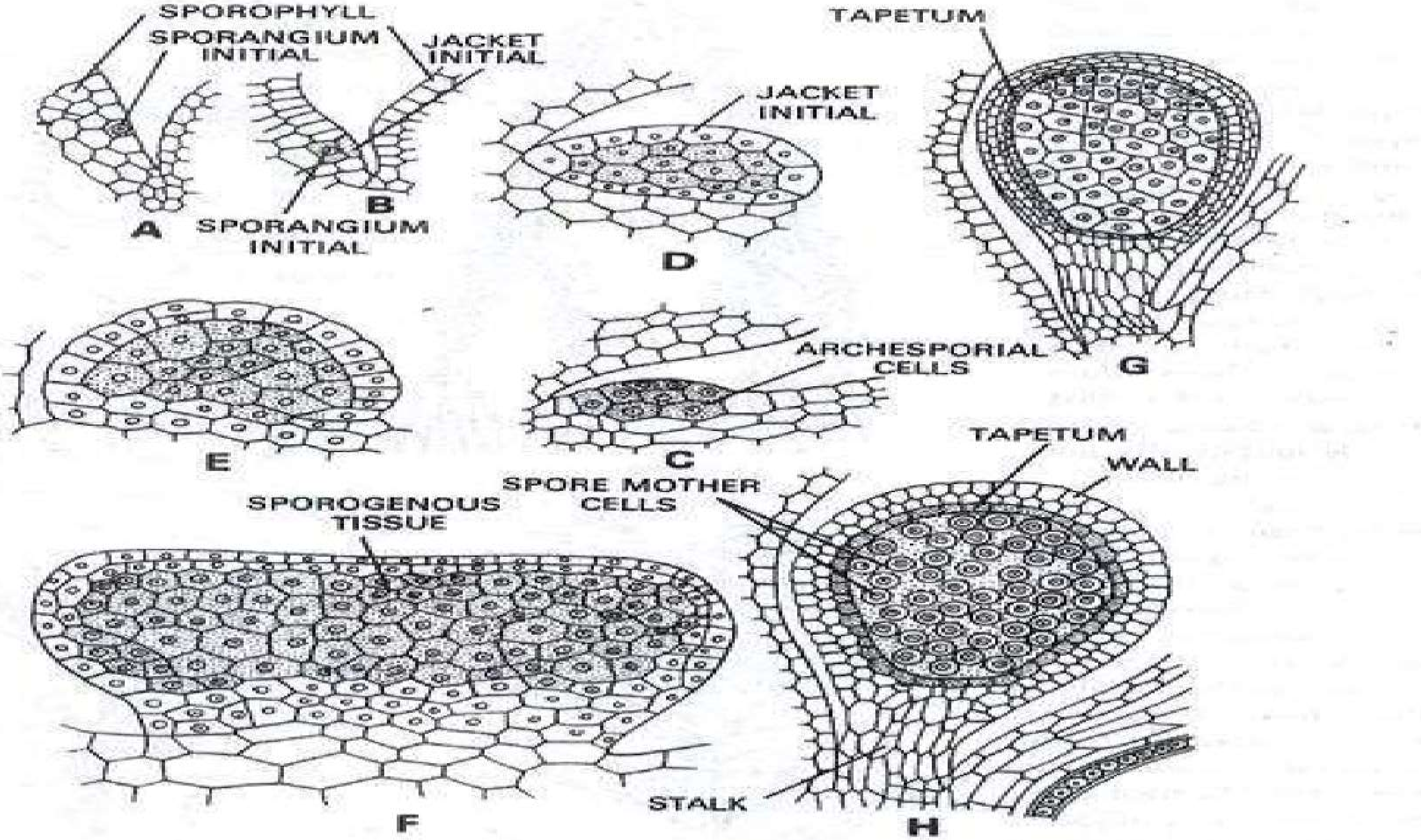


Fig. 27.11. *Lycopodium* sp. Development of sporangium-A, radial section through base of young sporophyll showing sporangial initial, B, slightly later stage; C-E, successive stages in the development of sporangium; F, sectional view of young sporangium showing sporogenous tissue; G, radial section of a later stage, showing development of tapetum; H, stalked sporangium about to mature containing spore mother cells.

Germination of spore and development of prothallus:

The small spores (*about .03 to* .05 mm. diameter) are uniform in size and shape, i.e., homosporous.

This way Lycopodium is similar to most of the ferns and Equisetum. The spores are round or tetrahedral in shape.

The spores settle on the ground after their liberation from the sporangium and each germinates into a prothallus.

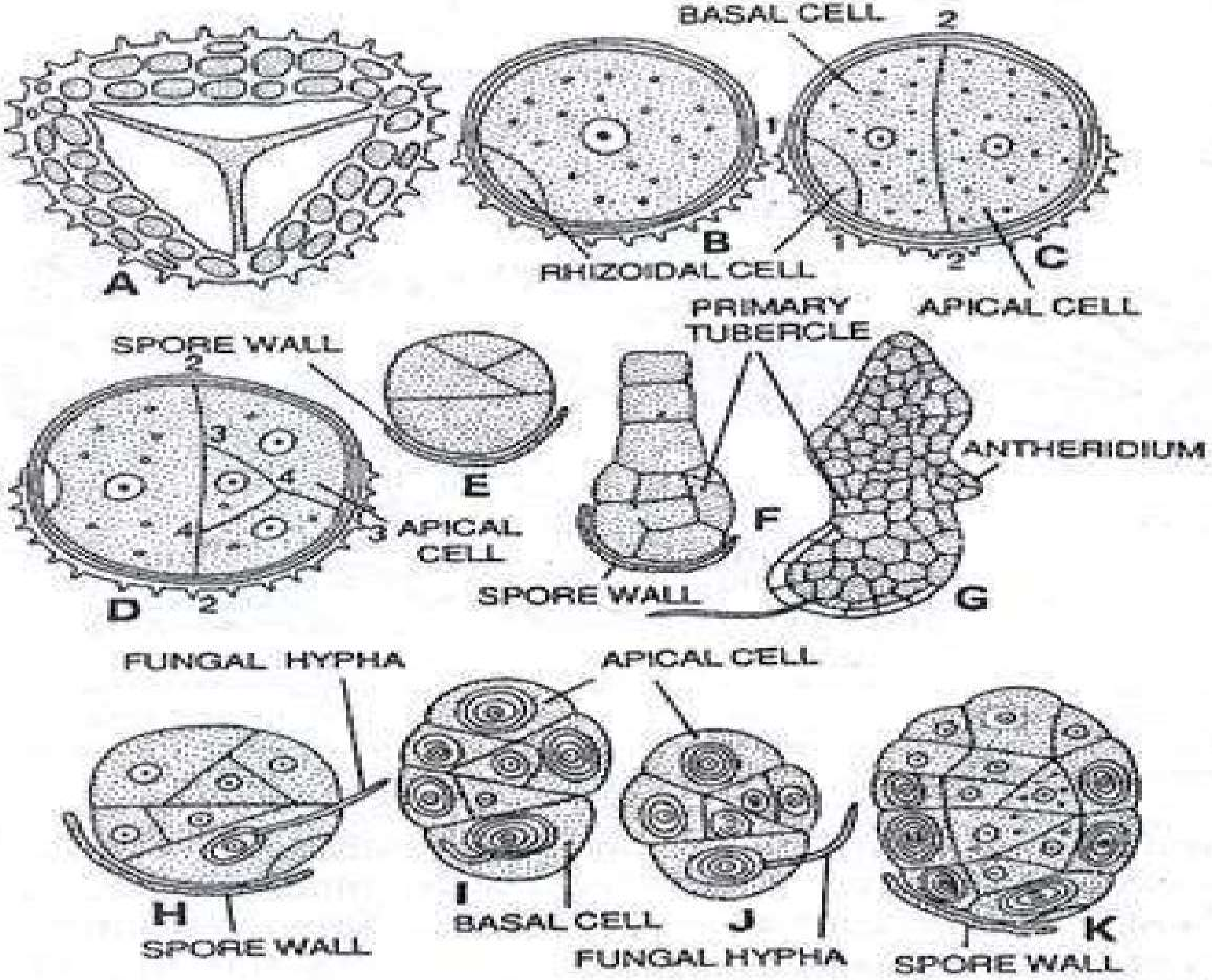


Fig. 27.15. *Lycopodium* spp. Spore germination and development of gametophyte. A, spore of *L. clavatum*; B-D, early stages in the development of gametophyte of *L. clavatum*; E-G, early stages in the development of gametophyte of *L. cernuum*; H-K, gametophytes of *Lycopodium* showing origin of mycorrhizal association.

Type I or Cernuum type:

Gametophyte is partially aerial and partly in soil. The prothalli are usually 2 to 3 millimetre in height and 1-2 millimetre in diameter. The gametophytes (prothalli) grow at the surface of the ground and consist of a colourless basal portion buried in soil and a conspicuous upright, fleshy, green aerial portion having lobes (Fig. 11 A).

The sex organs develop between the green expanding lobes. The prothallus itself is a nourishing body. The underground part contains endophytic fungus e.g., L. cernuum, L. inundatum etc.

Type II or Clavatum Type:

The gametophyte is wholly subterranean and totally saprophytic i.e., non- green structure. It is tuberous and without lobes. It may be one to two centimentre long or wide and is top shaped, conical or discoid in shape (Fig. 11 B, C). The endophytic fungus is present. Sex organs are formed on the upper surface e.g. L. annotinum, L. complanatum, L. clavatum etc.

Type III or Phlegmaria type:

The gametophyte is subterranean, saprophytic and colourless. This type of prothallus is seen in L. phlegmaria and other epiphytic species. The prothallus is about 2 millimeter in diameter and monopodially branched (Fig. 11 D). Sex organs are borne on upper surface of large branches and are interspersed with slender filaments known as paraphyses.

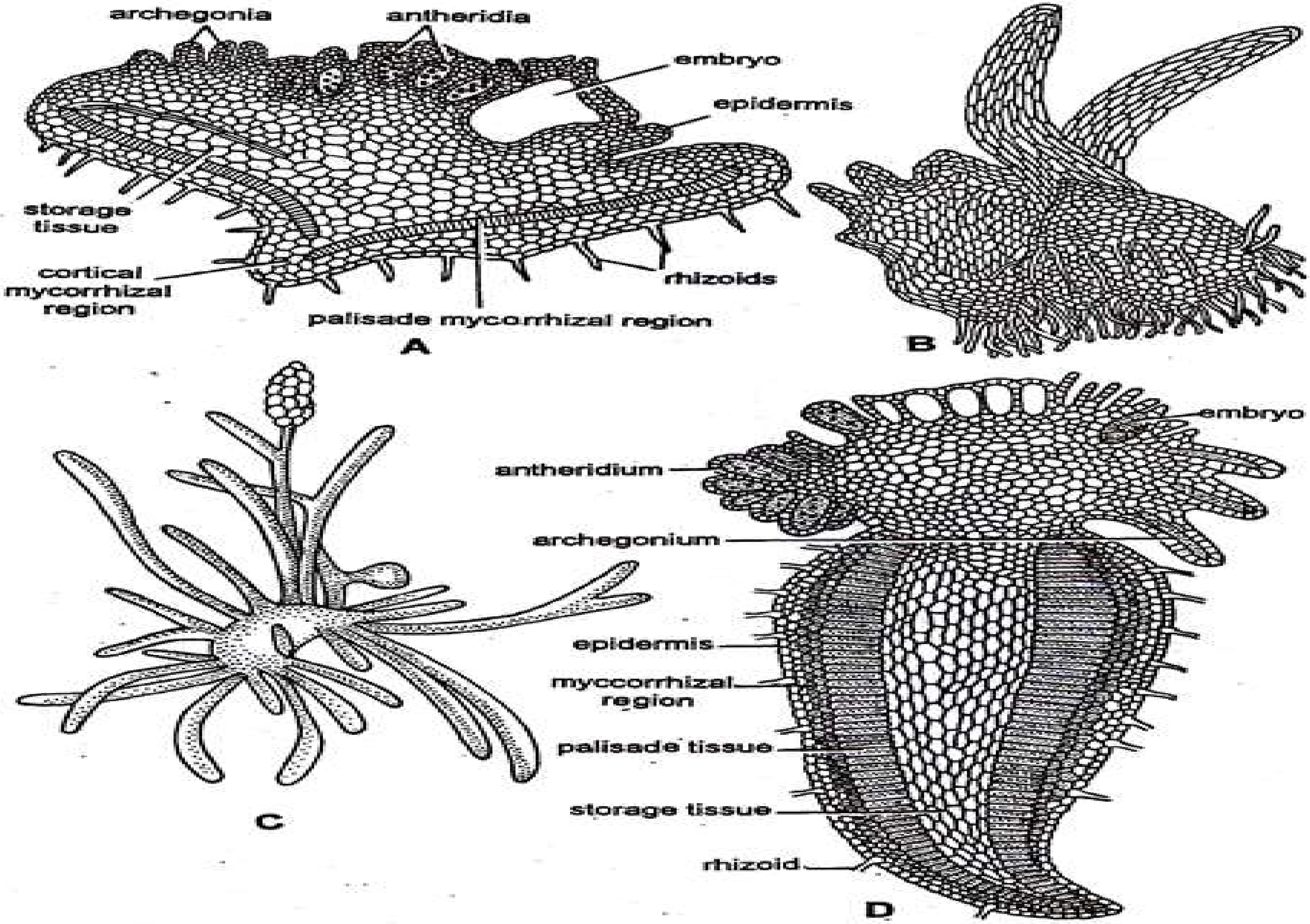


Fig. 11 (A–D). *Lycopodium* : A. *L. cernuum*, B. *L. clavatum*, C. *L. complanatum*, D. *L. phriegmaria*

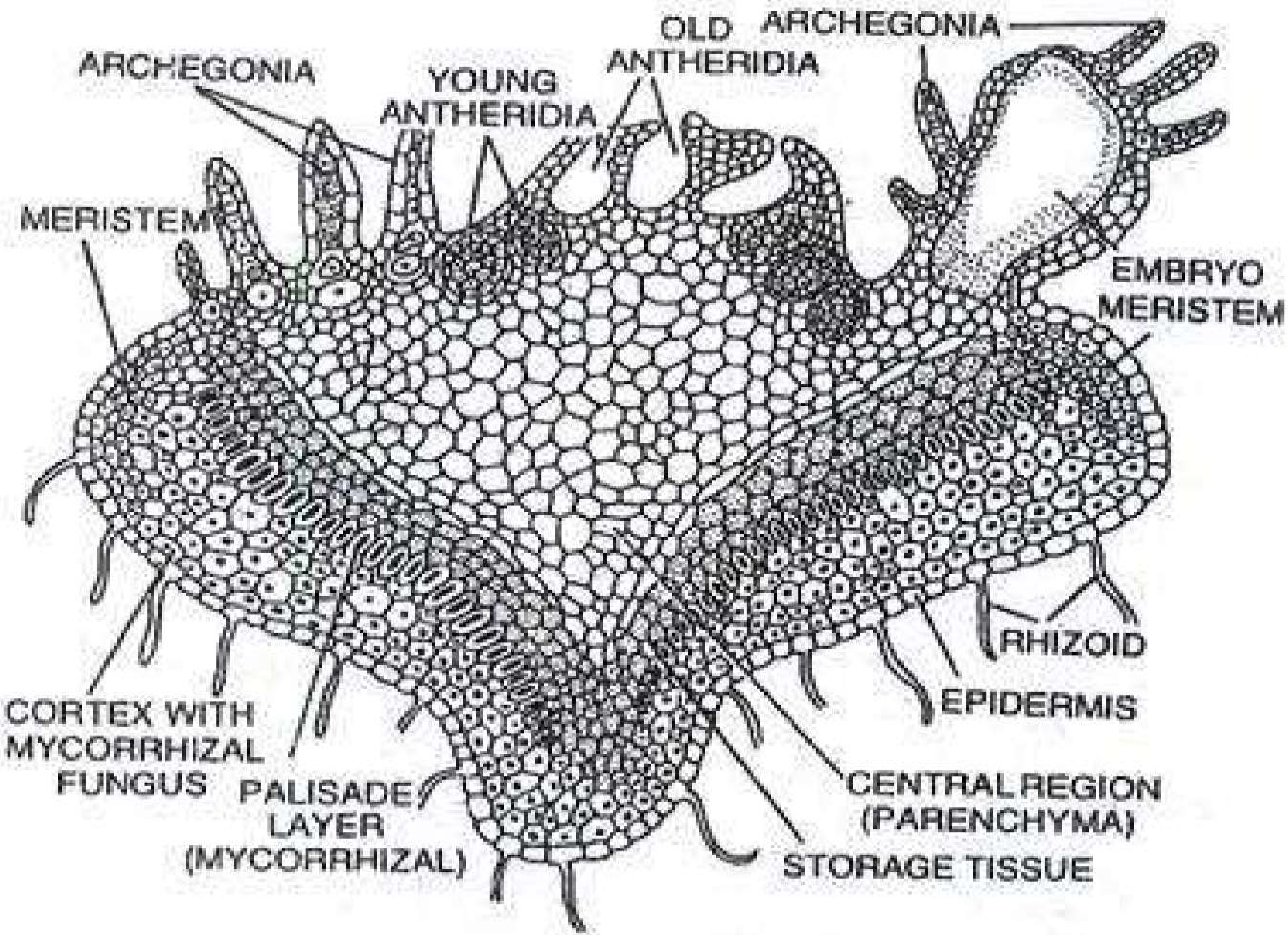


Fig. 27.16 (a). *Lycopodium clavatum*. Gametophyte; median vertical section through a mature prothallus showing mycorrhizal zone, archegonia, antheridia, embryo, etc.

Development of sex organs:
Both the sex organs i.e., antheridia (male) and archegonia (female) develop on the same prothallus, usually in distinct patches on the upper surface. The gametophytes are protandrous i.e., antheridia develop before archegonia. Sex organs develop just on the back of the apical meristem.
Development of antheridium:
A single superficial cell situated just away from the meristematic cells gives rise to an antheridium. This superficial cell is known as antheridial initial (Fig. 12 A). This cell divides periclinally to form an outer cell known as jacket initial (primary wall cell) and an inner cell known as primary androgonial initial or cell (Fig. 12 B).
The jacket initial divides only anticlinally by several divisions resulting in the formation of single layered covering known as jacket layer. In the middle of the jacket layer a triangular cell is differentiated, which is known as opercular cell.
Simultaneously, the primary androgonial divides by various divisions, forming a mass of cells embedded in the prothallus, known as androgonial cells which finally give rise to androcytes (antherozoid mother cells, Fig. 12 C-F). The number of androcytes per antheridium varies in different species.

Each androcyte later on metamorphosis into a biflagellated antherozoid. Each antherozoid is a haploid, uninucleate, fusiform structure with broad rounded posterior end and an upper pointed biflagellated anterior end (Fig- 12 G).
The triangular opercular cell becomes mucilaginous as a result of which an opening is formed at the apex of antheridium through which water enters into it. The antherozoids absorb water and swell up as a result of which a pressure is created on the wall of antheridium which finally ruptures and the antherozoids are liberated.

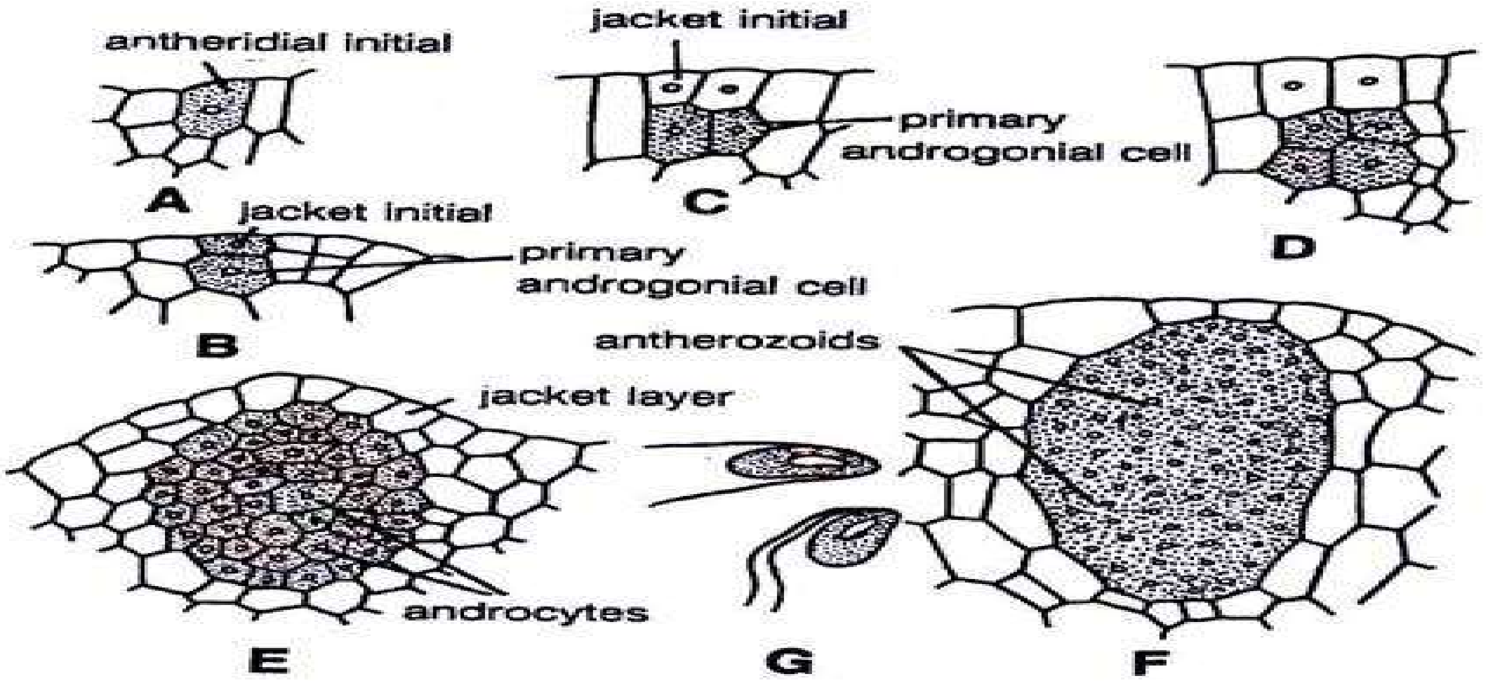


Fig. 12 (A–F). *Lycopodium* : Development of antheridium

Development of archegonium:

Just like antheridium, the archegonium also arises from a single superficial cell called archegonial initial, situated just away from the meristematic cells at the apex (Fig. 13 A). The archegonial initial divides by periclinal division into an upper primary cover cell and lower basal central cell (Fig. 13 B).

The primary cover cell later on divides vertically by two successive divisions at right angle to each other forming four neck initials which later on by transverse divisions form a 3-4 cells high neck. Each tier of the neck consists of 4 cells.

The central cell divides transversely forming an, upper primary canal cell and a lower primary ventral cell (Fig. 13 D). The primary canal cell by successive transverse divisions produces a variable number of neck canal cells (usually one in L. cernuum, seven in, L. selago and 14-16 in L. complanatum).

The primary ventral cell may directly behave as an egg or may divide transversely to form an upper ventral canal cell and a lower egg (Fig. 13 E-G). The egg is somewhat broader then the rest part of archegonium. The archegonial jacket is absent. The archegonium is a sunken flask shaped structure with neck projecting out of the prothallus.

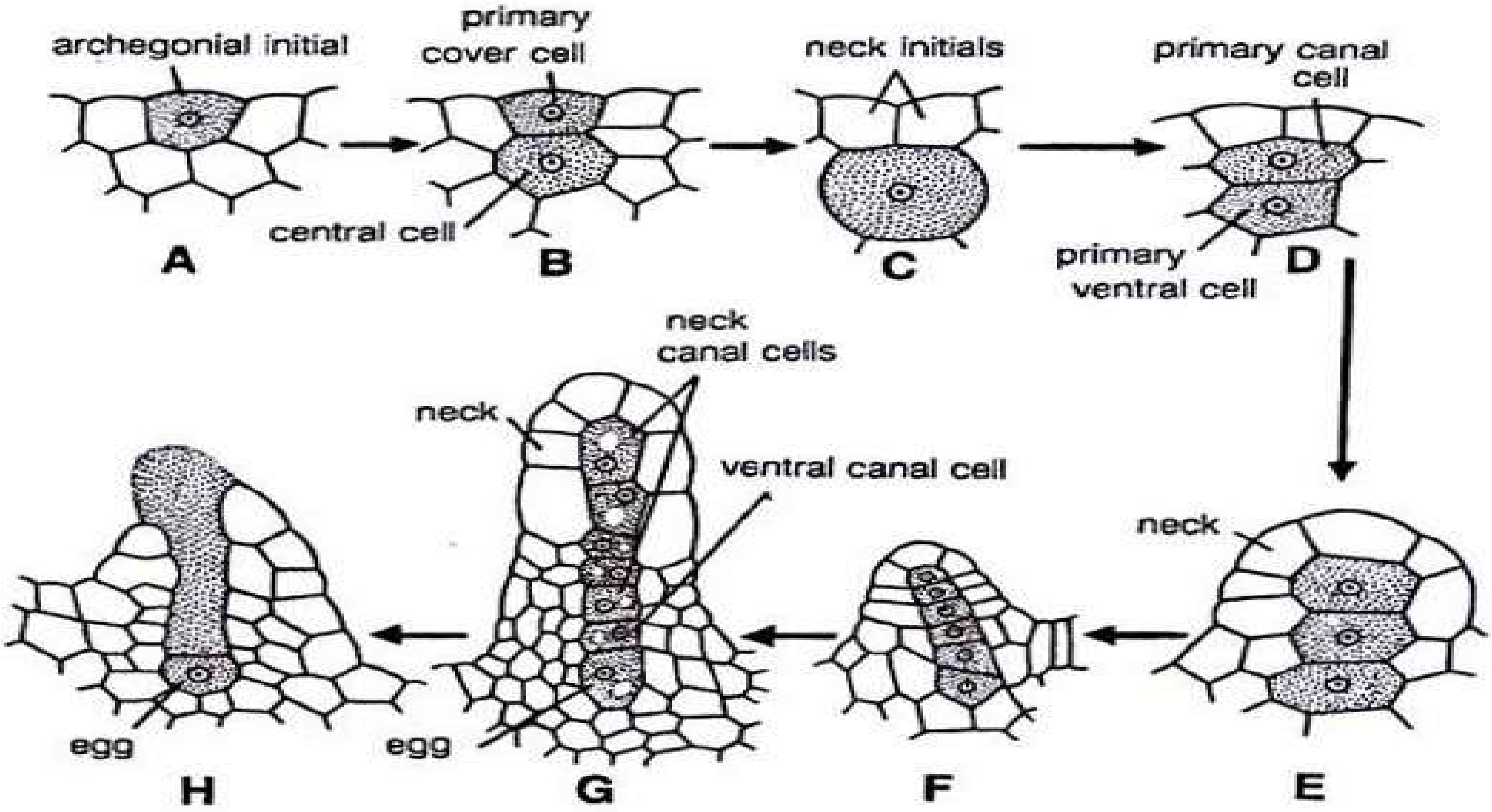


Fig. 13 (A–H). *Lycopodium* : Development of archegonium

Fertilization:

At the time of fertilization the neck canal cells and the ventral canal cell disorganise and the cells of the upper-most tier of neck slightly separate apart forming a passage upto the egg (Fig. 13 H). Fertilization is brought about in the presence of water.

The biflagellate antherozoids reach the archegonium by swimming in water on the surface of prothallus. The antherozoids are perhaps attracted towards the neck of archegonium by a chemotactic movement. They enter the archegonium through neck and reach the egg.

Only the nucleus of one antherozoid fuses with the egg nucleus thus forming a diploid structure-known as oospore (2x). The act of fertilization ends the gametophytic generation and the initial stage of sporophytic generation is formed.

Embryo Development (Young Sporophyte):

The rate of development of the embryo is extremely slow. In Lycopodium embryo develops downward into the gametophytic tissue instead of developing upward i.e., towards the neck of archegonium. The first division of the oospore is always transverse, forming an upper cell (epibasal) and a lower cell (hypobasal) known as embryonic cell.

The upper cell does not divide further and behaves as suspensor. The lower cell (embryonic cell) divides by two vertical divisions at right angle to each other, followed by a transverse division, forming 8 cells (octant, Fig. 14 A–D). The 4 cells of the octant, situated near the suspensor by further division, form a multicellular foot which acts as a haustorium and helps in the absorption of food material from the gametophytic tissue.

Out of the 4 remaining cells of the octant, the 2 cells towards the meristematic region give rise to stem and the other 2 cells give rise to primary leaf and primary root (Fig. 14 D-J). The primary stem is short lived and is replaced by adventitious outgrowth which gives rise to horizontal stem. More roots develop from the stem.

The primary roots of the sporophyte are exogenous in origin while those arising later on are endogenous in origin. The embryo obtains its nourishment for a long time from the gametophyte.

In some species e.g., L. cernuum etc. the gametophyte is generally green. The oospore normally divides transversely forming suspensor and embryonic cell

The embryonic cell forms an octant. The tier which gives rise to stem, leaf and primary roots, develops into a massive spherical structure of parenchymatous cells, known as protocorm (Fig. 14 K, L). It grows through the gametophyte, becomes green and develops rhizoids on its lower surface.

The upper surface of the protocorm gives rise to a few to many erect outgrowths which are leaf like and are known as protophylls.

The protophylls are provided with stomata. At this stage the protocorm separates from the gametophyte. Now at the upper side of protocorm a region is differentiated which develops into stem.

Protocorm is regarded as the intermediate phase in between normal embryo and definite leafy shoot.

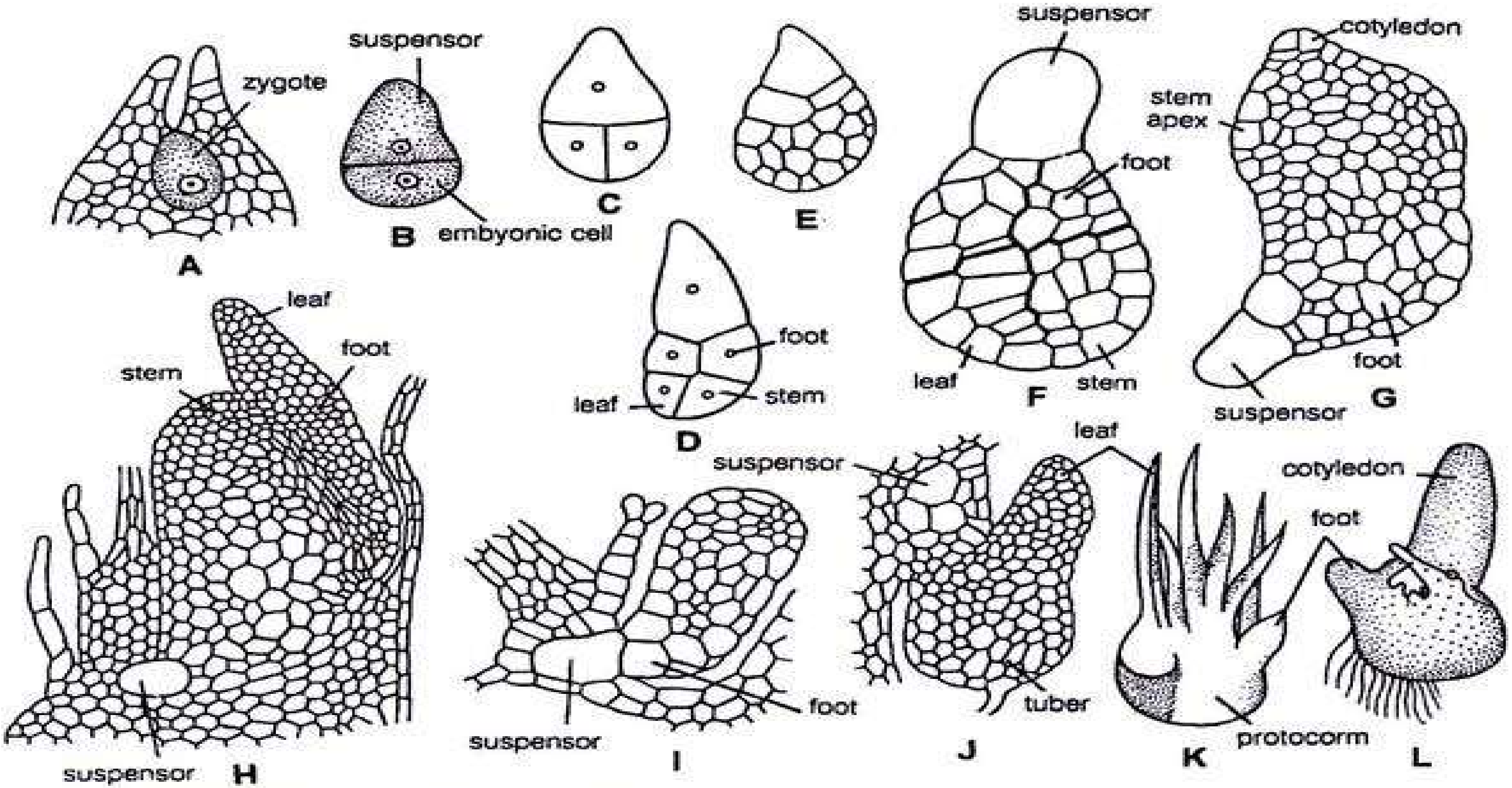
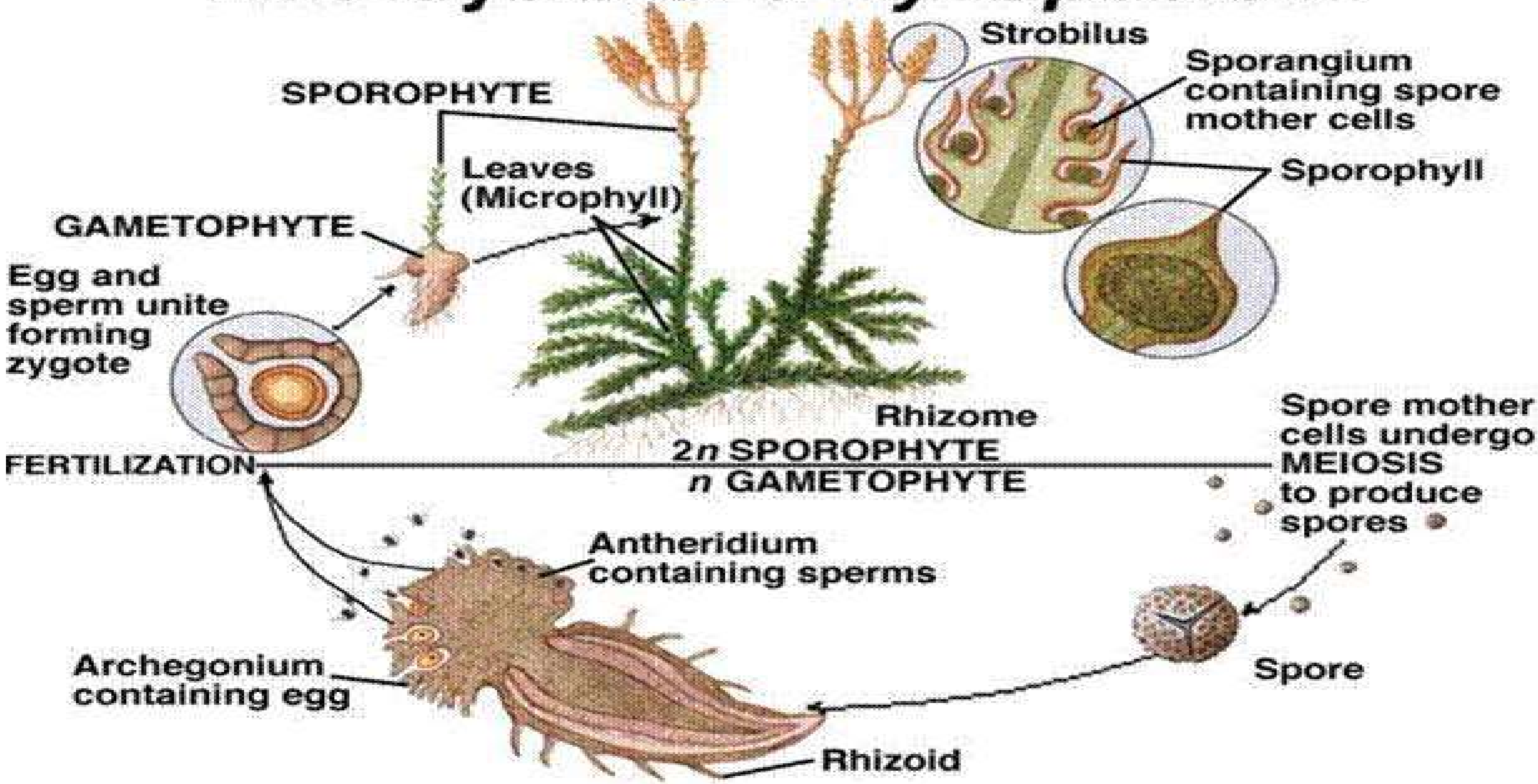


Fig. 14 (A–L). *Lycopodium* :(A–J). Stages in the development of embryo, (K, L). Portocorm

Life Cycle of a *Lycopodium*



Selaginella

Taxonomic position

- Division : Lycophyta
- Class: Ligulopsida
- Order: Selaginellales
- Family: Selaginellaceae
- Genus: Selaginella

Selaginella

Distribution and habitat

- It is commonly called as club moss and spike moss.
- It has world wide distribution
- Abundant in tropics and grows in ground and shady places
- Most common species is
- *Selaginella kraussiana*

Vegetative morphology

- The plant body is sporophyte and it is differentiated in to

1. Root
2. Stem
3. Leaves
4. Ligules
5. rhizophores

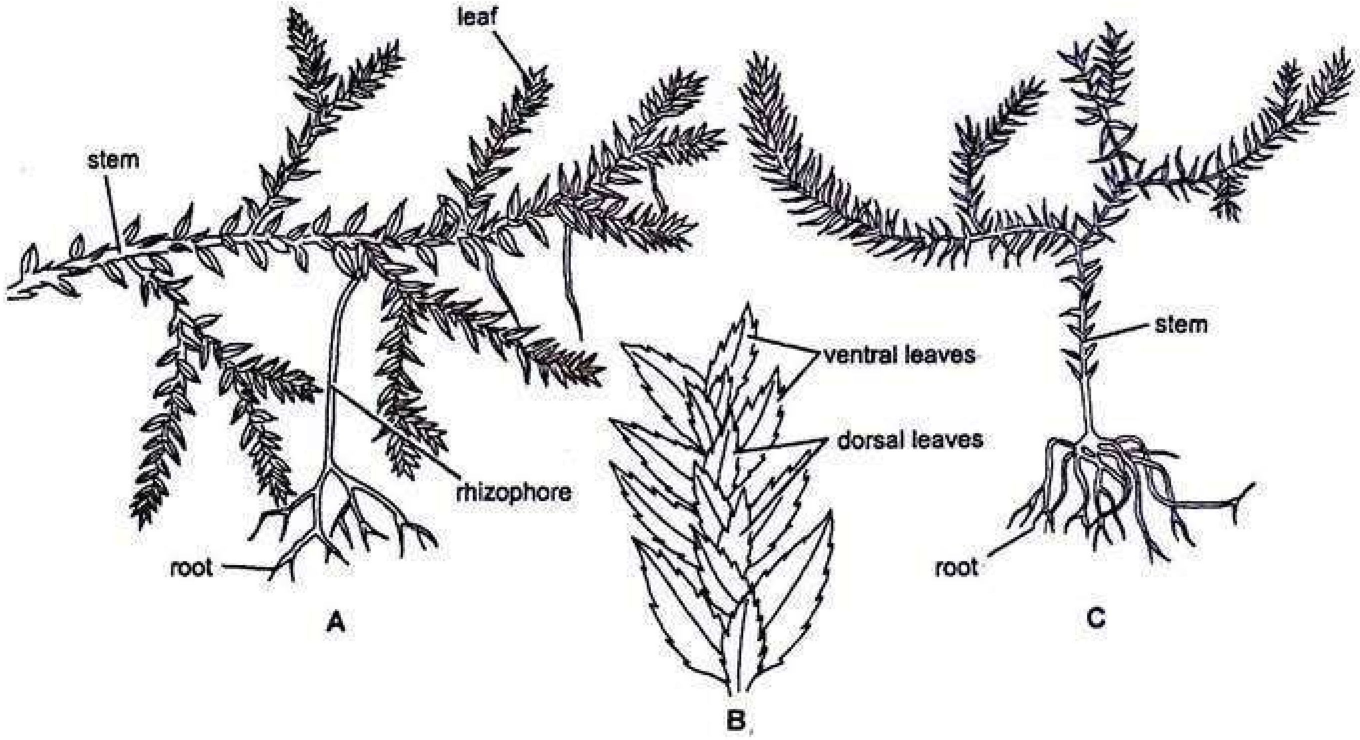
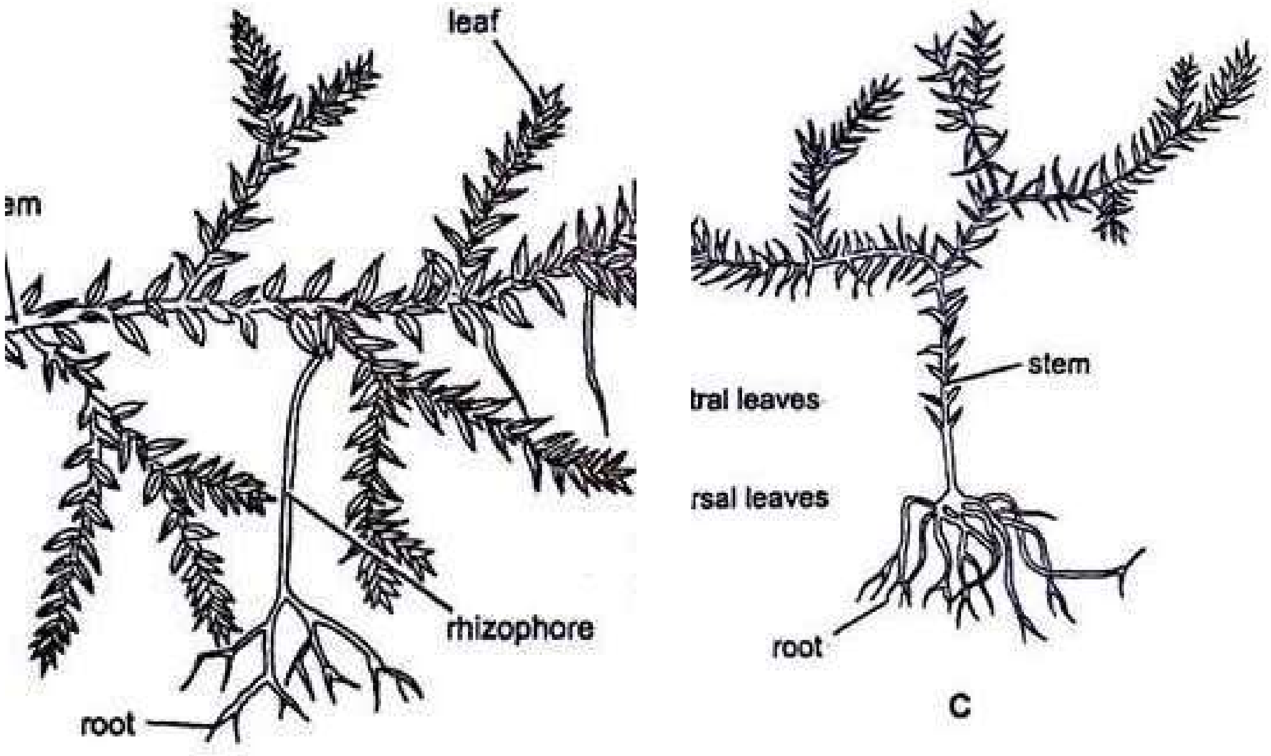


Fig. 1 (A–C). *Selaginella*. External features : A. *S. kraussiana*, B. Leaf arrangement in a branch of *S. kraussiana*, C. *S. spinulosa*

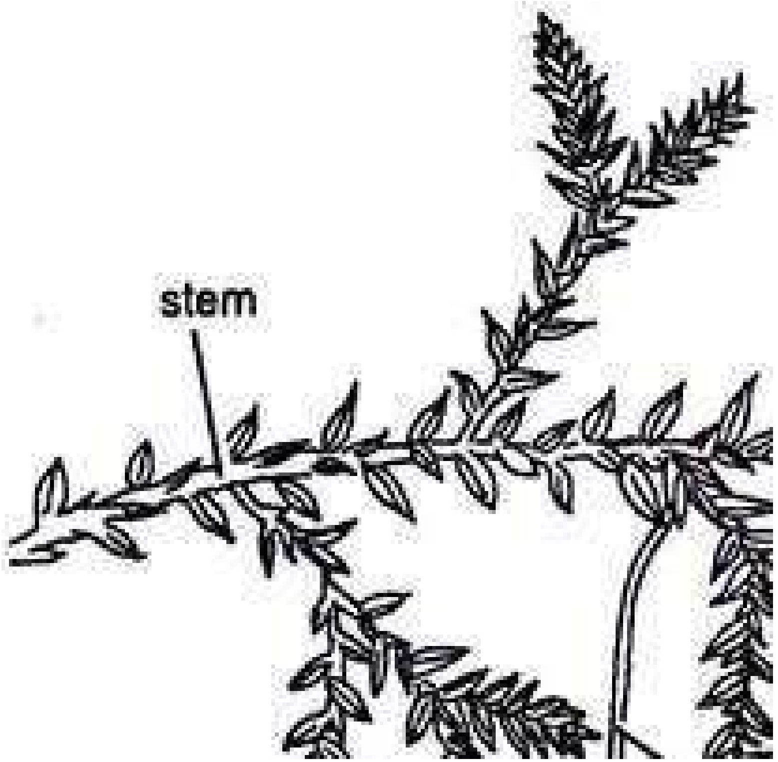
Root

- The root of young sporophyte is of primary root while others are adventitious
- The adventitious roots are at the tips of rhizophores
- Aerial roots have developed caps, and cutinized epidermal cells And enter soil.



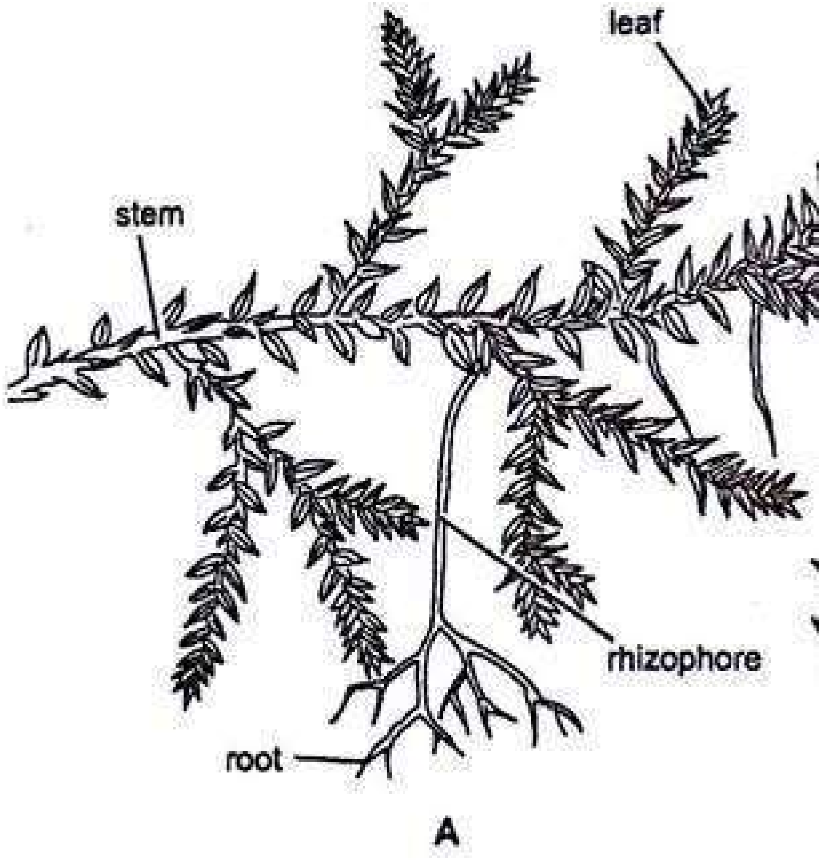
Stem

- Stem is green, dorsiventral and prostrate with short erect branches
- The branches are arranged dichotomously
- They are also pseudomonopodia (false ,growth from one point)
- The shoot apex consists of a single apical cell in most cases



Rhizophore

- In some species , leafless and colorless branches arise from the prostrate stem near point of branching.
- These grow downwards and have group of adventitious roots
- They are called as rhizophores
- Some scientist consider them branches and some consider them as roots and still other consider it as an organ for protection or other function.
- But recently they are known as adventitious roots that have dichotomous branches at tip.



Leaves

- Microphylls are present. (leaves are small and single veined. They are of 2 types

1. Isophyllous
2. Anisophyllous.

The anisophyllous leaves are in pairs. They may be

- Small: these are inserted on the dorsal side of stem
- Larger: these leaves are inserted on the ventral side of stem

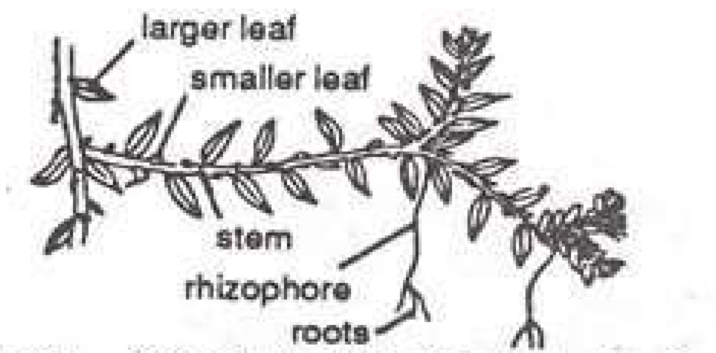
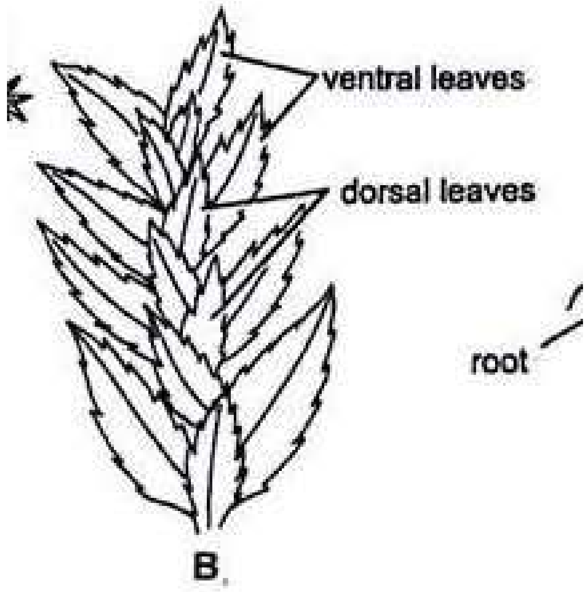


Fig. 209. *Selaginella. Part of a plant showing external features.*



Ligules

- Ligule: there is small outgrowth on adaxial side (upper side) of the leaf near base. It is vestigial organ and provide water .
- https://www.youtube.com/watch?v=leRc58hS3o o

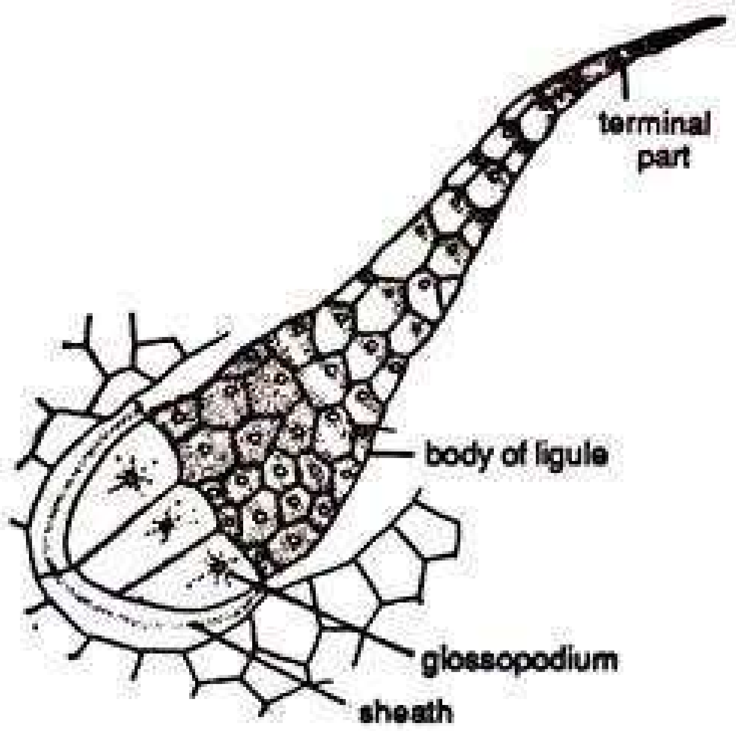


Fig. 212. *Selaginella. A single ligule.*

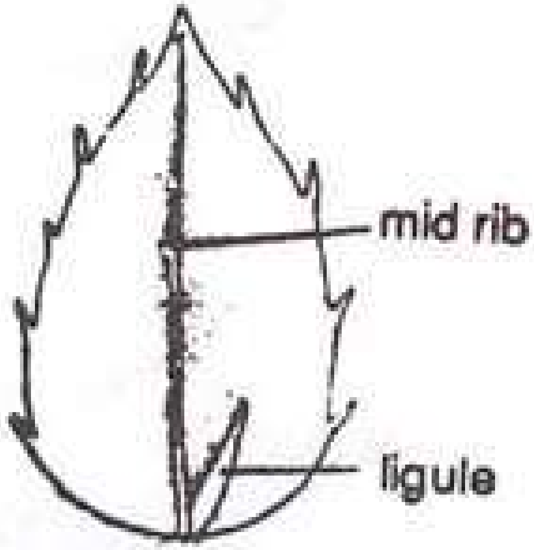


Fig. 210. *Selaginella. Adaxial surface of a leaf showing ligule.*

Anatomy

- Stem anatomy
- Steler system
- Leaf anatomy
- Root anatomy

Stem anatomy

- Epidermis : thick epidermis , thin walled, rectangular cells, covered with cuticle
- cortex : many layered , outer 2-4 are thick walled called as hypodermis

Below is thin walled parenchyma having chloroplast, have small intercellular spaces.

Central portion is separated from cortex by a cavity having air spaces

- endodermis :the cortex and central tissue is connected by radially elongated cells called trabeculae

They contain casparian strips, trabuculae are modified endodermal cells.

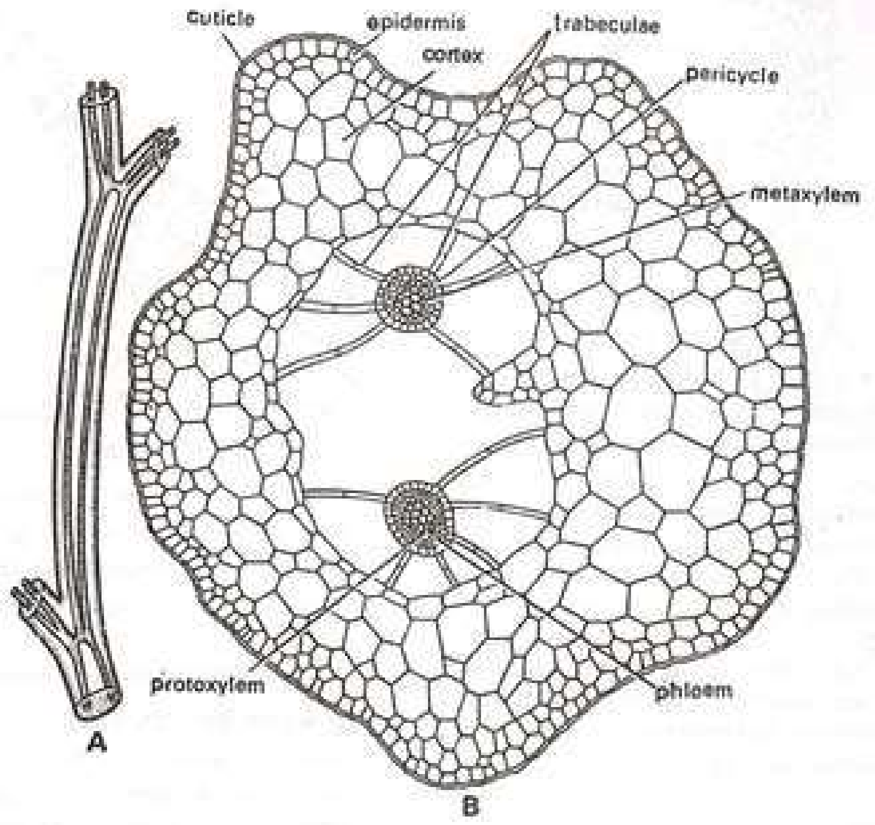
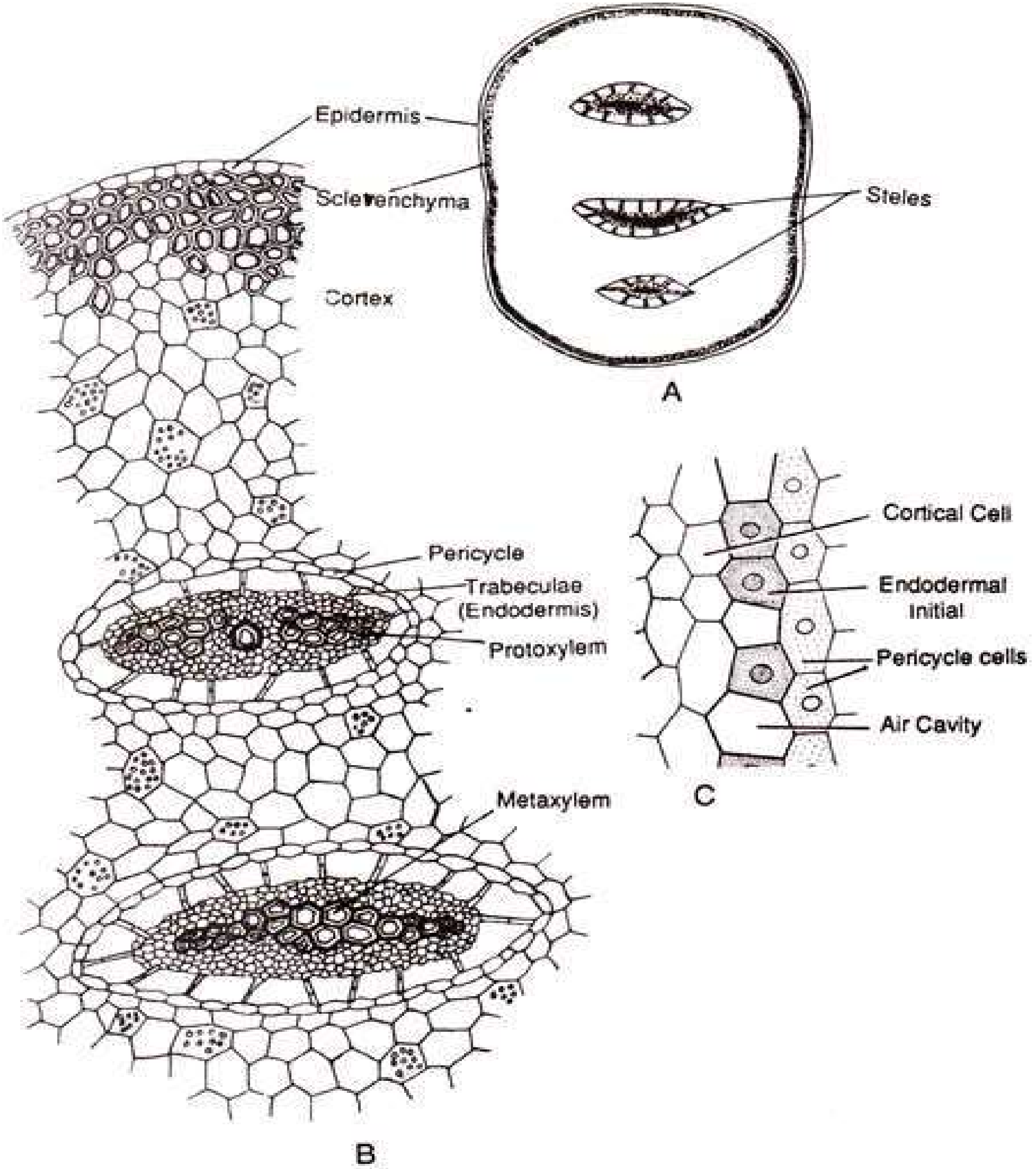


Fig. 213. Selaginella kraussiana. A, A part of cleared distelic stem showing vascular cylinder; B, T. S. of a distelic stem.


Epidermis
Sclerenchyma
Cortex
Steles
A
Cortical Cell
Endodermal Initial
Pericycle cells
Air Cavity
C
Pericycle
Trabeculae (Endodermis)
Protoxylem
Metaxylem
B

Steler system

- Pericycle : there is single layer of pericycle formed of thin walled cells, enclosing vascular tissue (xylem and phloem)
- Phloem : there are phloem composed of sieve cells and phloem parenchyma, companion cells are absent , phloem surrounds the xylem completely
- Xylem : present in center , it consists of

1. Protoxylem : occupies two ends of meta xylem
2. Metaxylem: occupies the major portion of stele

These are composed of tracheid and parenchyma cells

Fibers are absent.

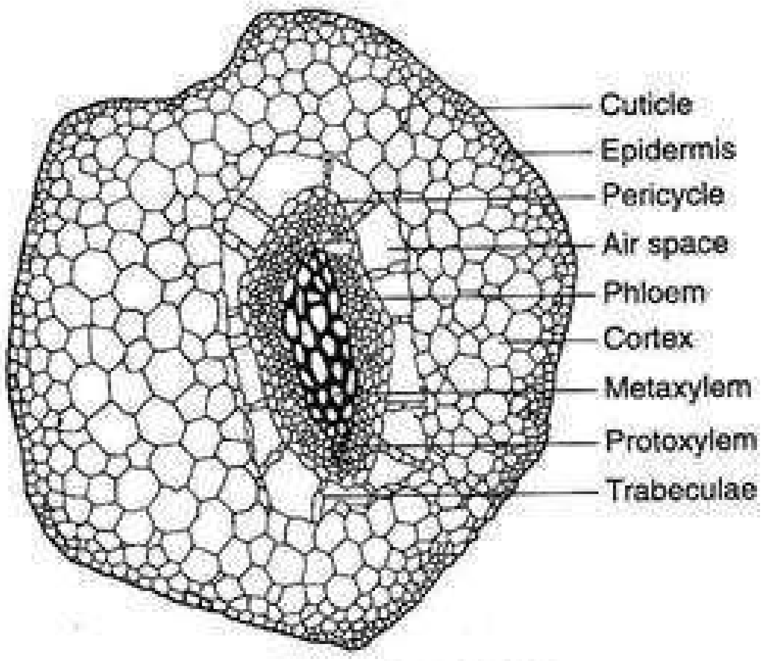
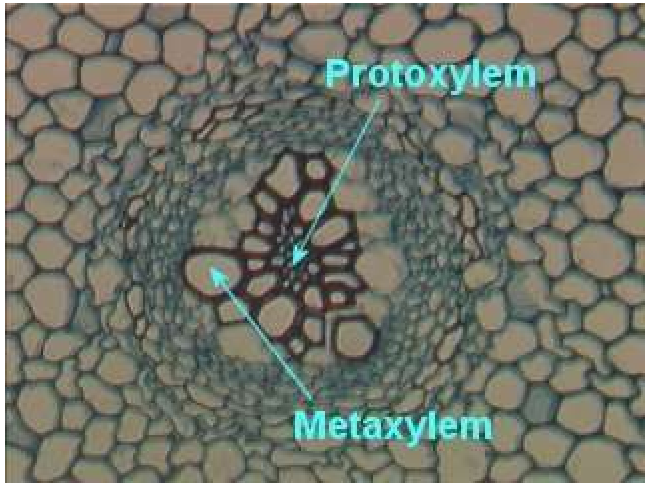


Fig. 7.47 : T.S. of *Selaginella* stem



Rhizophore

- Outermost layer is epidermis
- It is of thick walled and single layer cells
- Beneath the epidermis there is cortex

1. Hypodermis (thick walled)
2. Thin walled parenchymatous region
3. Inner most layer is endodermis

- Thin walled pericycle is present around the vascu tissue
- Stele is protostele (xylem is in center and phloer surrounds the xylem)

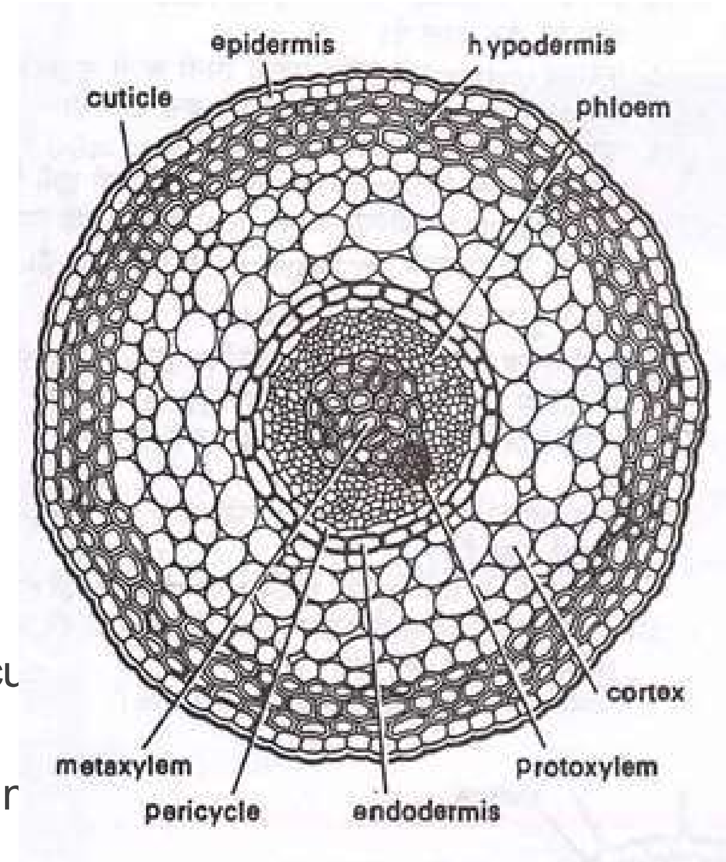


Fig. 215. *Selaginella*. T.S. rhizophore.

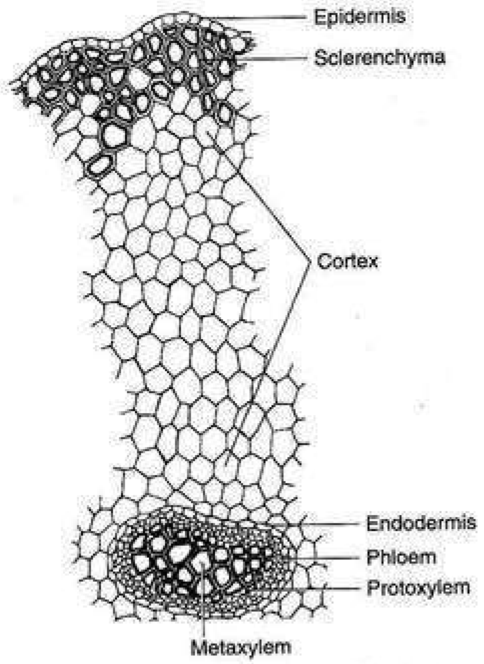


Fig. 7.48 : T.S. of rhizophore of *Selaginella*

- **Rhizophore**

I. Similarities with Root:

- i. Rhizophores are positively geotropic in nature.
- ii. It does not bear leaves.
- iii. Monarch xylem like that of root.
- iv. Presence of root cap in some species, e.g., S. densa, S. kraussiana, S. martansii, S. wallacei (Webster and Steeves, 1967).

- **II. Similarities with Stem:**
- i. Exogenous in origin like stem.

Leaf anatomy

- The upper and lower epidermis are present
- They are one celled thick and contain chloroplast
- Stomata are present on upper and lower epidermis (but majority have in lower side)
- Below the epidermis there is mesophyll tissue having thin walled parenchyma cells, these contain chloroplast and have small and large air spaces
- Vascular tissue is present in center
- Phloem has few sieve cells and many parenchyma
- Vascular bundle is surrounded by single layer forming bundle sheath.

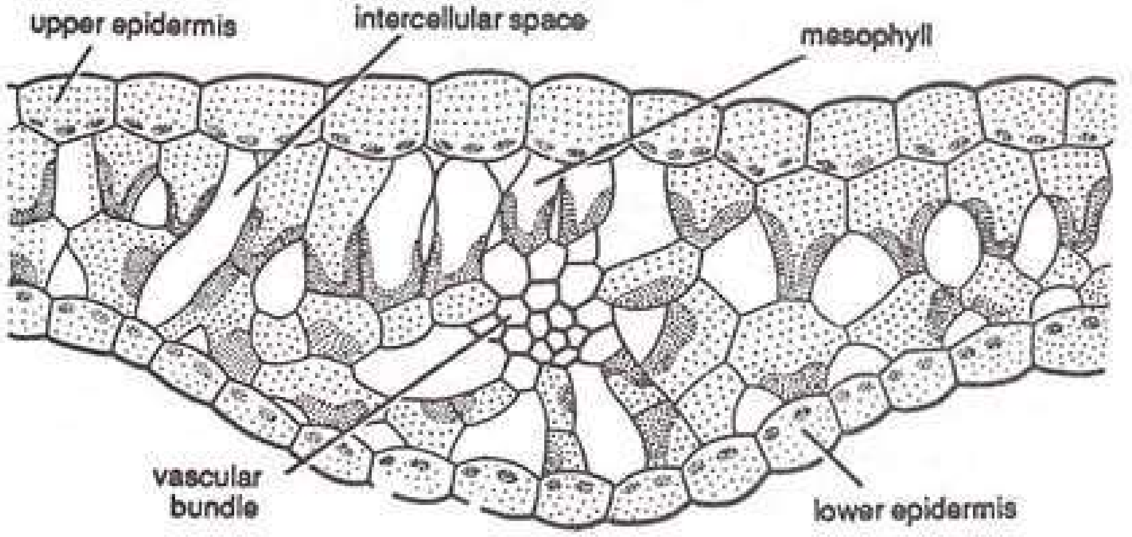


Fig. 216. *Selaginella. T. S. leaf.*

Ligule

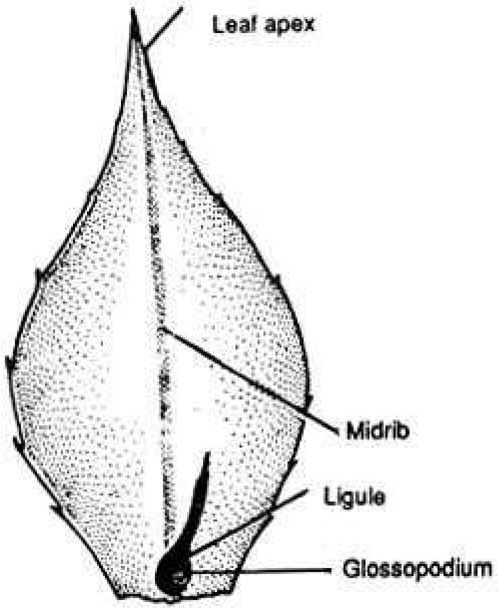


Fig. 60. *Selaginella* : Surface View of Leaf showing Ligule

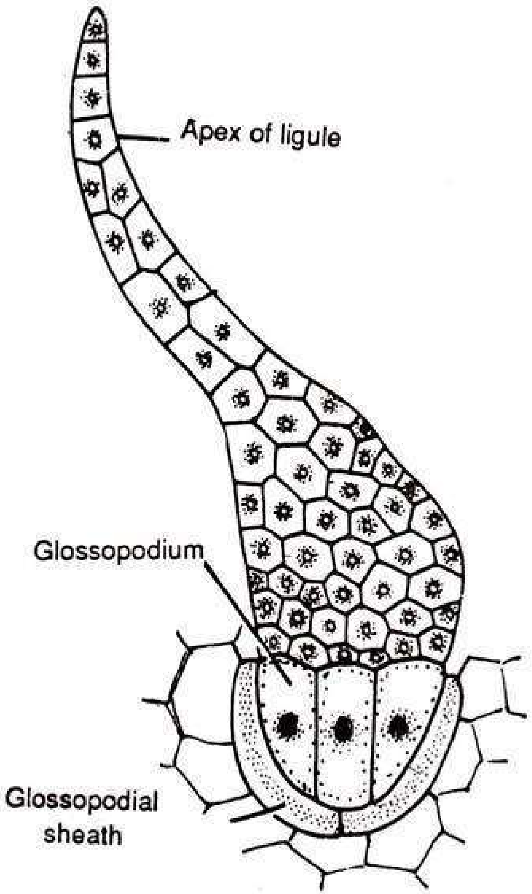


Fig. 65. *Selaginella* : A Ligule enlarged

Root anatomy

- Outermost layer is epidermis (single layer), covered
- by thin cuticle
- Root hairs are present and arise fro
- Beneath the epidermis, wide zone
1. Outer hypodermis (have sclerench
2. Endodermis (inconspicuous)
- Single layered pericycle is present
- Protostele is next
- Xylem is surrounded by phloem

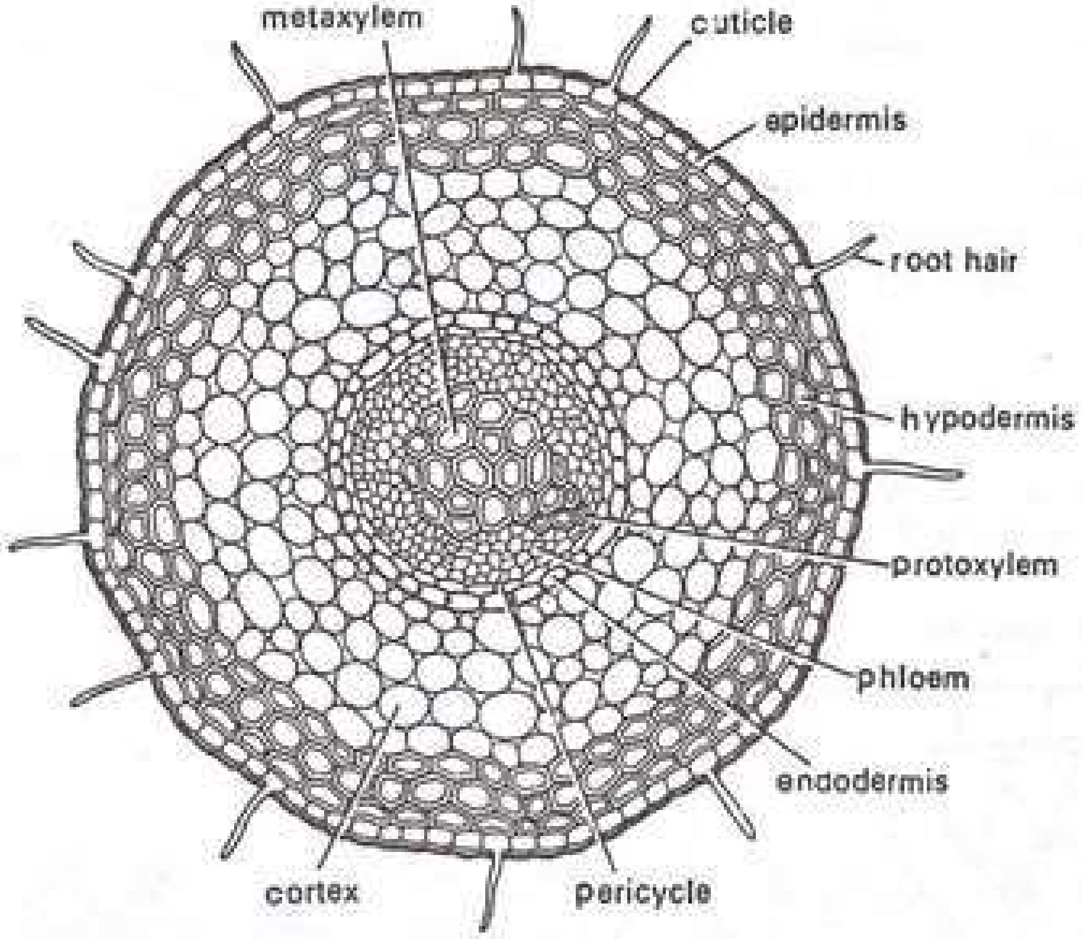


Fig. 214. Selaginella. T.S. root.

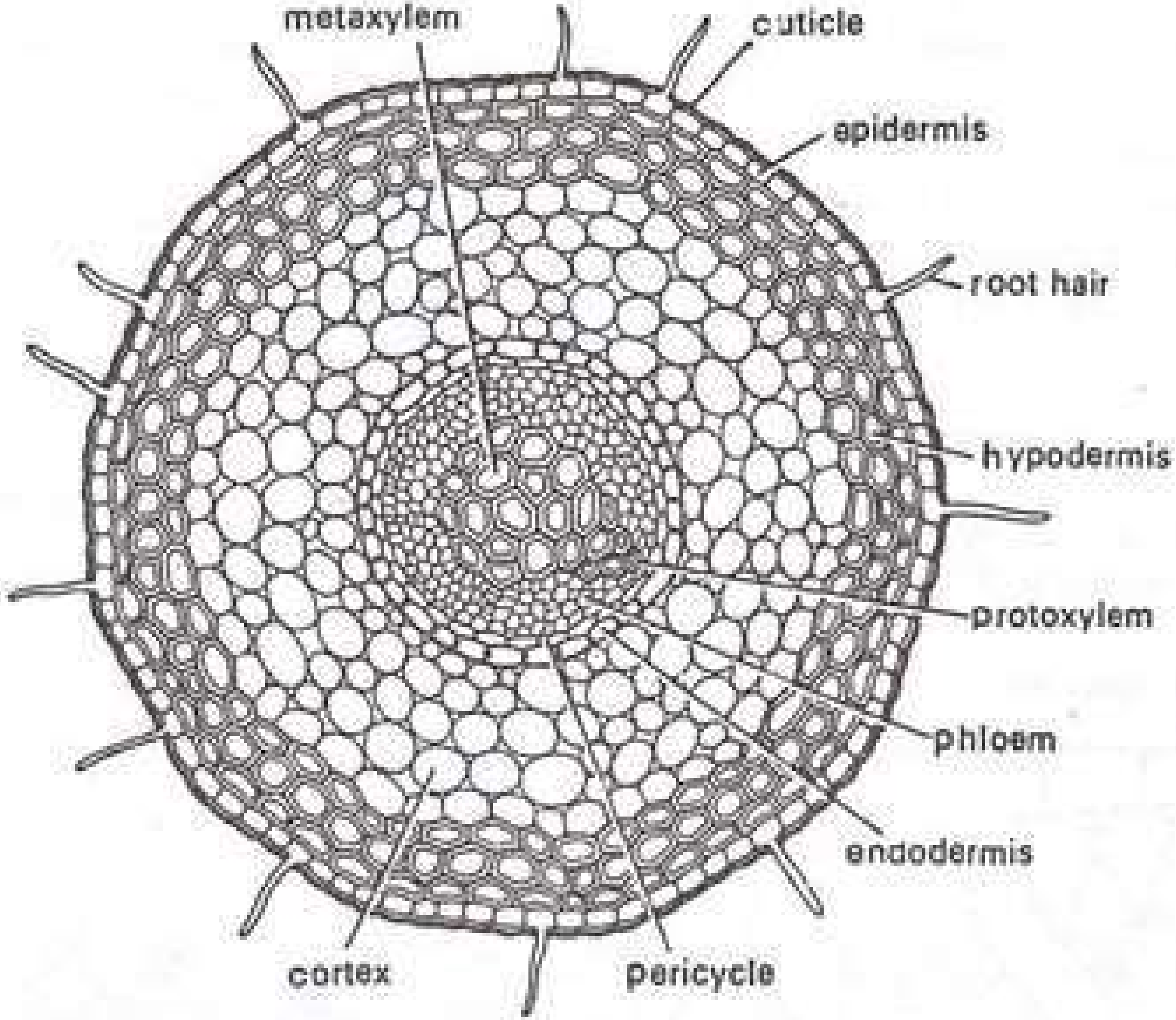
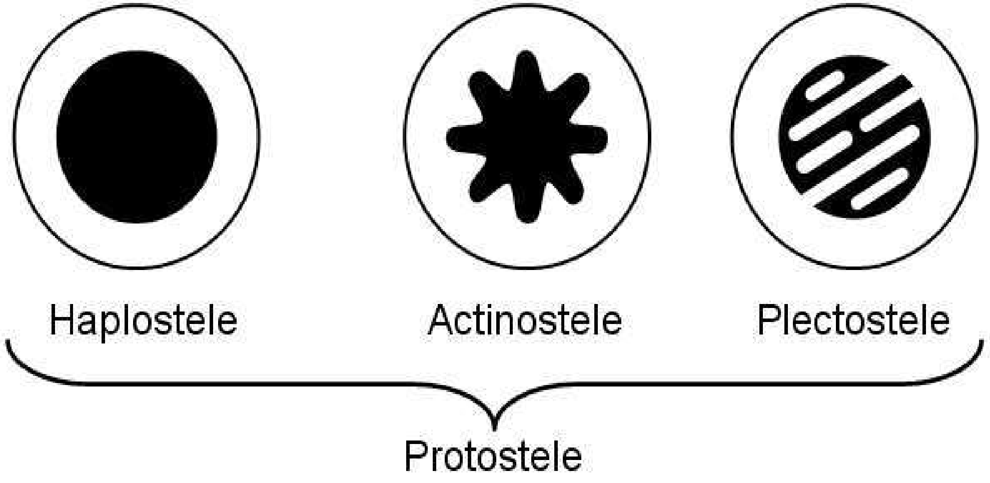
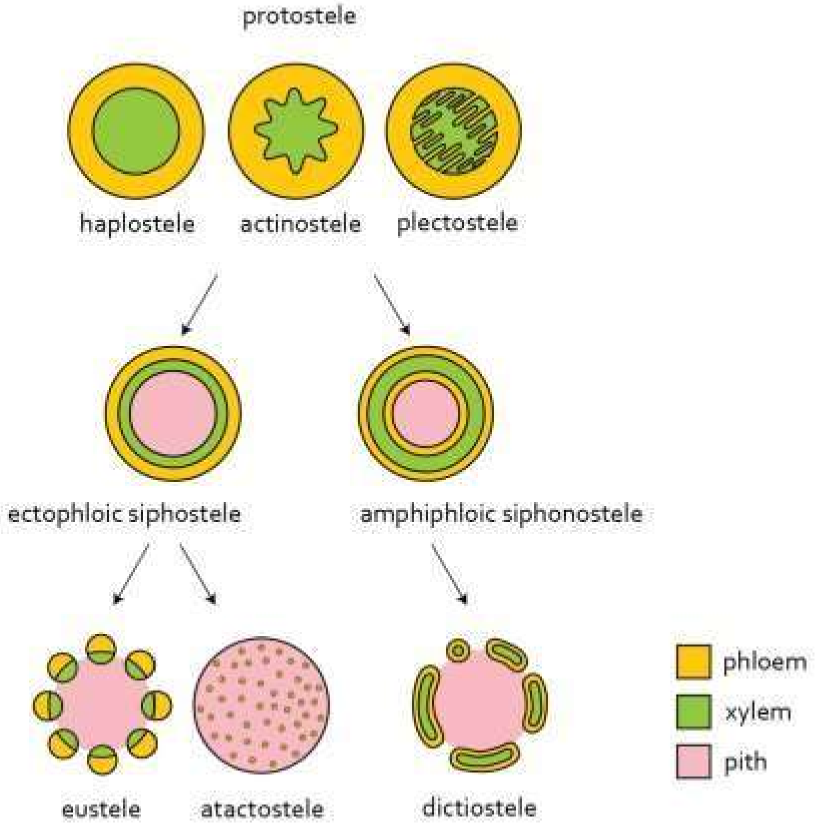


Fig. 214. *Selaginella. T.S. root.*



Haplostele
Actinostele
Plectostele
Protostele



protostele
haplostele
actinostele
plectostele
ectophloic siphostele
amphiphloic siphonostele
eustele
atactostele
dictiostele
phloem
xylem
pith

Reproduction

- Life cycle in Selaginella is characterized by alternation of generation
- Both spore producing and gamete producing generations are independent .
- Some species reproduce by vegetative reproduction

The sporophyte : Vegetative and Asexual reproduction

There are following methods for vegetative reproduction

- Adventitious branches
- Tuber production during unfavorable conditions
- By production of resting buds at the ends of aerial branches. (these are surrounded by leaves and can survive in adverse conditions, upon reaching suitable conditions they develop into new plants.

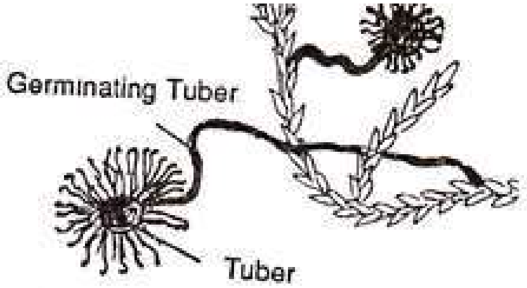


Fig. 67. *Selaginella* : Plant Body of *S. Chrysorrhizos* with

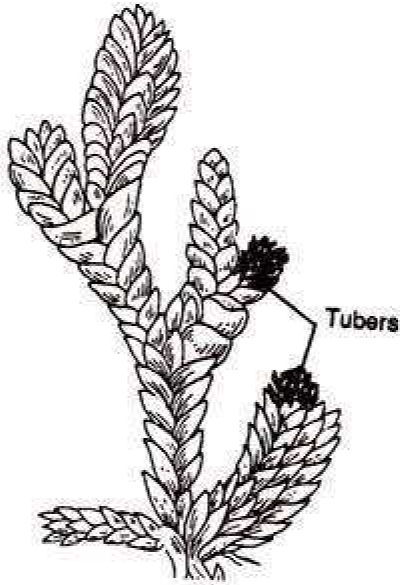
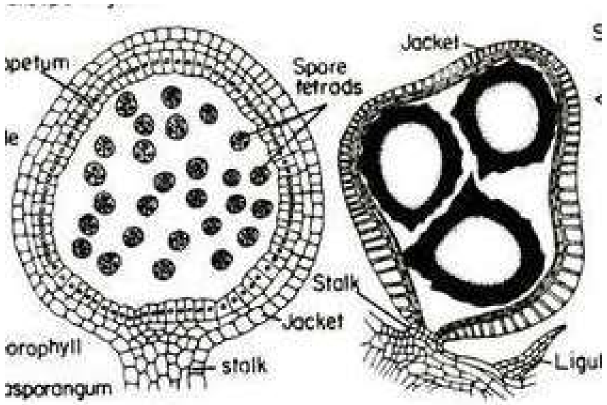


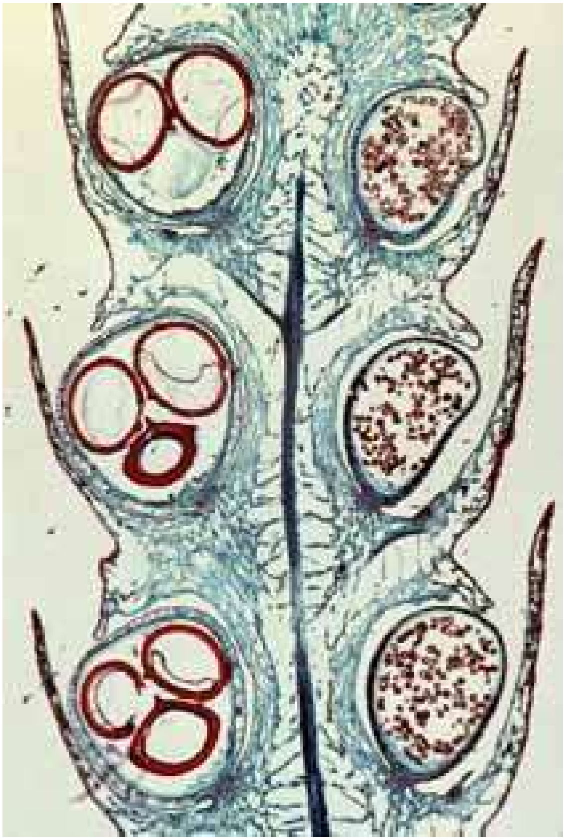
Fig. 68. *Selaginella* : Plant Body of *S. chrysocaulos* with Tubers in Aerial Branches

Sexual reproduction

- These are hetrosporous

1. Microspore of smaller size produced in microsporangia
2. Macrospores of larger size produced in macrosporangia .





Sporangioferous spike

- Sporangia are produced on the axils of ligulated leaves called sporophylls
- These sporophylls are organized to form strobili at the ends of shoots
- The sporophylls in strobilus is arranged just like bracts in angiosperm plants. That's why it is also called as sporangioferous spike

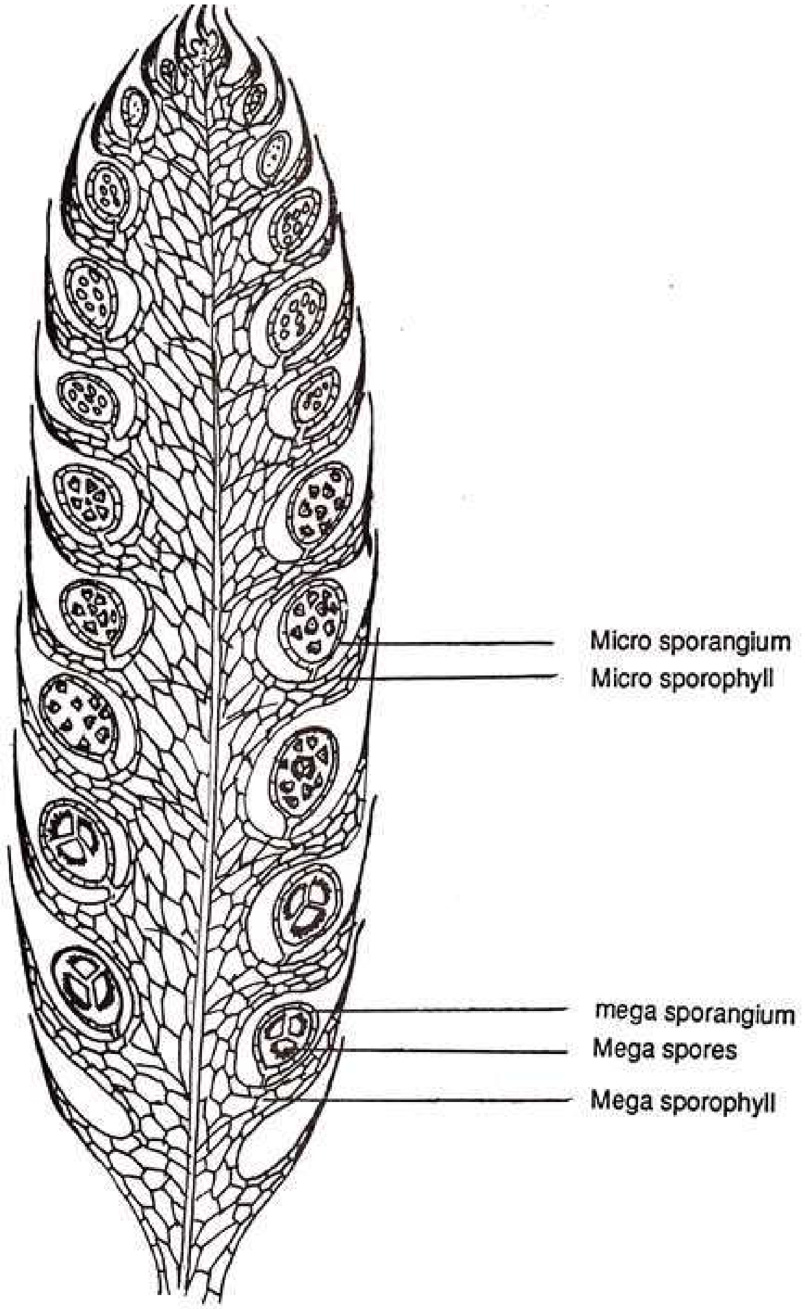


Fig. 70. *Selaginella* : L.S. of Strobilus (megasporangia at the base and microsporangia at the top)

Structure of sporangia

- Microsporangia : they are small, stalked, oval and varying in shapes,
- Mega sporangia : they are stalked and 4 lobes, larger in size and present at base of strobilus , spores are of larger size.

1. Both consist of 2 layered sporangial wall surrounding the tapetum and sporogenous tissue.
2. Tapetum is developed from innermost layer of sporangial wall.
3. Both differ in their size, location, and number of spores
4. To release spore, both sporangia form vertical cleft in wall .

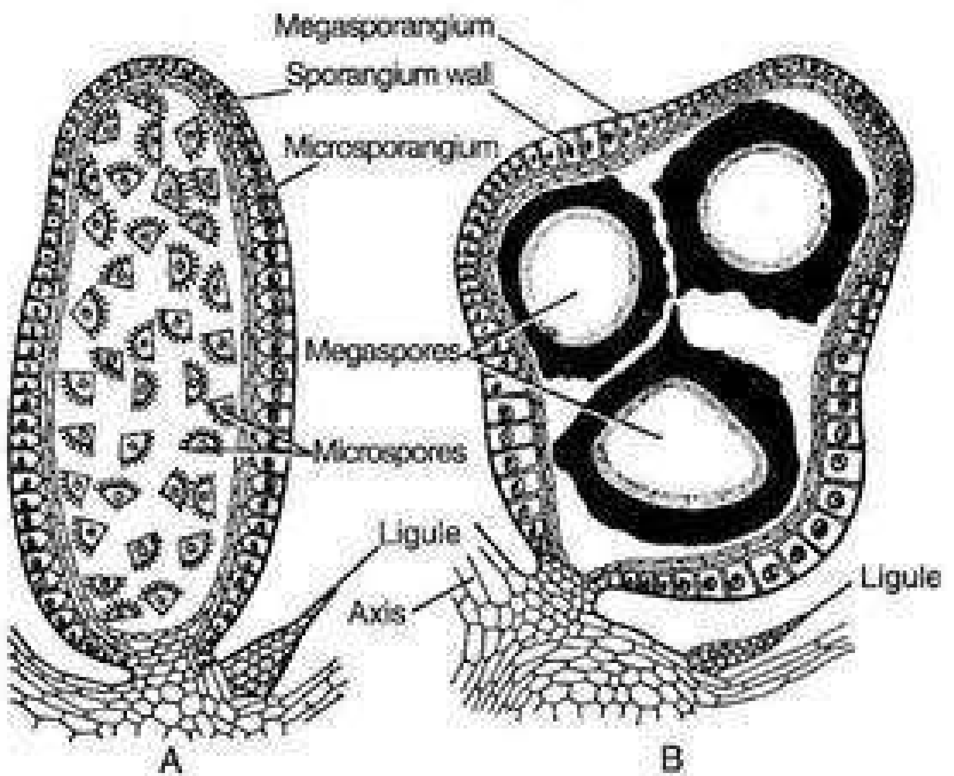


Fig. 7.52 : *Selaginella* : A. A mature microsporangium, B. A mature megasporangium

Development of Sporangium:

- Initially the development of micro- and megasporangia are similar. The sporangial development is of eusporangiate type i.e., the sporangium develops from a group of initial cells (Fig. 7.53A-E).

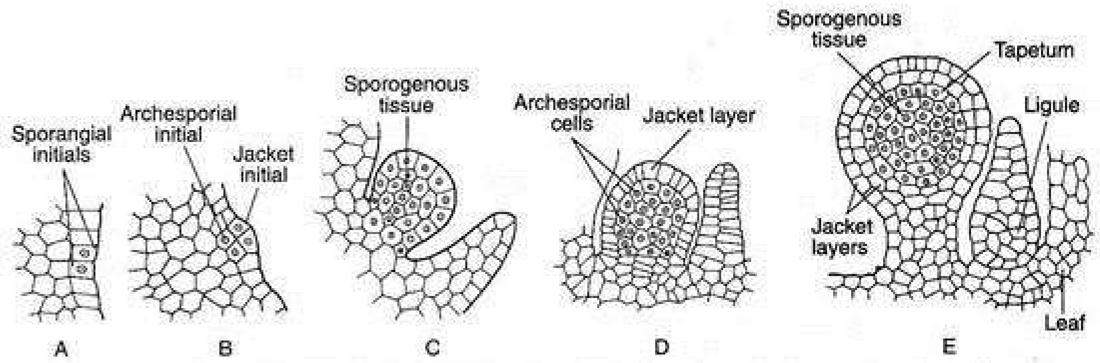
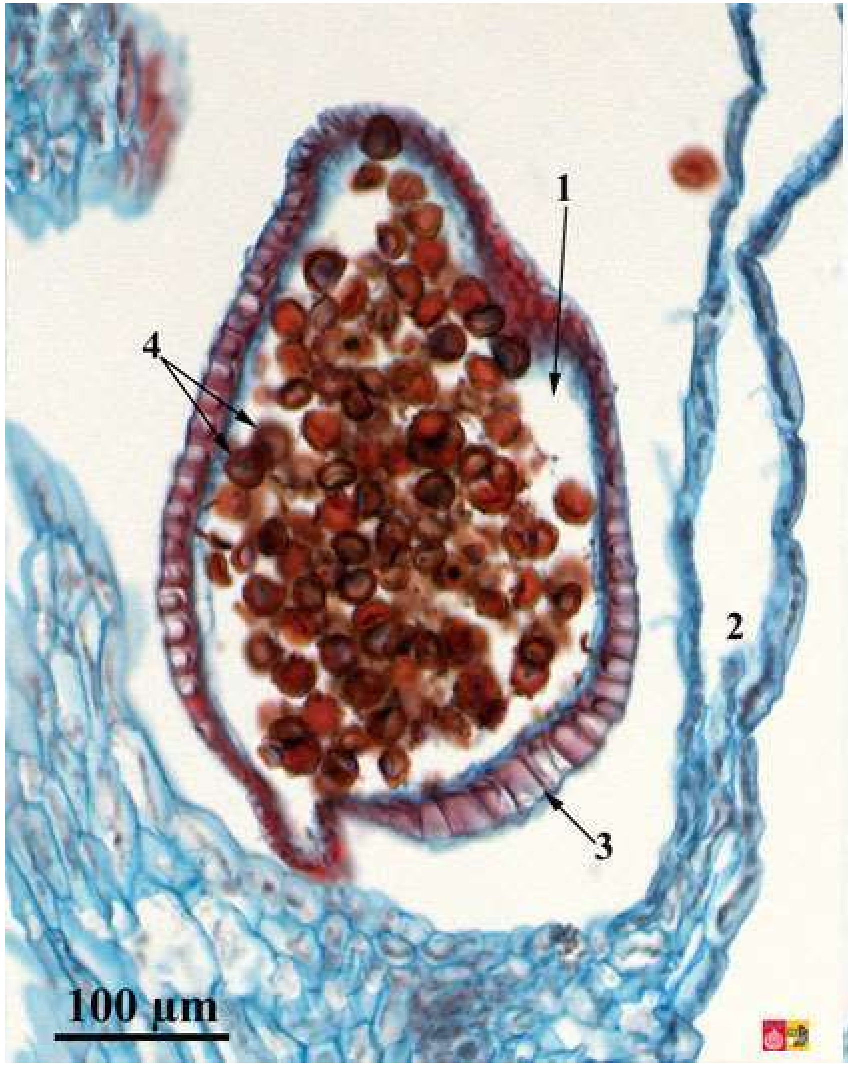


Fig. 7.53 : *Selaginella* : A–E. The stages in the development of sporangium

- The site of sporangial initiation (micro- or mega-sporangium) is in superficial cells of the axis, directly above the sporophyll, or in cells near the base of the sporophyll on the adaxial (upper) side.

Periclinal divisions in these initial cells produce two tier of cells: the outer jacket initials and the inner archesporial initials (Fig. 7.53A-B). A two-layered sporangial jacket is formed by repeated anticlinal and periclinal divisions of the jacket initial. The periclinal division of the archesporial cells produces an outer and inner layer of cells.

The outer layers of cells eventually develop into tapetum; the inner cells, by repeated divisions in various planes, produce sporogenous tissue (spore mother cells) (Fig. 7.53C-E). The sporangium at this stage consists of an immature sporangial wall of two layers, a short stalk and a conspicuous tapetal layer enclosing numerous sporogenous tissue. At this stage, microsporangia and megasporangia are indistinguishable.


1
2
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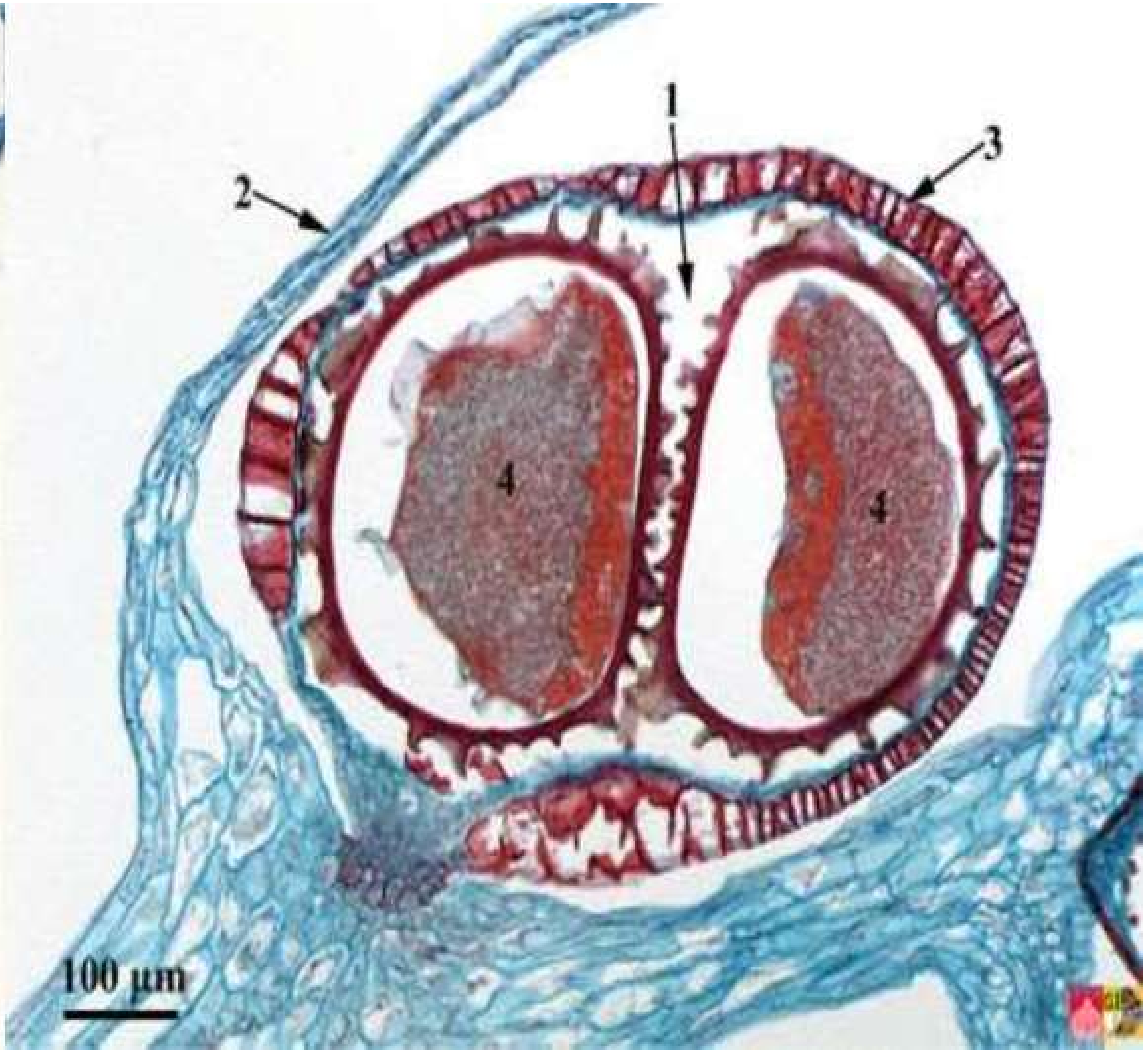
1
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Further Development of Sporangenous Tissue: Differentiation of Micro- and Megasporangium:

- **Microsporangium:**
- In micro- sporangium, about 80-90% of the sporogenous tissue undergoes meiosis and forms tetrads of haploid microspores. The microspores are more or less tetrahedral in shape. They are quite small in size (0.015 to 0.06 mm in diam.). The wall of the spore is divisible into outer thick and ornamented exine and inner thin intine.
- **Megasporangium:**
- In a potential megasporangium, only one spore mother cell becomes functional. The remaining non-functional megaspore mother cells develop large vacuoles and accumulate starch, while

Gametophyte:

- The haploid spores germinate to form the endosporic gametophytes. The development of microspores and megaspores generally starts while they are still inside their respective sporangia. Therefore, the spores are shed at multicellular stage.

Male Gametophyte:

The microspore germinates to form the male gametophyte (Fig. 7.54A-I). The first unequal division (1-1) in a microspore results in the formation of a small lenticular prothallial cell (vegetative cell) and a large antheridial initial. The prothallial cell does not divide further. The antheridial initial divides (2-2) vertically forming two primary antheridial cells.

The upper two cells divide anticlinally (3-3) by means of a curved transverse wall forming four antheridial cells and the lower two cells do not divide constituting the first jacket cells of the antheridium. The antheridial cells nearer to the prothallial cell divide (4-4) periclinally by means of a curving vertical wall to form two small distal cells (2nd jacket cells) and two large inner cells (androgonial cells).

The other two antheridial cells divide (5-5) anticlinally to form two distal cells (3rd jacket cells and two proximal cells which again divide periclinally (6-6) by means of a curving vertical wall to form two outer (4th jacket) cells and two inner antrogonial cells.

Thus, at this stage, the male gametophyte has 13 cells (1 prothallial cell, 8 jacket cells and 4 androgonial cells) and male gametophyte is shed at this 13- celled stage (Fig. 7.54G, K).

The haploid spores germinate to form the endosporic gametophytes. The development of microspores and megaspores generally starts while they are still inside their respective sporangia. Therefore, the spores are shed at multicellular stage.

- After shedding, the four primary androgonial cells undergo several divisions forming 128 or 256 androcytes. Each androcyte gets metamorphosed into a biflagellate sperm (antherozoid) which on disintegration of the jacket cells and rupture of the spore wall along the triradiate ridge are liberated (as free-swimming sperr
- The antherozoi ... ow and about 15-5(... sperm/anthero: ... The sperms of Selag
- Since the whole ... e takes place insi(... endosporic (where gametophyte develops inside the spore wall)

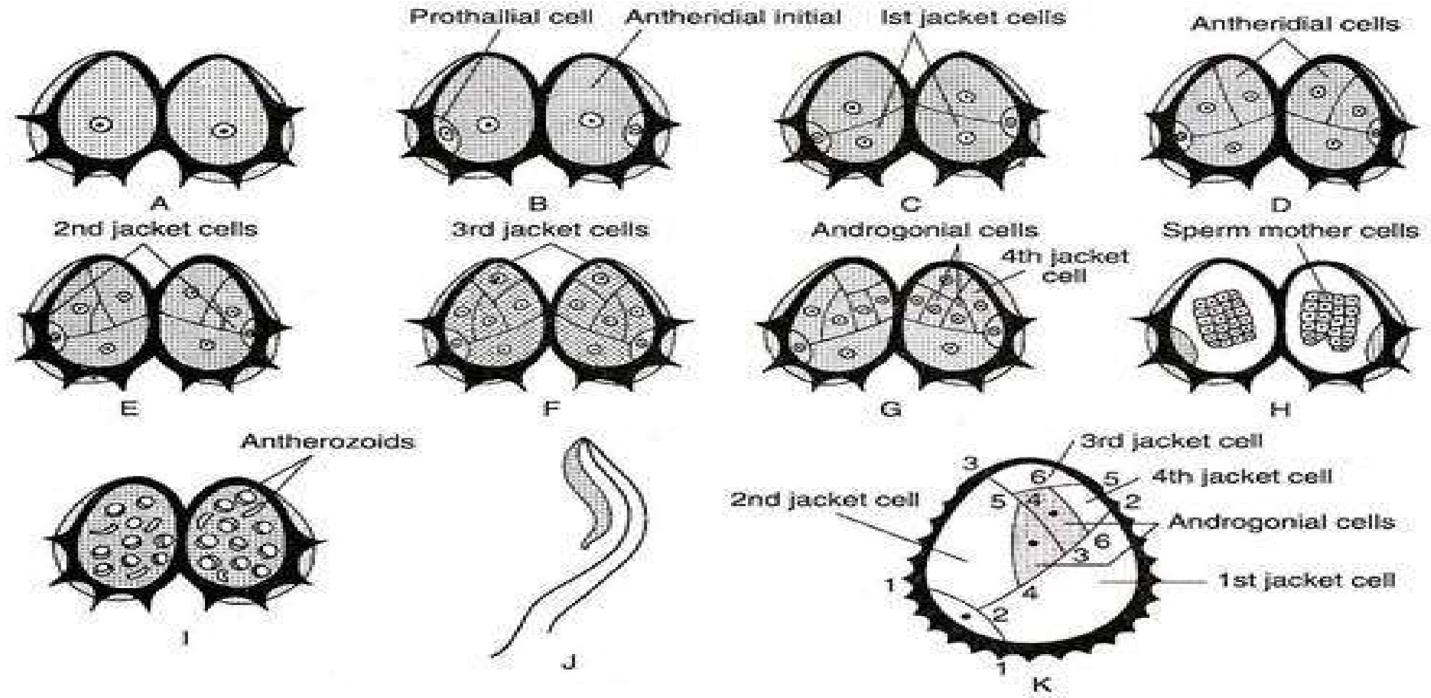


Fig. 7.54 : *Selaginella kraussiana* : A–I. Stages in the development of male gametophyte, J. A sperm, K. A part of the spore showing plane of cell division during gametophyte development

Female Gametophyte:

- Like the male gametophyte, the megagametophyte (female gametophyte) development of Selaginella begins while the megaspores are still inside the megasporangium (Fig. 7.55A-E). A conspicuous vacuole develops within the cytoplasm of the megaspore at a very early stage. Thus, the megaspore nucleus undergoes repeated nuclear

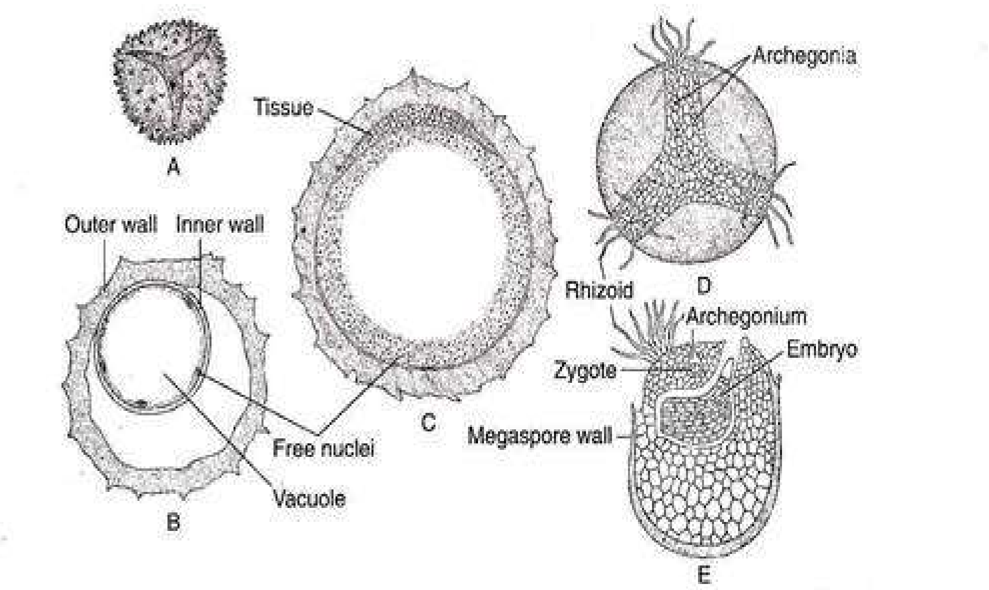


Fig. 7.55 : *Selaginella kraussiana* : A. A megaspore, B–D. The stages in the development of female gametophyte, E. A fully mature female gametophyte

As a result a thin layer of multinucleate cytoplasm is developed around the large vacuole (Fig. 7.55B, C).
The formation of cell walls around each nucleus starts initially at the apical end beneath the triradiate ridge and an apical patch of cells, two to three layered thick, is formed. In some species of Selaginella, the cell wall formation continues until the megagametophyte is entirely cellular.
In some species, e.g., S. kraussiana, the apical patch of cells is separated from the rest of the gametophyte by conspicuous arching diaphragm (wall). Ultimately the vacuole is obliterated by the formation of cells. The stage at which the megaspore is shed from the megasporangium varies from species to species.

- In majority of the species, the final stages of female gametophyte development, and fertilisation and germination of young sporophyll take place while the megaspore with its enclosed megagametophyte rests on the substratum. The female gametophyte increases in size and exerts pressure on the megaspore wall.
- This results in the splitting open the megaspore wall along the triradiate ridge. Tufts of rhizoids may develop from the exposed gametophytic tissue which play an important role in absorption of water and nutrients, also in anchorage.
- However, in S. rupestris, the megaspores are not shed

The primary cover cell follows two vertical divisions at right angle to each other to form four neck initials which again divide transversely to form eight neck cells, arranged in two tiers. The central cell divides periclinally to form an outer primary neck canal cell and an inner primary venter cell. The primary neck cell does not divide further so that a neck canal cell is formed, while the primary venter cell divides transversely into a ventral canal cell and an egg (Fig. 7.56C-E). Thus, a single archegonium consists of eight neck cells arranged in two rows of four cells each, one neck canal cell, one ventral canal cell and an egg.
The venter, along with the inner tier of neck, lies embedded in the gametophytic tissue, while the terminal neck cells extend above the surface of the gametophytic tissue.

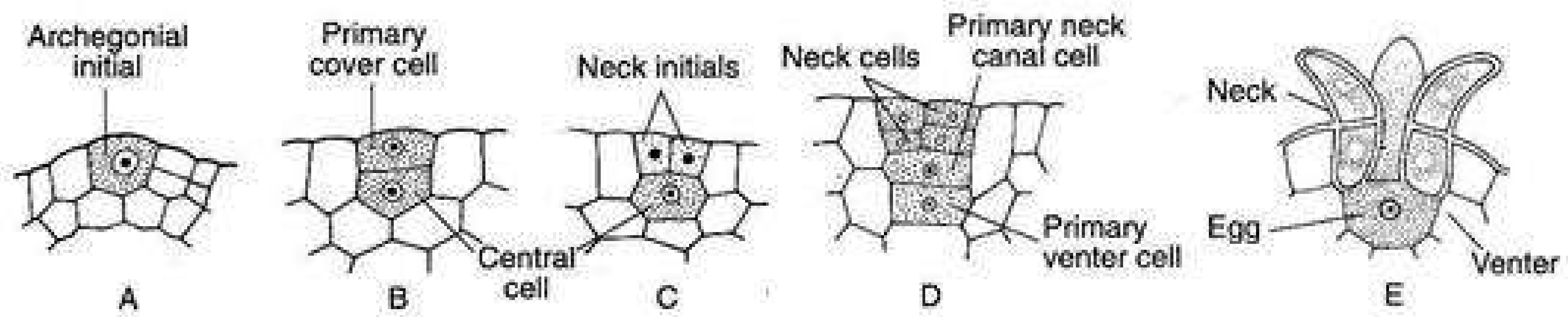


Fig. 7.56 : *Selaginella* : A–D. The stages in the development of archegonium, E. A mature archegonium

Fertilization

In majority of the species, fertilisation takes place after the megasporangium gets settled on the substratum, but in some cases (e.g., 5. rupestris), fertilisation occurs while the female gametophyte is still within the sporangium. Biflagellate sperms (haploid) are liberated, then they swim to the archegonia through a thin film of water and fertilise the egg (haploid) to form diploid zygote.

The Embryo (The New Sporophyte):

After fertilisation, the diploid sporophytic generation (i.e. zygote) is established. The first division of the zygote is generally transverse (Fig. 7.57A). The upper cell (epibasal) develops into one- or several-celled suspensor (that are toward the archegonial neck) and the lower cell (hypobasal) to the embryonic cell. The embryo is endoscopic (embryonic cell directed toward the base of the archegonium) in nature.

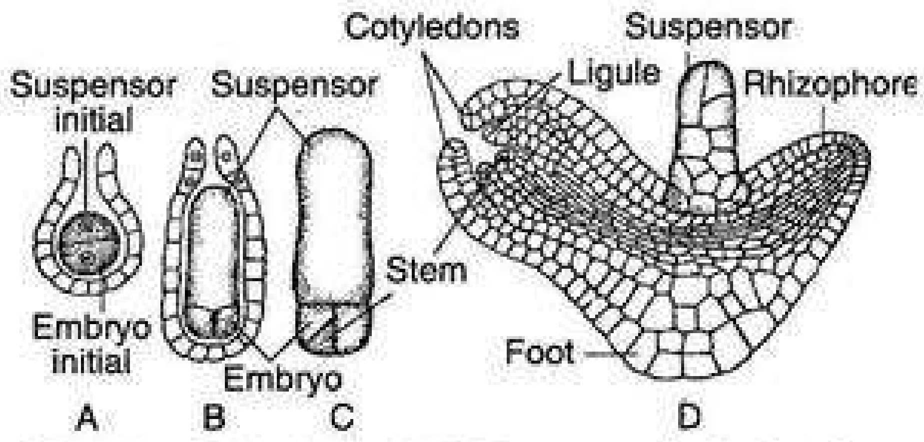


Fig. 7.57 : *Selaginella*. A–D. The stages in the development of embryo.

The embryonic cell divides by two vertical walls at right angles to each other resulting into a four-celled embryo (Fig. 7.57B). A short apical cell with three cutting faces is formed because of oblique divisions in one of the embryonic cells (Fig. 7.57C). At this stage, the embryo proper undergoes a 90-degree turn to its left.

The first pair of leaves are developed laterally on two sides of the shoot apex (Fig. 7.57D). Eventually a foot is formed on the lower side of the embryonic tissue and the primary root is developed between the suspensor and foot. The young sporophyte emerges from the gametophytic tissue through continued growth of the shoot and root

Life cycle of

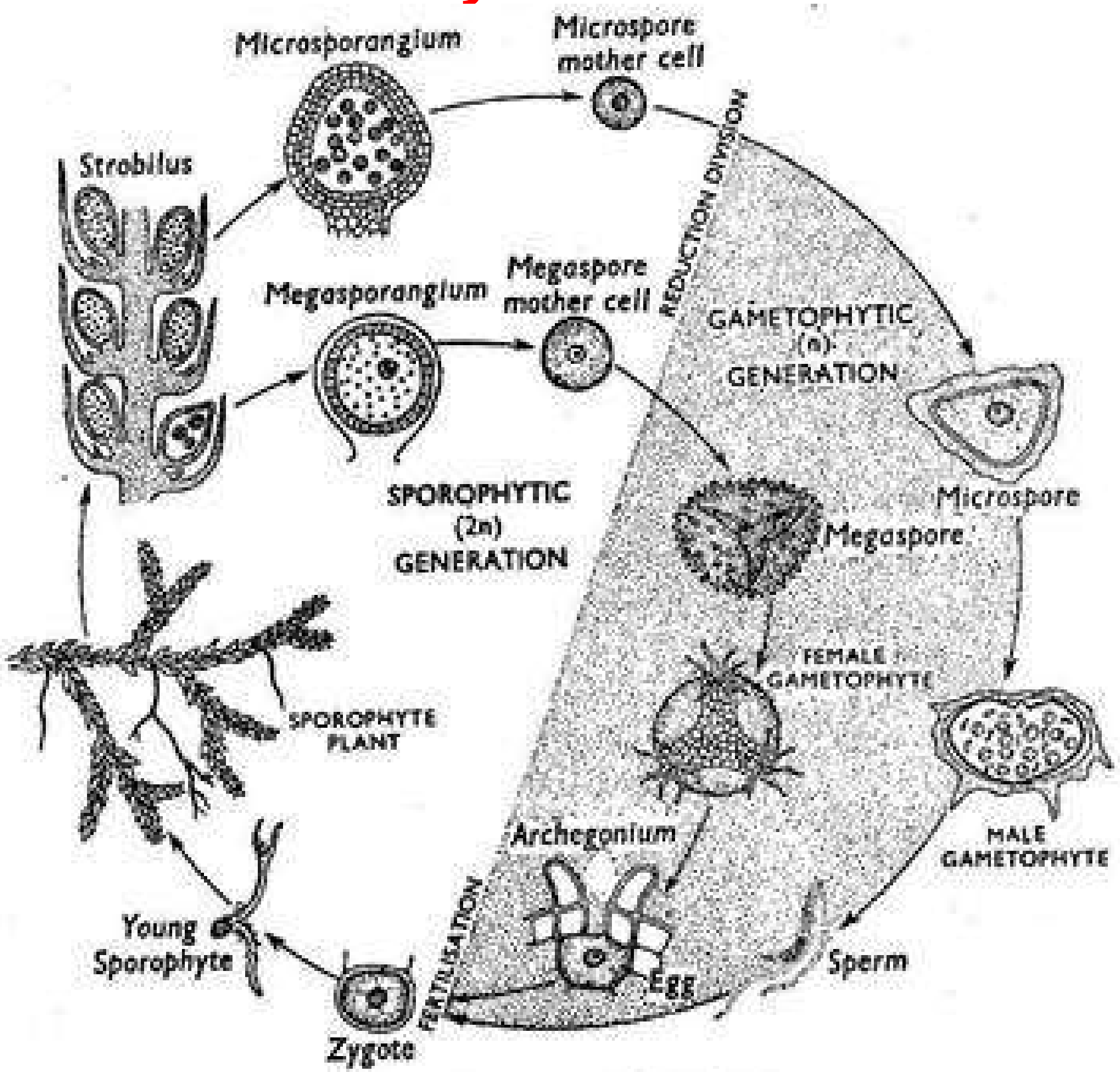


Fig. 7.58 : Life cycle of *Selaginella*

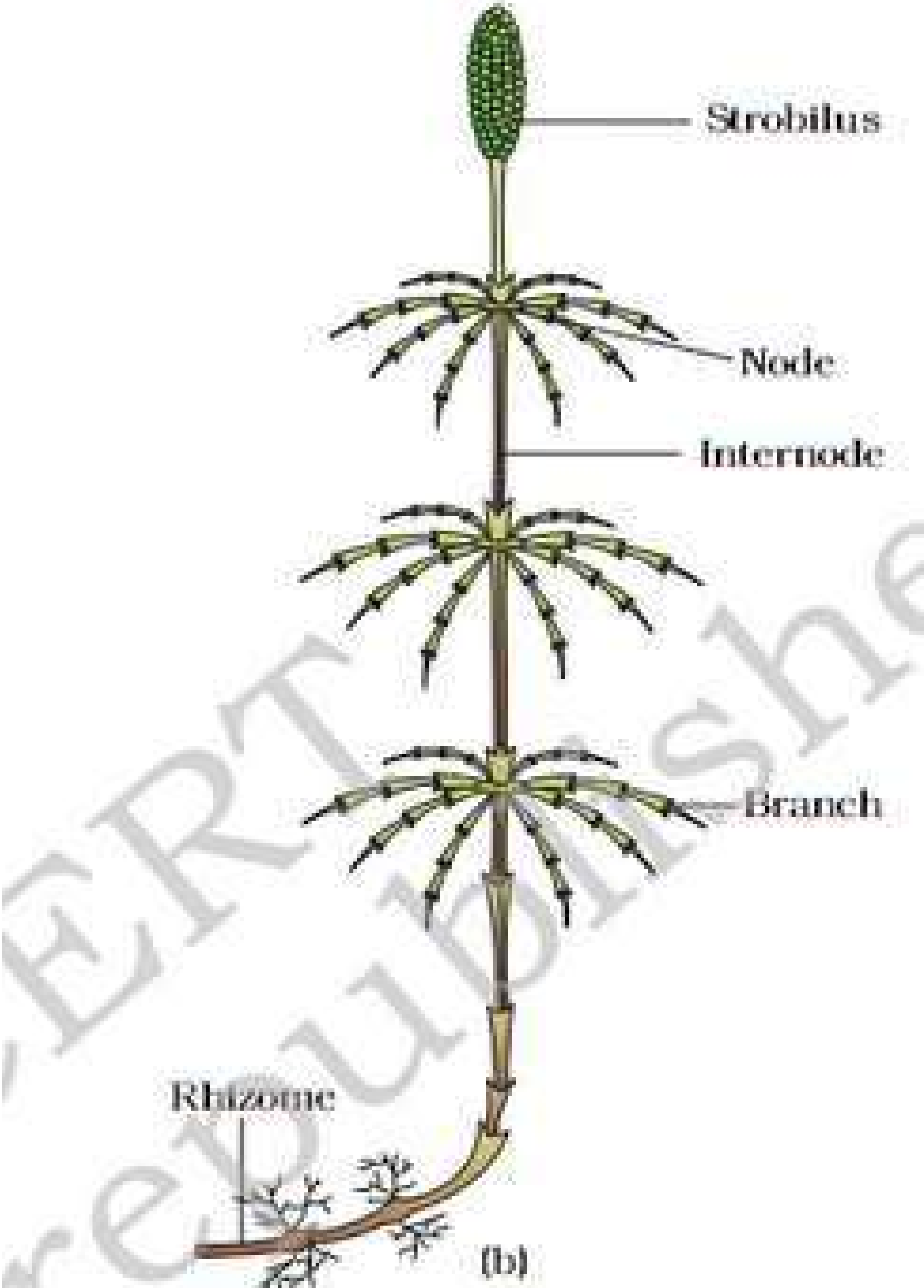
- **How far Selaginella approaches seed habit?**
- **Selaginella exhibits a significant approach towards seed habit because of the following notable features:**
- (i) It is a heterosporous pteridophyte.
- (ii) In some species of Selaginella, viz., S. rupestris and S. monospora, the megaspore number is reduced to one.
- (iii) In S. rupestris, the megaspore is retained within the megasporangium and the development of female gametophyte and subsequent fertilisation takes place in situ and even the young sporophyte can be seen developing on the parent plant.
- **(iv) Therefore, it becomes evident that the heterosporous vascular cryptogam, Selaginella, has considerably advanced towards seed habit in some species but its approach to the true seed is not complete due to the following reasons:**
- (a) The megasporangium wall is dehiscent and is not covered with the protective integuments,
- (b) The retention of the megaspore permanently within the megasporangium has not become established,
- (c) The absence of complete histological fusion between the megasporangium wall and the megaspore,
- (d) The direct access of sperms to the egg,
- (e) There is lack of resting period after the development of embryo.

EQUISETUM

Structure and Life Cycle

Habit and habitat of Equisetum:

- The plant body of Equisetum has an aerial part and an underground rhizome part. The rhizome is perennial, horizontal, branched and creeping in nature. The aerial part is herbaceous and usually annual. Majority of the species are small with a size range in between **15** and **60 cm** in height and **2.0 cm** in diameter.
- Equisetums generally grow in wet or damp habitats and are particularly common along the banks of streams or irrigation canals (*E. debile, E. palustre*). However, some species are adapted to xeric condition (e.g., *Equisetum arvense*).



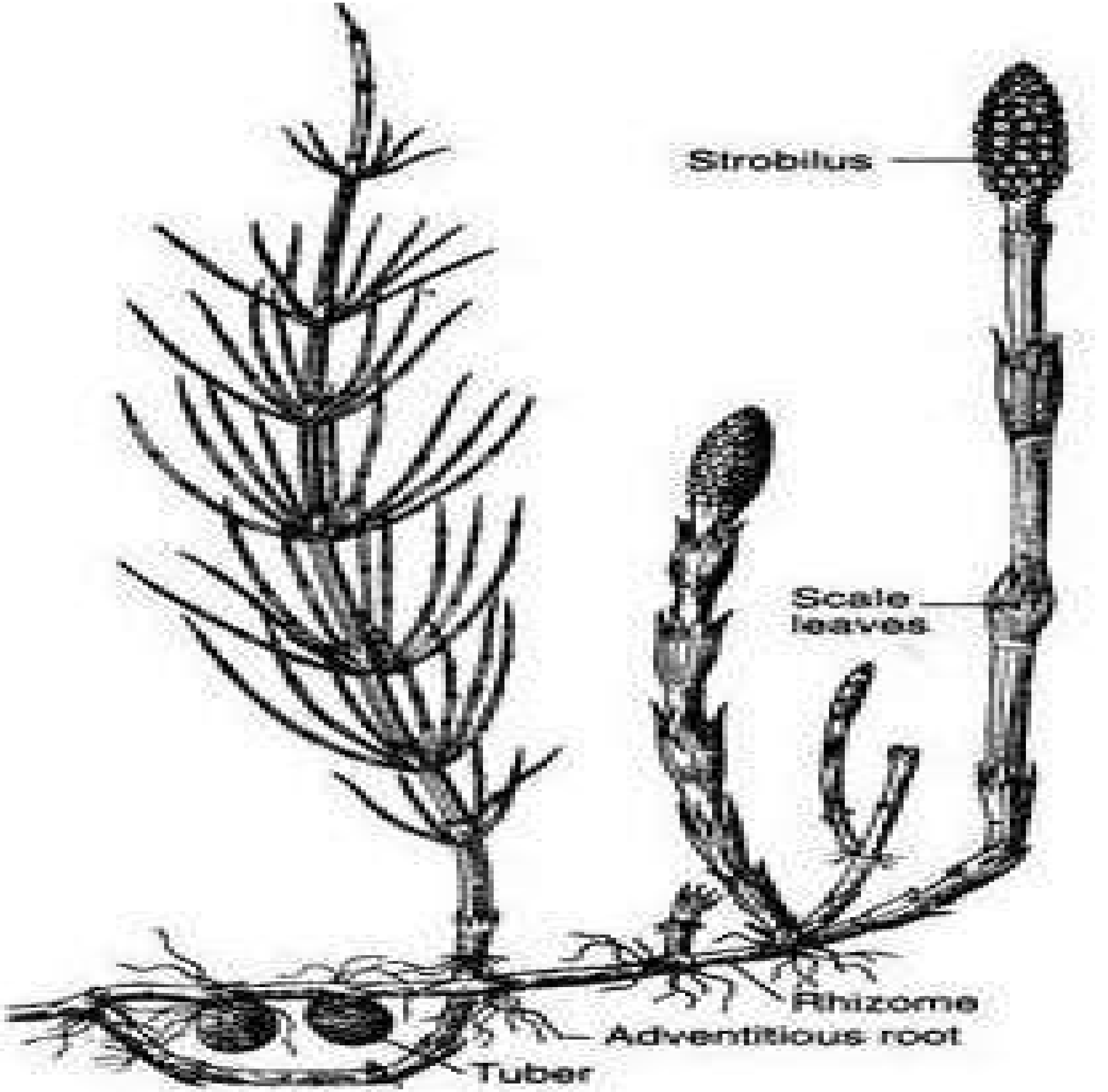


Fig. 7.83 : *Equisetum arvense* sporophyte

THE SPOROPHYTE MORPHOLOGY

The sporophytic plant body of Equisetum is differentiated into stem, roots and leaves.

Stem:

❖The stem of Equisetum has two parts: perennial, underground, much-branched rhizome and an erect, usually annual aerial shoot. The branching is monopodial, shoots are differentiated into nodes and internodes.

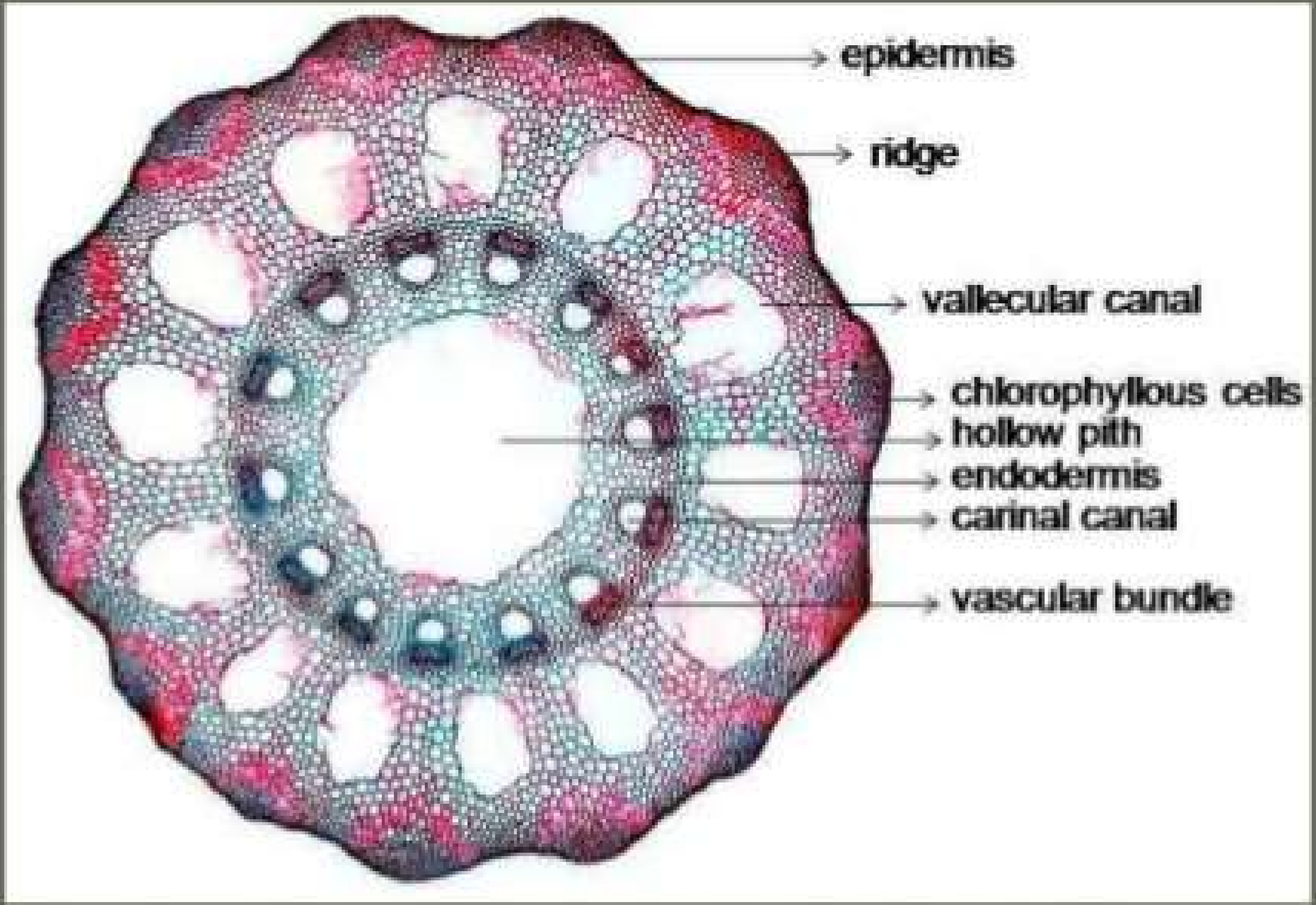
❖Sometimes shoot shows dimorphism (two types of shoots i.e., vegetative and fertile) e.g., ***E. arvense***. Some shoots are profusely branched, green (chlorophyllous) and purely vegetative. The others are fertile, unbranched, brownish in colour (achlorophyllous) and have terminal strobili.

❖The underground rhizome and the aerial axis appear to be articulated or jointed due to the presence of distinct nodes and internodes.

❖Externally, the internodes have longitudinal ridges and furrows and, internally, they are hollow, tube-like structures.

❖The ridges of the successive internodes alternate with each other and the leaves are normally of the same number as the ridges on the stem.

T.S. of aerial internode



Internal structure of aerial shoot (internode)

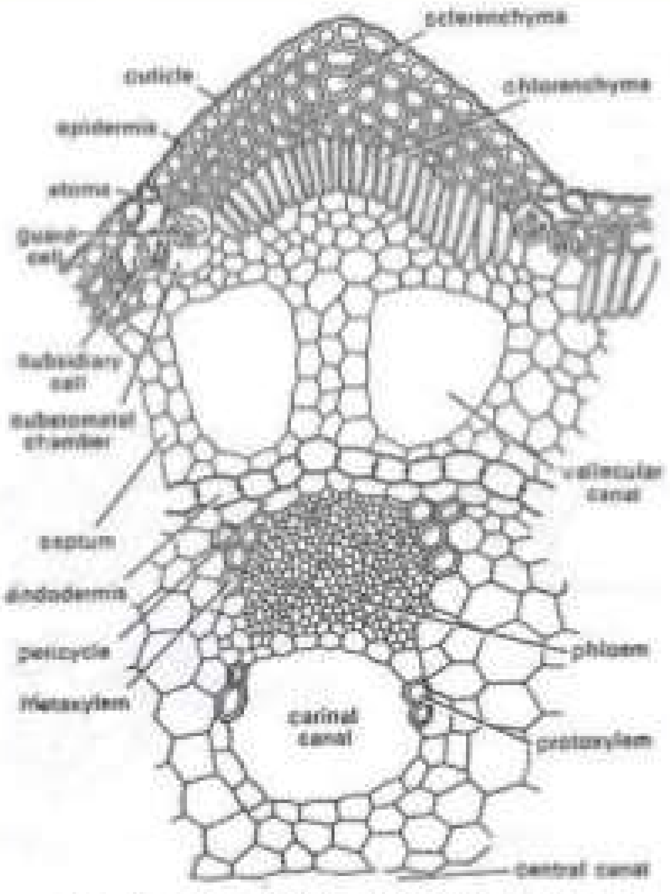


Fig. 208. Equisetum. T.S. internode of aerial shoot (a part).

Internal Features of Stem:INTERNODE

Internal Features of Stem:

- In T.S., the stem of Equisetum appears wavy in outline with ridges and furrows.
- The epidermal cell walls are thick, cuticularised and have a deposition of siliceous material.
- Stomata are distributed only in the furrows between the ridges.
- A hypodermal sclerenchymatous zone is present below each ridge which may extend up to stele in *E. giganteum*.
- The cortex is differentiated into outer and inner regions. The outer cortex is chlorenchymatous, while the inner cortex is made up of thin-walled parenchymatous cells. There is a large air cavity in the inner cortex corresponding to each furrow and alternating with the ridges, known as vallecular canal.
- New leaves and branches of Equisetum are produced by the apical meristem, however, most of the length of the stem are due to the activity of intercalary meristem located just above each node.

❖The stele is ectophloic siphonestele which is surrounded by an outer endodermal layer. An inner endodermis is also present in some species of Equisetum (e.g., E. sylvaticum). The endodermis is followed by a single-layered pericycle.

❖The vascular bundles are arranged in a ring which lies opposite to the ridges in position and alternate with the vallecular canals of the cortex. Vascular bundles are conjoint, collateral and closed. In the mature vascular bundle, protoxylem is disorganised to form a **carinal cavity** which lies opposite to the ridges.

❖The metaxylem tracheids (scalariform or reticulate) are present on both sides of the phloem. In some species vessels with reticulate perforations are reported. The central part of the internode of aerial shoot is occupied by a large pith cavity which is formed due to rapid elongation of the internodal region.

T.S. of aerial shoot through node

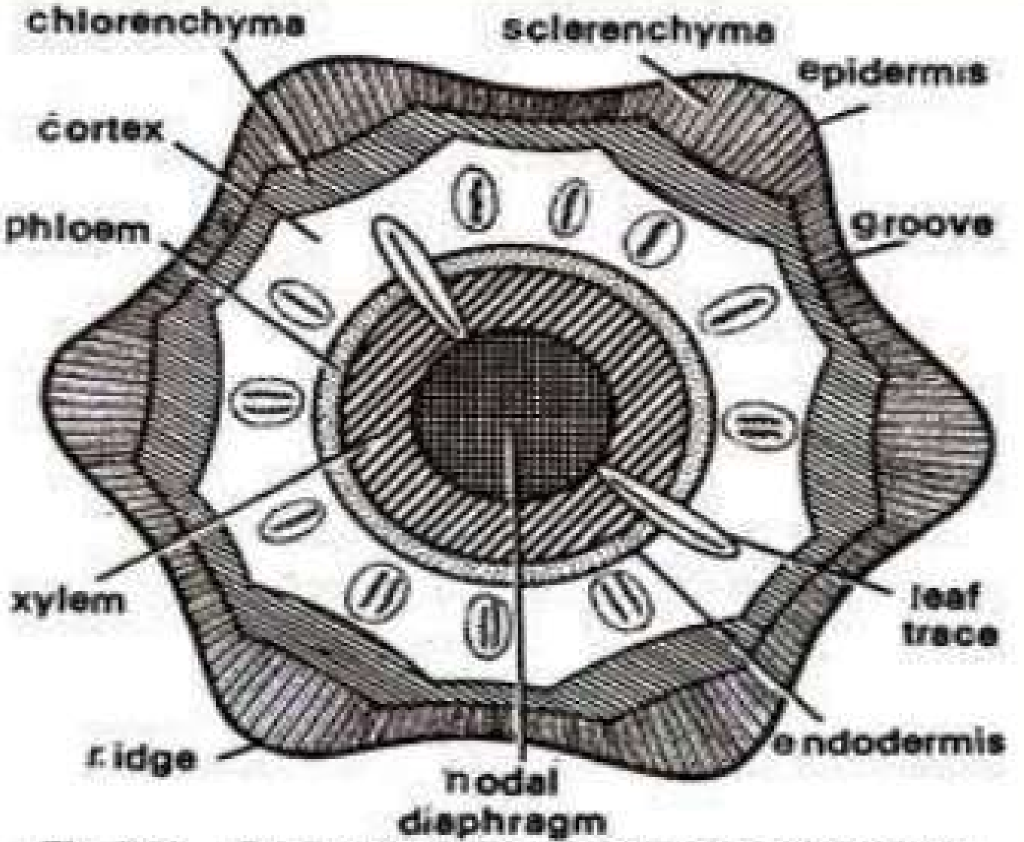


Fig. 241. Equisetum. T.S. node of aerial sterile shoot (diagrammatic).

INTERNAL STRUCTURE OF THE NODE REGION

In the nodal region, the xylem is extensively developed as a conspicuous circular ring. There are no vallecular or carinal canals at this level. In addition, a plate of pith tissue occurs at the node which separates one internode from another.

The xerophytic features are:

(i) Ridges and furrows in the stem,

(ii) Deposition of silica in the epidermal cells,

(iii) Sunken stomata,

(iv) sclerenchymatous hypodermis,

(v) Reduced and scaly leaves, and

(vi) photosynthetic tissue in the stem.

The hydrophytic characteristics on the other hand are

(i) we 11-developed aerating system like carinal canal, vallecular canal and central pith cavity, and (ii) reduced vascular elements.

Root

- The primary root is ephemeral. The slender adventitious roots arise endogenously at the nodes of the stems. In T.S., the root shows epidermis, cortex and stele from periphery to the centre. The epidermis consists of elongated cells, with or without root hairs.
- The cortex is extensive; cells of the outer cortex often have thick walls (sclerenchymatous) and those of the inner cortex are thinner parenchymatous.
- A large metaxylem element is present in the centre of the stele and the protoxylem strands lie around it. The space between the protoxylem groups is filled with phloem. There is no pith.

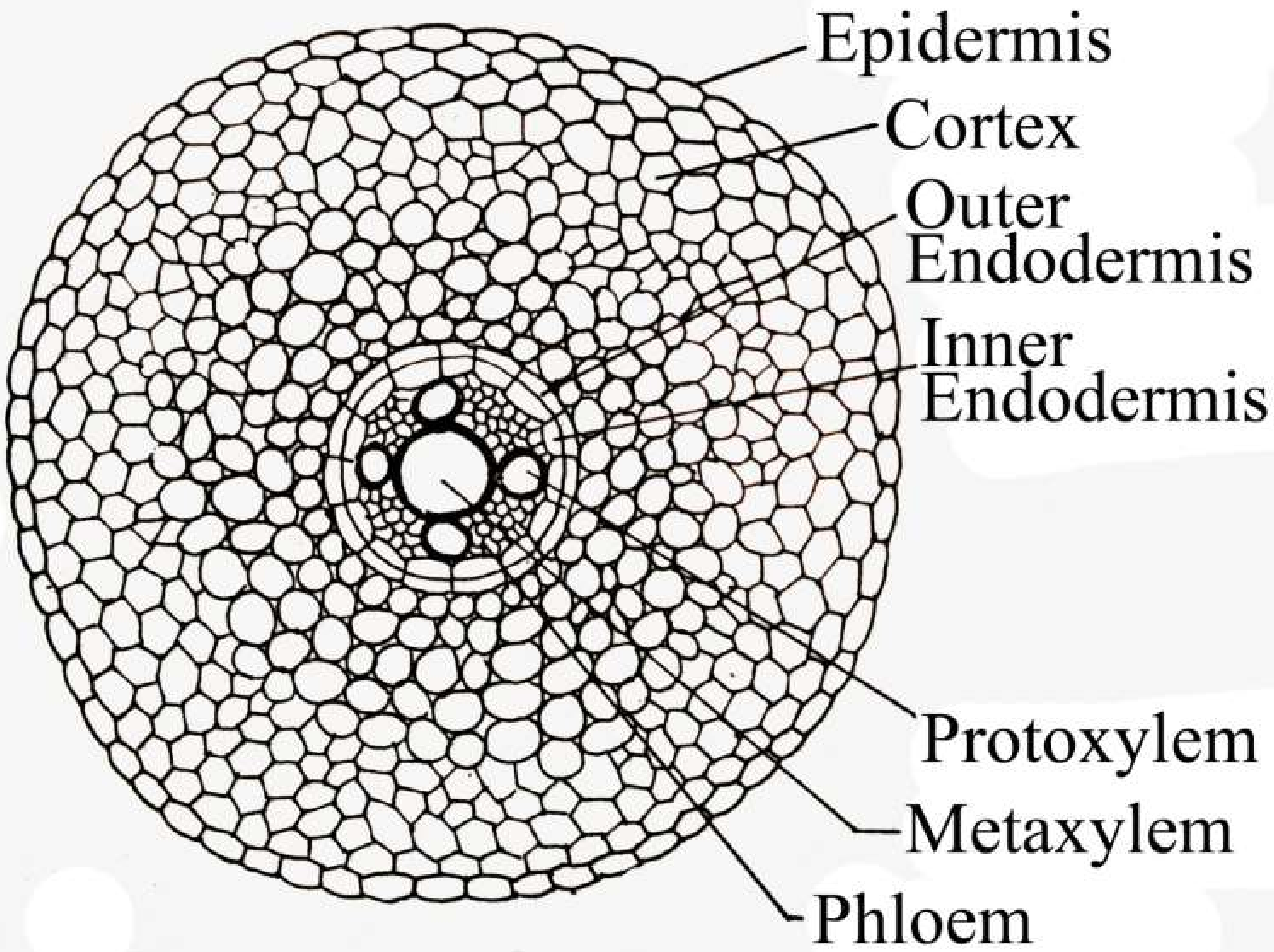
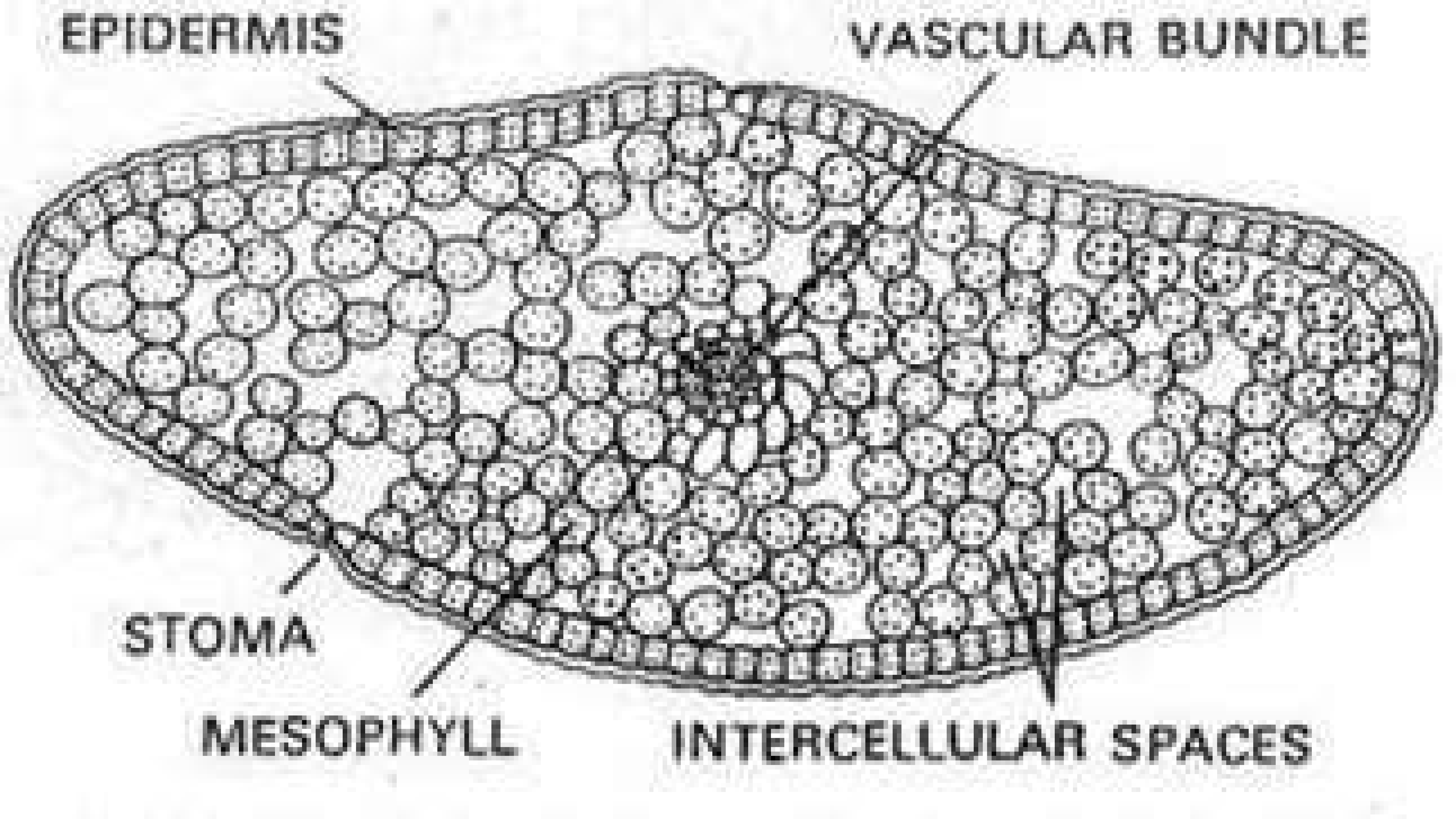


Fig: *Equisetum spp.* TS of root.

Leaves:

- The leaves of Equisetum are small, simple, scale-like and isophyllous; they are attached at each node, united at least for a part of the length and thus form a sheath around the stem. The sheath has free and pointed teeth-like tips.
- The number of leaves per node varies according to the species. The species with narrow stems have few leaves (e.g., 2-3 leaves in *E. scirpoides*) and those with thick stem have many leaves (e.g., up to 40 leaves in *E. schaffneri*).
- The number of leaves at a node corresponds to the number of ridges on the internode below. The leaves do not perform any photosynthetic function and their main function is to provide protection to young buds at the node.


EPIDERMIS
VASCULAR BUNDLE
STOMA
MESOPHYLL
INTERCELLULAR SPACES

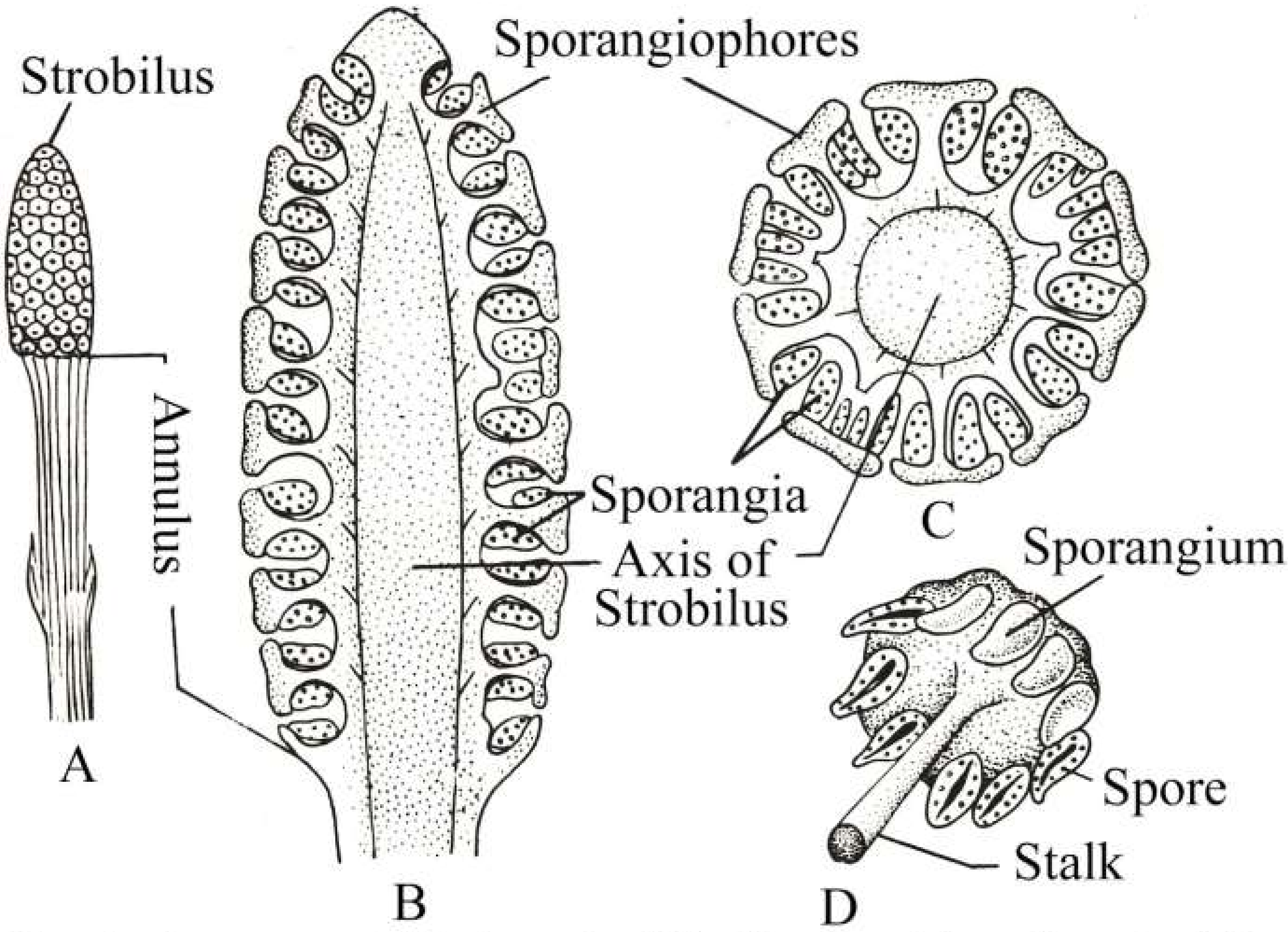


Fig: ***Equisetum spp.*** (A) A part of fertile shoot bearing strobilus; (B) LS of strobilus; (C) TS of strobilus; (D) Single sporangiophore.

Reproduction

Equisetum reproduces vegetatively and by means of spores.

i. Vegetative Reproduction:

The subterranean rhizomes of some species (e.g., E. telmateia, E. arvense) form tubers (Fig. 7.83) which, on separation from the parent plant, germinate to produce new sporophytic plants. The tubers develop due to irregular growth of some buds at the nodes of the rhizomes.

ii. Reproduction by Spores:

Spores are produced within the sporangia. The sporangia are borne on the sporangiophores which are aggregated into a compact structure termed strobilus or cone or sporangiferous spike.

Strobilus:

The strobilus are terminal in position and generally are borne terminally on the chlorophyllous vegetative shoot (Fig. 7.86A). However, they may be borne terminally on a strictly non- chlorophyllous axis (e.g., E. arvense).

The strobilus is composed of an axis with whorls of sporangiophores (Fig. 7.86B, C). Each sporangiophore is a stalked structure bearing a hexagonal peltate disc at its distal end (Fig. 7.86D). On the under surface of the sporangiophore disc 5-10 elongate, cylindrical hanging sporangia are borne near the periphery in a ring.

The flattened tips of the sporangiophores fit closely together which provide protection to the developing sporangia. The axis bears a ring-like outgrowth, the so-called annulus immediately below the whorls of sporangiophores which provide additional protection during early development.

The annulus has been interpreted as a rudimentary leaf sheath by some botanists, whereas others consider it to be sporangiophoric in nature as occasionally it bears small sporangia.

Development of Sporangium:

The mode of development of sporangium is eusporangiate, as it is not entirely formed from a single initial. Superficial cells adjacent to the original initial may also take part in the development of sporangium.

Sporangia are initiated in single superficial cell around the rim of the young sporangiophore. The periclvnal division of the sporangium initial forms an inner and an outer cell. The inner cell, by further divisions in various planes, gives rise to sporogenous tissue.

The outer cell, by periclinal and anticlinal divisions, gives rise to irregular tiers of cells, the inner tiers of which may transform into sporogenous tissue and the outer tiers become the future sporangial wall cells.

The innermost layer of the sporangial wall differentiates as the tapetum. The sporogenous cells separate from each other, round off and eventually transform into spore mother cell. All but the two outermost wall layers disorganise to form periplasmodial fluid.

However, not all of the sporogenous cells function as spore mother cells. Many of them degenerates to form a multinucleate nourishing substance for the spore mother cells. Each spore mother cell undergoes meiotic division (reductional division) and produces spore tetrad. All spores in a sporangium are of same size and shape i.e., homosporous.

Structure of Mature Sporangium:

The mature sporangium is an elongated saclike structure, attached to the inner side of the peltate disc of the sporangiophore. It is surrounded by a jacket layer which is composed of two layers of cells. The inner layer is generally compressed and the cells of the outer layer have helical thickenings which are involved in sporangial dehiscence.

Dehiscence of Sporangium:

At maturity, the strobilar axis elongates, as a result the sporangiophores become separated and exposed. Then the sporangium splits open by a longitudinal line due to the differential hygroscopic response of the wall cells.

Spores: The spores are spherical and filled with densely packed chloroplasts. The spore wall is laminated and shows four concentrate layers. The innermost is the delicate intine, followed by thick exine, the middle cuticular layer and the outermost epispore or perispore. The intine (endospore) and exine (exospore) are the true walls of the spore. The outer two layers i.e., cuticular layer and epispore are derived due to the disintegration of the nonfunctional spore mother cells and tapetal cells. These are called elaters. The elaters are hygroscopic in nature. The spores remain moist at early stages of development, thus the elaters are spirally coiled round the spore. The spores dry out at maturity and consequently the elaters become uncoiled.

Gametophyte Generation:

Equisetum is a homosporous pteridophyte. The haploid spores germinate to form gametophyte.

The germination takes place immediately if the spores land on a suitable substratum. If the spores do not germinate immediately, their viability decrease significantly. The spores swell up by absorbing water and shed their exine.

The first division of the spore results in two unequal cells: a small and a large cell. The smaller cell elongates and forms the first rhizoid. The larger cell divides irregularly to produce the prothallus.

The prevailing environmental conditions determine the size and shape of the prothallus. Mature gametophytic plants may range in size from a few millimeters up to 3 centimeters e.g., E. debile) in diameter.

They are dorsiventral and consist of a basal non-chlorophyllous cushion-like portion from which a number of erect chlorophyllous muticellular lobes develop upwards. Unicellular rhizoids are formed from the basal cells of cushion.

The prothallus bears sex organs and reproduces by means of sexual method.

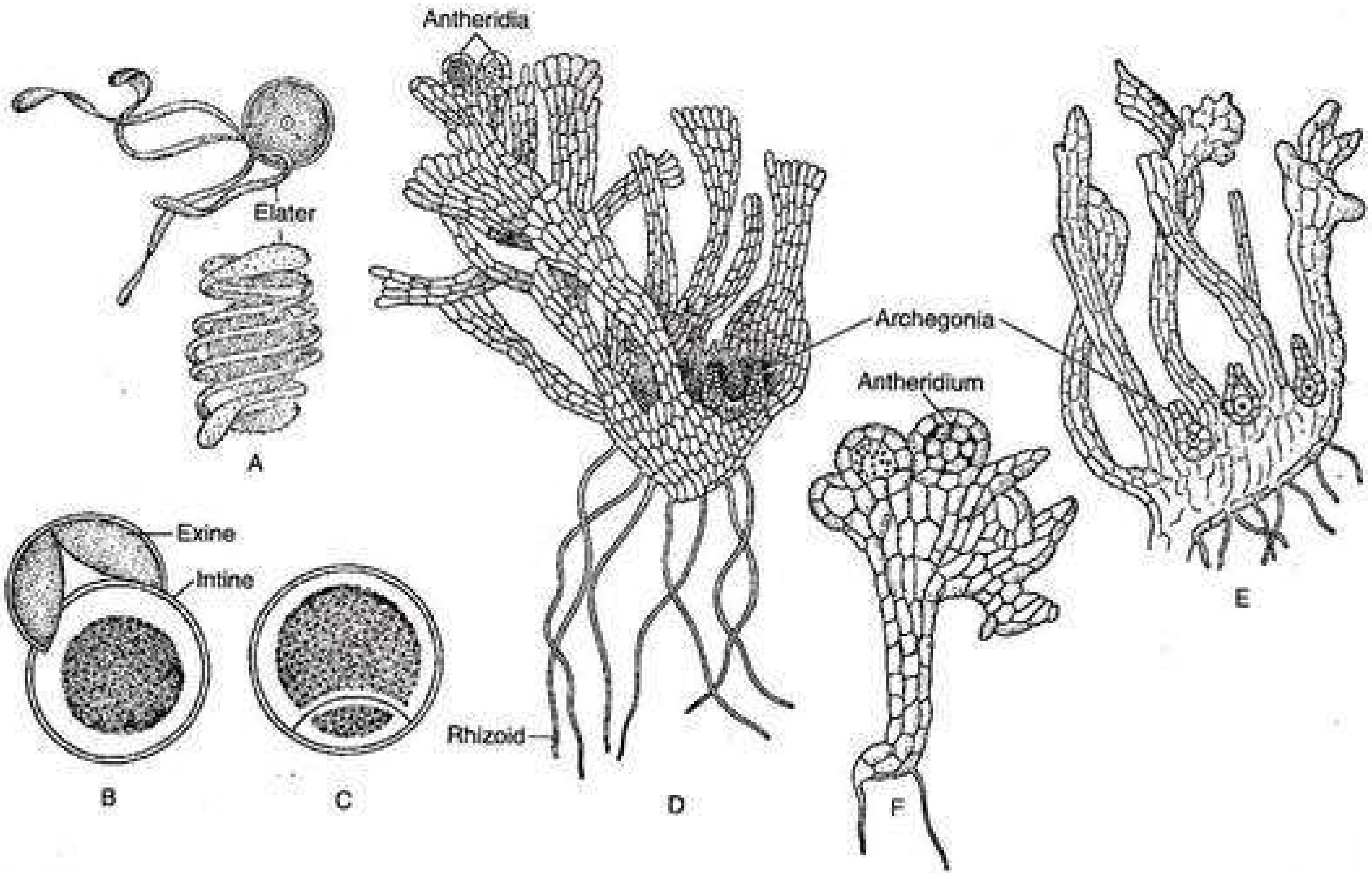


Fig. 7.87 : *Equisetum* : A. Spores with elaters, B–C. The stages of germination of spore, D. Monoecious gametophyte, E. Female gametophyte, F. Male gametophyte

Sex Organs of Equisetum:

Antheridium:

- In monoecious species, antheridia develop later than archegonia. They are of two types — projecting type and embedded type. Antheridia first appear on the lobes of the gametophyte. The periclinal division of the superficial antheridial initial gives rise to jacket initial and an androgonial cell.
- The jacket initial divides anticlinally to form a single-layered jacket. The repeated divisions of androgonial cells form numerous cells which, on metamorphosis, produce spermatids/antherozoids. The antherozoids escape through a pore created by the separation of the apical jacket cell. The apical part of the antherozoid is spirally coiled, whereas the lower part is, to some extent, expanded.

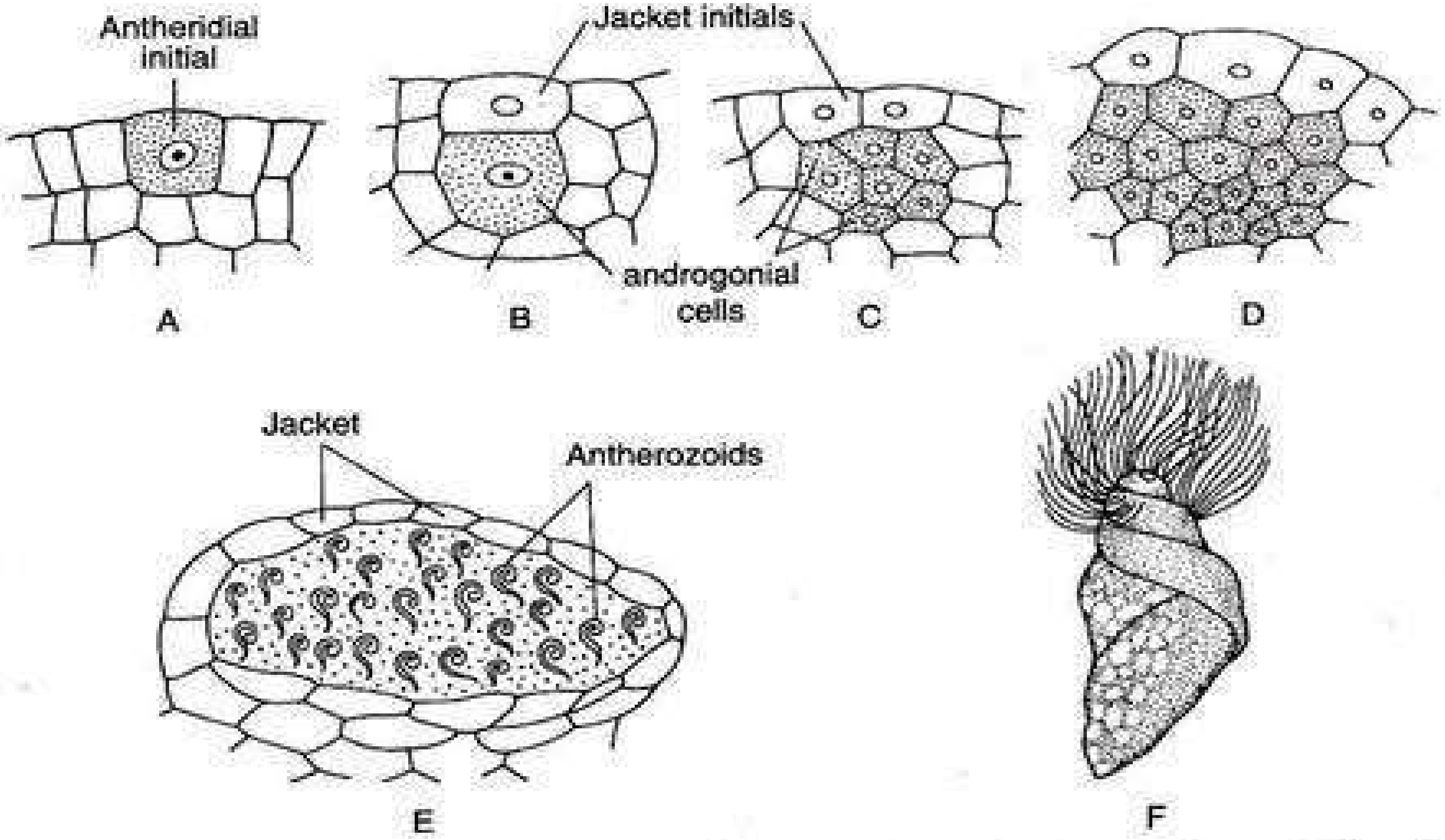


Fig. 7.88 : *Equisetum* : Development of antheridium. A–D. Successive stages in the development of antheridium, E. A mature antheridium, F. An antherozoid

Archegonium:

Any superficial cell in the marginal meristem acts as an archegonial initial which undergoes periclinal division to form a primary cover cell and an inner central cell. The cover cell, by two vertical divisions at right angle to each other, forms a neck. The central cell divides transversely to form a primary neck canal cell and a venter cell.

Two neck canal cells are produced from the primary neck canal cell. While, the venter cell, by a transverse division, forms the ventral canal cell and an egg.

At maturity, an archegonium has a projecting neck comprising of three to four tiers of neck cells arranged in four rows, two neck canal cells of unequal size, a ventral canal cell, and an egg at the base of the embedded venter.

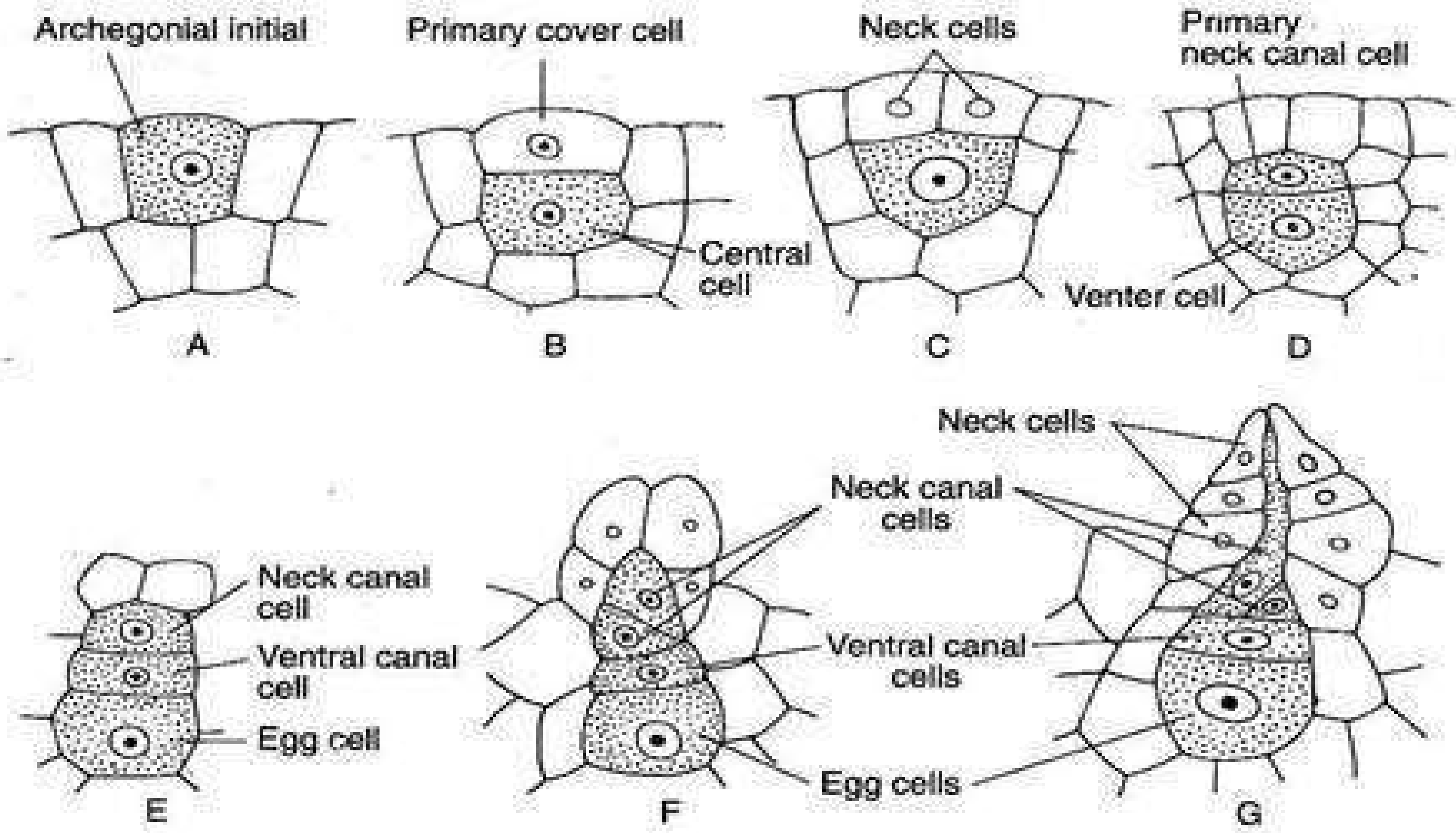


Fig. 7.89 : *Equisetum*. Development of archegonium : A–E. Successive stages in the development of archegonium, G. A mature archegonium

Fertilization
:

Water is essential for fertilization. The gametophyte must be covered with a thin layer of water in which the motile antherozoides swim to the archegonia. The neck canal cells and ventral canal cell of the archegonia disintegrate to form a passage for the entry of antherozoids.

Many antherozoids pass through the canal of the archegonium but only one of them fuses with the egg. Thus diploid zygote is formed. Generally more than one archegonia are fertilized in a prothallus.

Embryo (The New Sporophyte):

The embryo is the mother cell of the next sporophytic generation. Unlike most pteridophytes, several sporophytes develop on the same prothallus. The first division of the zygote is transverse. This results in an upper epibasal cell and lower hypobasal cell. The embryo is therefore exoscopic (where the apical cell is duacted outward. No suspensor is formed in Equisetum.

The epibasal and hypobasal cells then divide at right angles to the oogonial wall, and as a result a tour-celled quadrant stage is established.

All the four cells of the quadrant are of different size and shape.

The four-celled embryo undergoes subsequent divisions and the future shoot apex originate from the largest cell and leaf initials from the remai-

ning cells of one quadrant of the epibasal hemisphere.

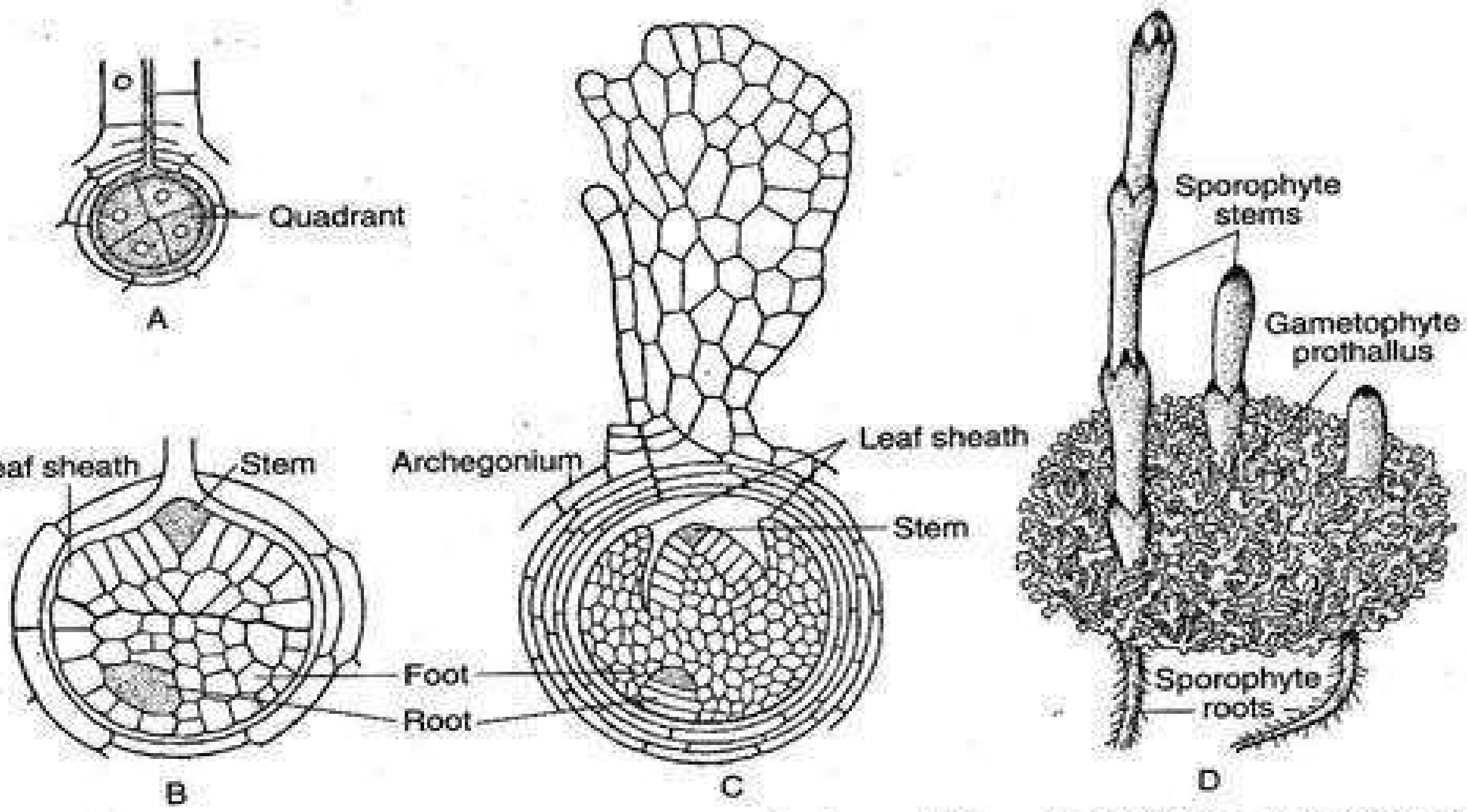


Fig. 7.90 : *Equisetum* : A–C. The stages in the development of embryo within venter, D. Young sporophytes developing from a gametophyte

Later the root grows directly downward and penetrate the gametophytic tissue to reach the soil or substratum. A number of such sporophytes may develop from a large mature gametophyte if more than one egg is fertilized

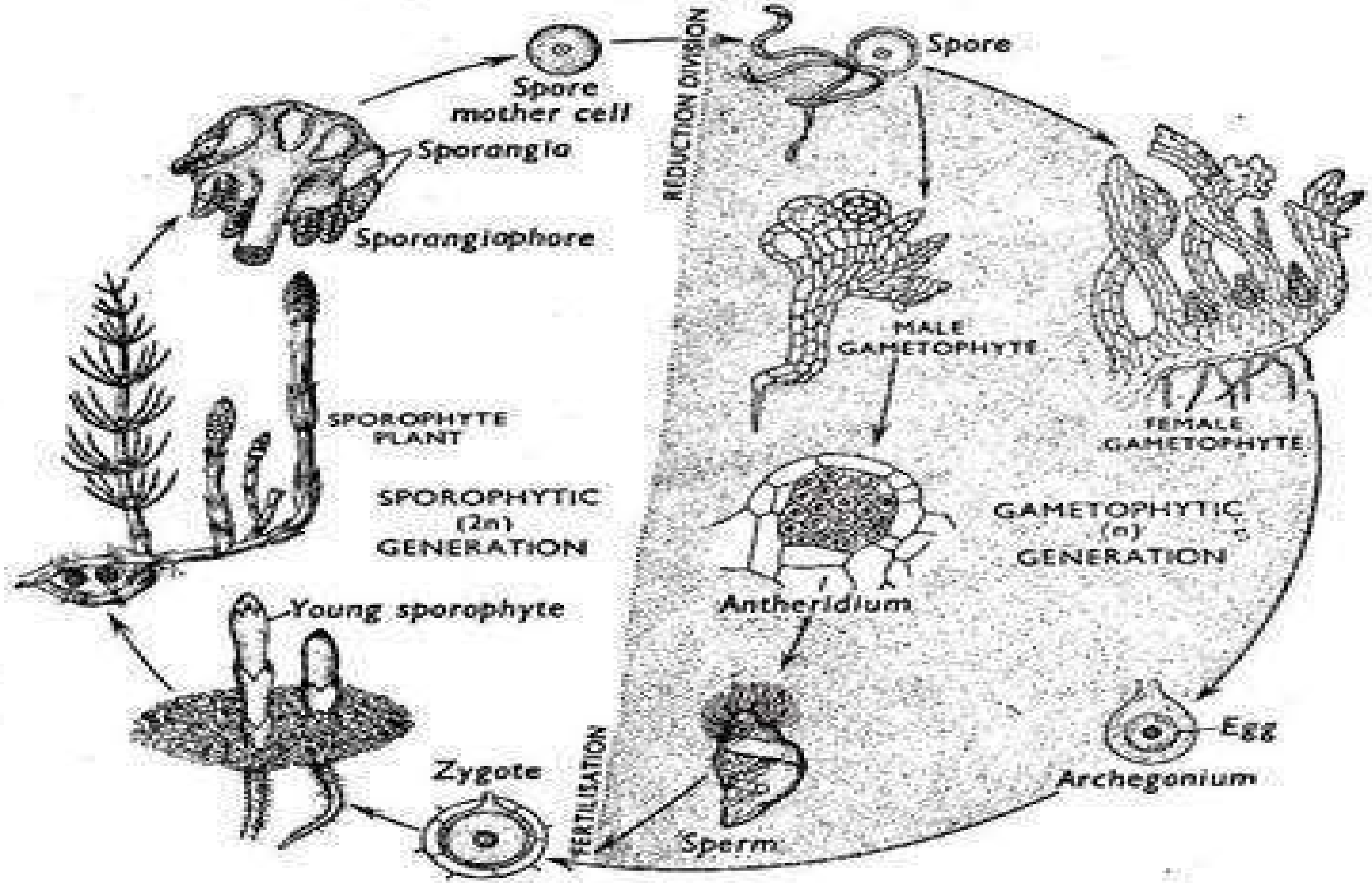
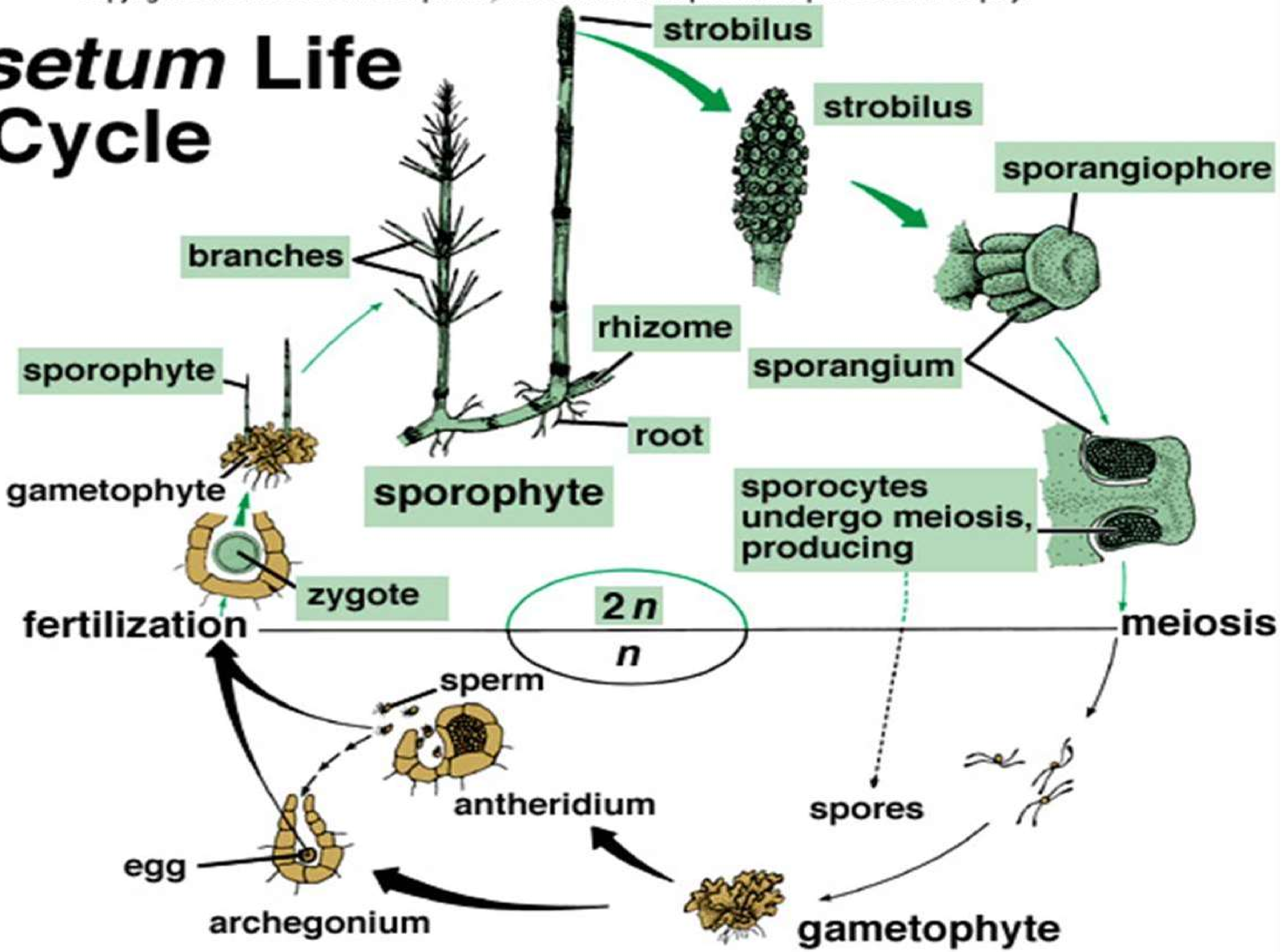


Fig. 7.91 : Life cycle of *Equisetum arvense* (dioecious)

Equisetum Life Cycle



Adiantum

Morphology, anatomy, Reproduc

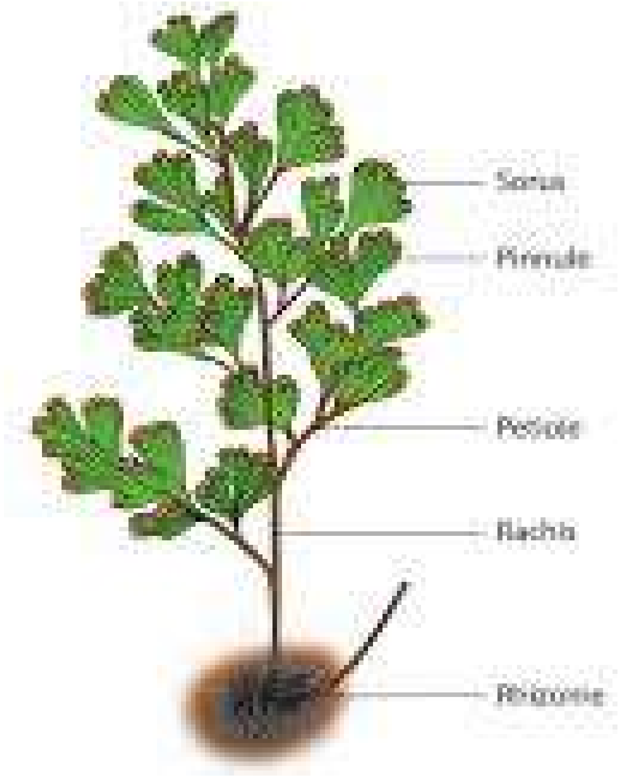
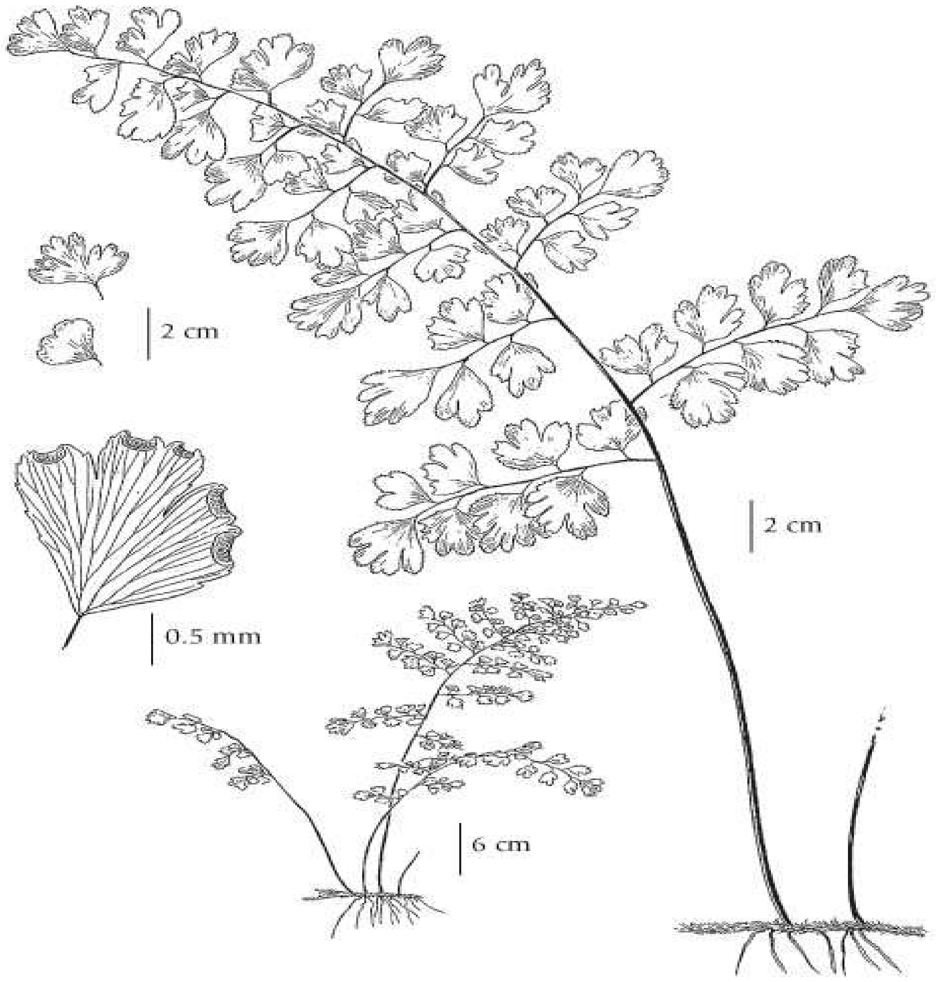


Figure 2.31: Adiantum Habit



Adiantum capillus-veneris

Adiantum Classification

- Class Filicopsida.
- Order **Polypodiales**.
- Family Pteridaceae – **Maidenhair Fern** family.
  Genus **Adiantum** L. – **maidenhair fern**

Occurrence and Distribution

- Adiantum is popularly called ‘Maiden hair fem’ because of the shiny black rachis of the leaves.
- It is one of the most widely distributed genera (Other genera are Cheilanthes, Pellaea, Ceratopieris and Anogramma) of the family growing luxuriantly in both tropical and sub topical regions of the world.
- It grows ubiquitously wherever nature offers a moist, shaded locality. There are nearly 200 species.
- 24- Indian species of Adiantum. Some of the common Indian species are – A. capillus-veneris, A.pedatum, A. incisum, A. caudatum, A. venustum, A. lunulatum, A. edgowrthii etc.
- Species of Adiantum are commonly cultivated in green houses because of their attractive foliage.

Sporophyte of Adiantum

- Morphology of the plant: The sporophytic plant body consists of an underground rhizome from which are produced leaves and roots. The rhizome is covered with chaffy scales (Paleae). It may be erect (A. caudatum), semi erect (A. peltadatum), or creeping (A. capillus-veneris).
- Studies of Nicholas (1985) in *Adiantum trapeziforme* indicate that the erect rhizome of the young sporophyte quickly transforms itself into creeping. The rhizome may be hard or soft and brown in colour.
- The chaffy scales that cover the rhizome are of various shapes and sizes. Nayar (1961) has made a detailed study of these scales in 24 species of Adiantum. From the undersurface of the rhizome arise a number of adventitious roots. The roots are stiff and black in colour. Occasionally they may be branched.

- The leaves are produced in acropetalous succession on the creeping rhizome. They show circinate vernation typical of ferns. The rachis of the leaf is hard, wiry, shiny and black or dark brown in colour thus giving the name maiden hair fern. The rachis has a medium dorsal groove, and is covered with paleae at the basal region. In addition to this, glandular hairs may also be present.
- The leaves may be unipinnate (Axaudatum) or bi or tri-pinnate as in , A. capillus – veneris (Fig. 149). The pinnae are stalked and have a dichotomous venation. The rachis may terminate in a pinna or may bear a bud. In A capillus veneris the rachis divides pinnately and the ultimate branches bear pinnae in an alternate fashion.
- There is no distinction between fertile and sterile leaves in Adiantum. The whole leaf may be sporangiferous or only certain pinnae may bear sporangia. The soral organisation is very evident. Sori are borne on the ventral surface of the pinnae.

Adiantum

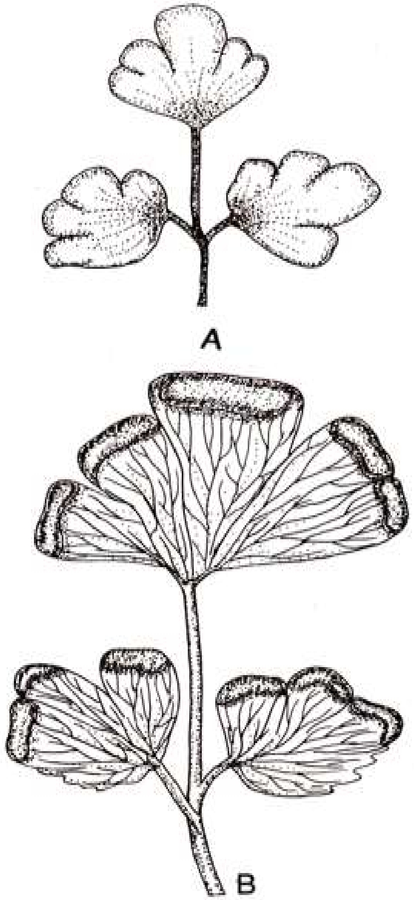


Fig. 149. *Adiantum* : Sterile (A) and Fertile (B) Leaflets of *A. capillus veneris*

Sporophyte Anatomy

- **Internal Structure:**
- **1. Rhizome:**
- A transection reveals the usual three zones epidermis, cortex and stele (Fig. 150). The outline of the section would be wavy. Epidermis is single layered and the cells may be thin walled or thick walled. There is a cuticle external to the epidermis.
- Cortex lies internal to the epidermis. It may be wholly parenchymatous (A. rubellum), (Fig. 150) or it may have sclerenchyma and parenchyma. In A. pectinatum, scattered masses of sclerenchyma are found embedded in the parenchymatous ground tissue. In A. caudatum, sclerenchyma constitutes the hypodermal region.
- The central vascular cylinder exhibits great variety. In A. capillus veneris, it is a dictyostele consisting of a ring of meristeles. In the young condition the stele may be a solenostele. In A. rubellum the stele is a typical amphiphloic solenostele, with characteristic features such as outer endodermis, outer pericycle, outer phloem, xylem, inner phloem, inner pericycle and inner endodermis lining the parenchymatous pith.

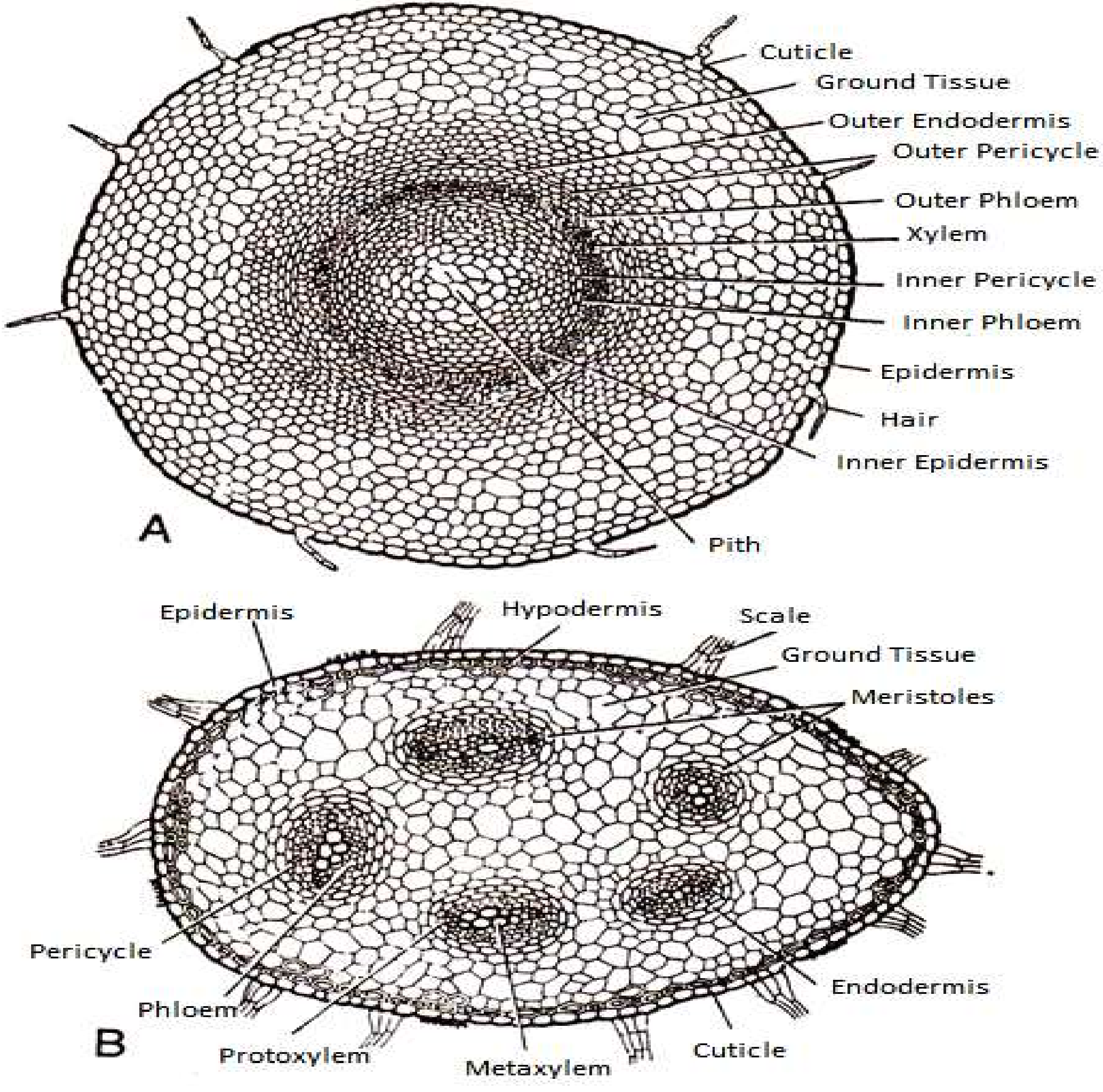


Fig. 150. *Adiantum* : Anatomy of Rhizome
A. Amphiphloic Siphonostele in *A. rubellum*, B. Dictyostele in *A. capillus veneris*

- **Leaf:**
- The petiole shows an epidermis, parenchymatous cortex and the vascular trace. Srivastava (1979) has studied the foliar epidermis of Adiantum. There is a thick walled hypodermis next to the epidermis. The number of leaf traces entering the leaf, varies.
- It is single in A. caudatum and others and double in A. capillus – veneris. Even when there are two leaf traces, both of them unite further up resulting in a single bundle. The xylem is concave at the base but triradiate higher up with three protoxylem groups. Xylem is exarch.
- In A. bausei there is a patch of included parenchyma in the xylem. Khare and Shankar (1986) studied the vascular organisation of the petiole in Adiantum caudatum, A.edgeworthii, A.pedatum, A.phillippense, A.pubescens and A.trapeziforme and have reported two types of vascular supply to the leaf.
- In A.phillipense, A.caudatum and A.edgeworthii there is always a single vascular trace from the rhizome which remains unaltered in the petiole, while in the other three species two distinct traces originate from the rhizome.
- These two merge into one after entering the petiole. In a comparative anatomical study of the stipe of Adiantum, Bidin and Walker (1985) have reported eight different types of xylem configurations. According to them this is of systematic value.

- The lamina shows the two epidermal layers upper and lower the mesophyll is generally undifferentiated. It is highly reduced in A. capillus – veneris, A pedatum, etc., having only two layers of cells. In A. pedatum, in some regions the mesophyll is totally absent and at such places the two epidermal layers are closely appressed to each other.
- The mesophyll (when present) as well as the epidermal layers are chlorophyllous. The epidermal layers are chlorophyllous. The epidermal cells over the veins are thick walled. The stomata are scattered throughout the surface of the leaf. Paleae or ramenta may be borne even on the epidermis of the lamina. The vein may or may not have a bundle sheath. The vascular tissues show the characteristic X\P arrangement.

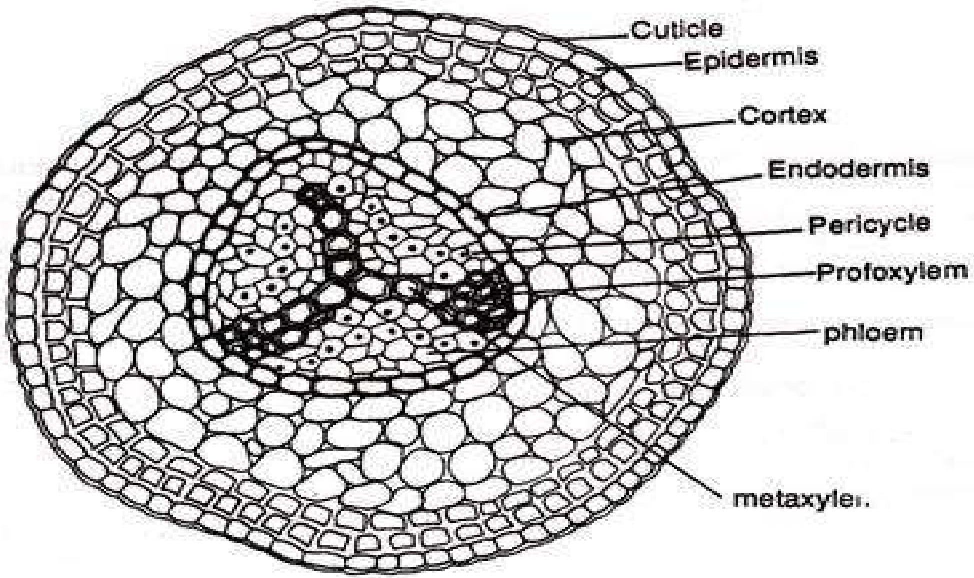


Fig. 151. *Adiantum* : T.S. of Petiole

3. Root:

- A transection shows a very prominent piliferous layer, a two zoned cortex and the central protostele. The piliferous layer has brown coloured cell walls. Cortex has an outer parenchymatous zone and an inner sclerotic zone.
- Surrounding the stele is a conspicuous endodermis with prominent casparian thickenings. The xylem is exarch and diarch, phloem completely surrounds the xylem. External to phloem is a single layered pericycle.

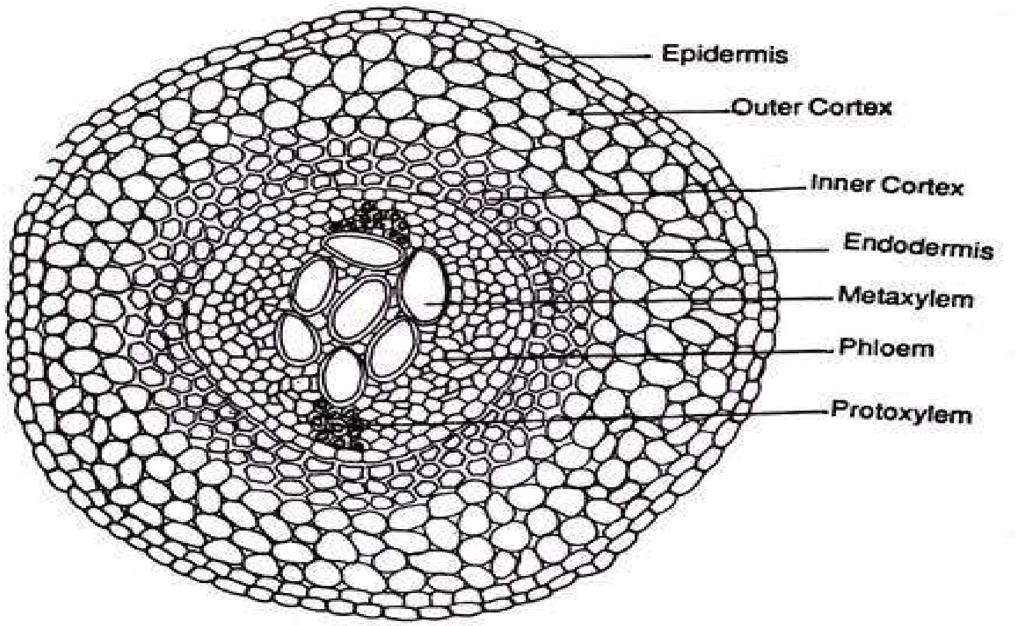


Fig. 152. *Adiantum* : T.S. of Root

Reproduction

- Vegetative propagation is brought about by buds produced at the leaf tips. The buds enter the ground when the leaf bends and touches the soil. There they develop into a new individual. This, in turn may repeat the process leading to the walking Habit. Walking habit is seen in A caudatum.

- **Spore Producing Organs:**
- **T**here is no distinction into fertile and sterile leaves. The sori are born at the distal end of the pinnae. But the sori are not exactly marginal. They are borne a little behind the tip of the veins.
- The sorus bearing margin of the leaf incurls and forms the false inducium. In some cases sporangia may develop at the distal ends of the veins (A. phillippense). In the sori paraphyses may be present in between the sporangia as in A. rubellum, A. tenerum, etc. The sorus is of the mixed type.

Structure of Sporangium

- Sporangium shows leptosporangiate development because it is developed from single initial.
- It has a multicellular, long slender stalk called pedicel or seta and globose or oval body known as capsule or spore sac.
- Spore sac has single layered jacket. Some cells of the jacket are modified to form annulus and stomium.
- Annulus is ring like structure with vertically elongated cells. It begins from the stalk on one side, encircles the top and extends upto half way on the other side where it joins with the epistomium of stomium.
- Annulus cells have thin outer tangential and lateral walls and thickened inner tangential and radial walls. It helps in the dehiscence and dispersal of spores.
- Stomium is present in between the end of annulus and stalk that forms the remaining portion of the ring.

- Stomium cells are long, flat and thin walled and permit easy cleavage of the sporangium and dehiscence. The middle two cells of the stomium are narrow, radiallly elongated and called as lip cells. Two or three cells present above the lip cells form the epistomium and 2 or 3 cells below the lip cells form the hypostomium.
- The other cells of jacket are thin walled and polygonal or hexagonal. Interior to jacket 1 or 2 layered nutritive tissue, tapetum is present. It encircles the sporogenous tissue.
- Sporogenous tissue usually forms 12 spore mother cells that divide meiotically and form 48 haploid, morphologically similar spores (Homosporous).
- Young sporangium is green and mature sporangium is dark brown.
- Sporangial dehiscence
- At maturity the capsule is dry. In dry conditions, the annulus contracts and the sporangial wall is broken transversely at stomium between the lip cells.
- The stomium bends backwards carrying the upper half of the broken capsule containing the spores that are exposed for wind dispersal.
- When the annulus absorbs moisture, it flips forward hurling the spores with some force and snaps back to its original position like spring. This mechanism of spore dispersal is known as sting or catapult mechanism.
- The spores are carried away by wind and remain viable for longer period.

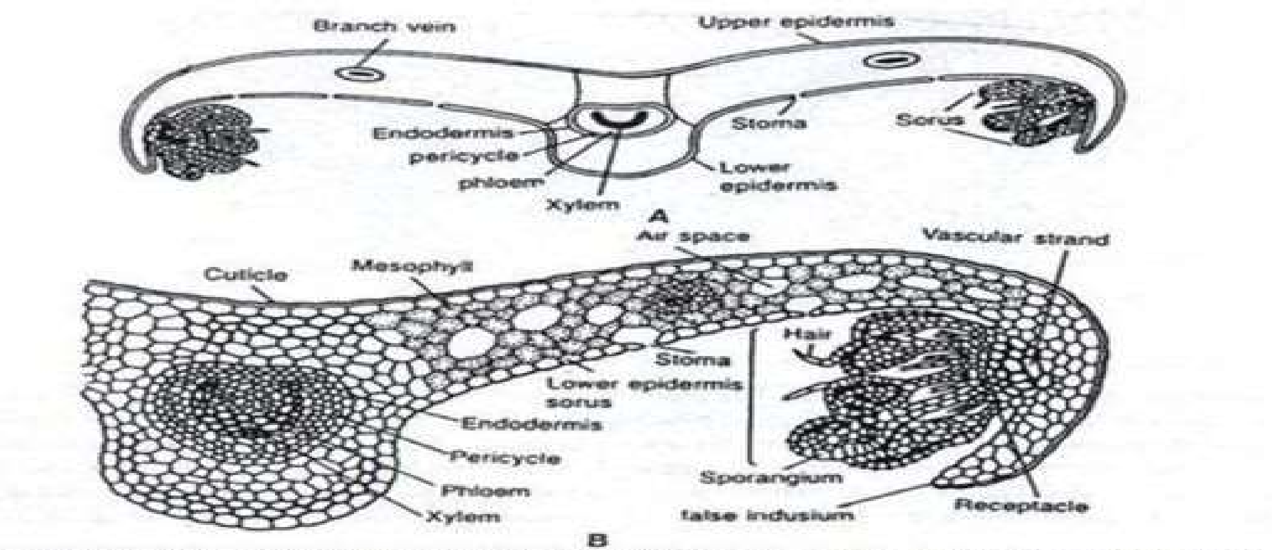
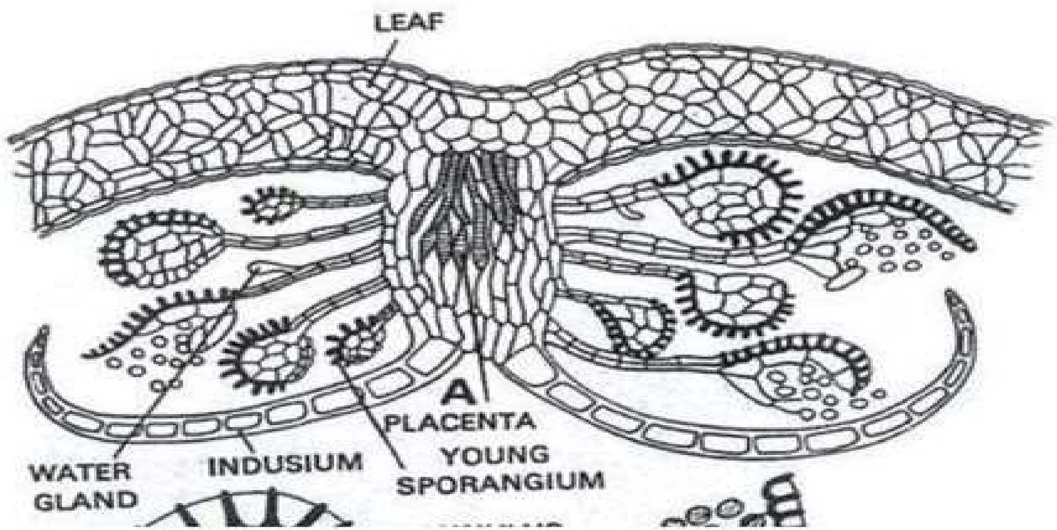


Fig. 31.4. (A–B). *Pteris vittata.* A. Outline figure of T.S. fertile leaflet showing internal structure; B. portion of 'A' in detail.



- It is protected by the upper indusial flap that is formed by the curving of margins of the pinnae (false indusium)

- A delicate membranous structure, known as indusium also arises from the lower side placenta and covers the sorus of sporangia ruptures at stomium during dehiscence of capsule.

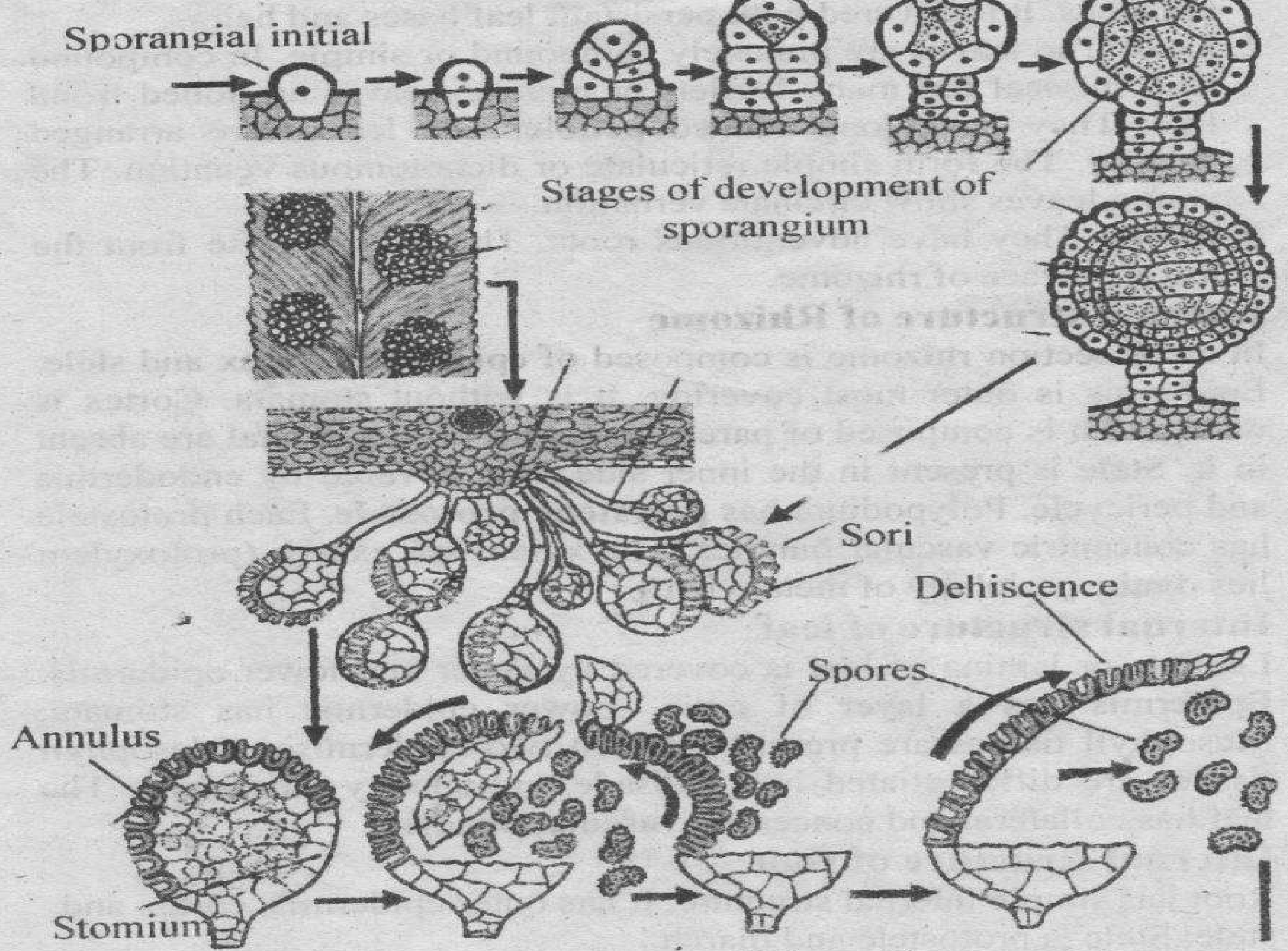


Fig: Development of Sorangium

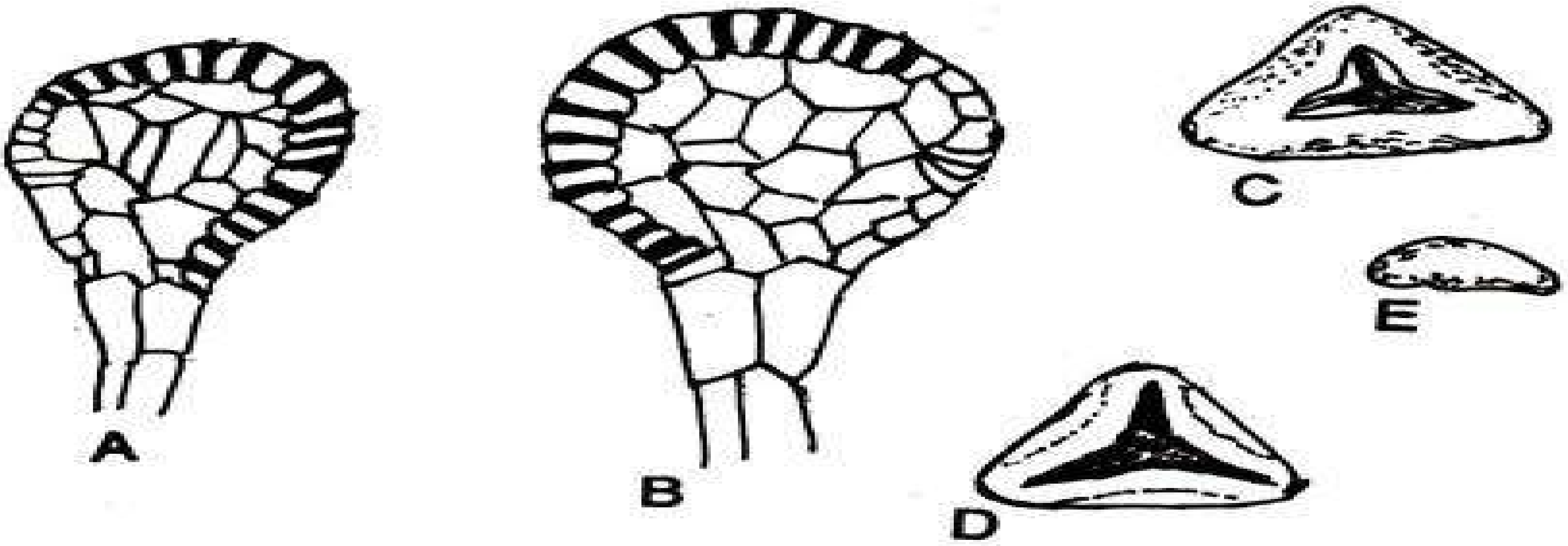


Fig. 153. *Adiantum* : Sporangia and Spores of *A. capillus veneris*
A-B. Sporangia, C-E. Spores

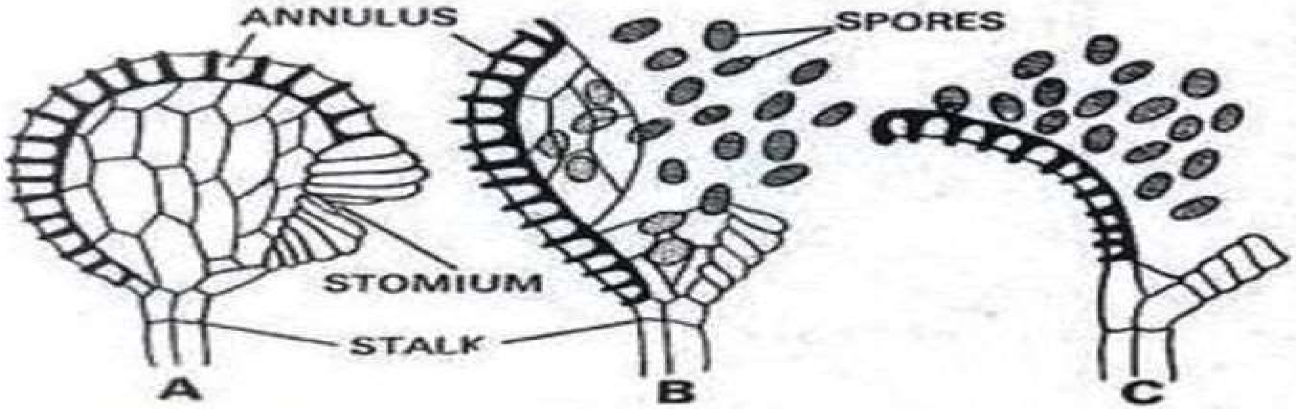


Fig. 31.26. *Adiantum* (Fern). A, sporangium; B—C, escaping spores from sporangium.

Structure and germination of the spores

- Spores are tetrahedral in shape. The wall is two layered. Exine is thick and smooth and has a brownish tinge. On falling upon a suitable substratum the spore germinates. The first sign of germination is the rupturing of exine and the protruding out of the germ tube.
- The germ tube undergoes several transverse divisions to form a short filament. The lowest cell (Fig. 154a) forms a lateral rhizoid. The terminal cell becomes an apical cell with three cutting faces. By the division of the apical cell, a spatulate pro-thallus is formed first.

Gametophyte of Adiantum

- The prothallus developed from spore is involved in sexual reproduction.It is cordate or heart shaped, dorsiventral, short lived, anterio-posterior, independent gametophyte.
- It grows in moist, shady habitats with growing point located in the notch. Its survival depends on the availability of moisture.
- It is less adapted to land when compared to the sporophyte.
- The developed prothallus is green, small, flat, thin, thallus like autotrophic structure. It has a deep 'U' shaped apical notch inside which a few meristematic cells are present. It is thick cushion like with many celled thick at the centre and gradually becomes thin towards the margins. It is single celled in thickness at the margin.
- It is parenchymatous with elongated polygonal or hexagonal cells without intercellular spaces.
- Each cell has central large vacuole that pushes the cytoplasm as thin layer towards the periphery (Primordial utricle).
- The peripheral cytoplasm has a haploid nucleus and discoid chlorplasts. Some of the posterior cells of ventral surface give rise brown, delicate, hair like, thin walled unicellular rhizoids. These help in fixation and absorbing mineral water.
- It is usually monoecious. The sex organs are developed on the ventral surface and exposed directly to moisture which is needed for the development and dehiscence. Male sex organs are called as antheridia. These are developed earlier than the female sex organs archegonia. Hence prothallus is protandrous. These are developed among the rhizoids from antheridial initials that ensures proper availability of moisture for the movement of antherozoids.
- Archegonia are developed from the cushion like region behind the apical notch. These sex organs slightly protrude out from the prothallus.
- In some cases the prothallus is dioecious and in still others it produces functionless sex organs and reproduce by apogamy

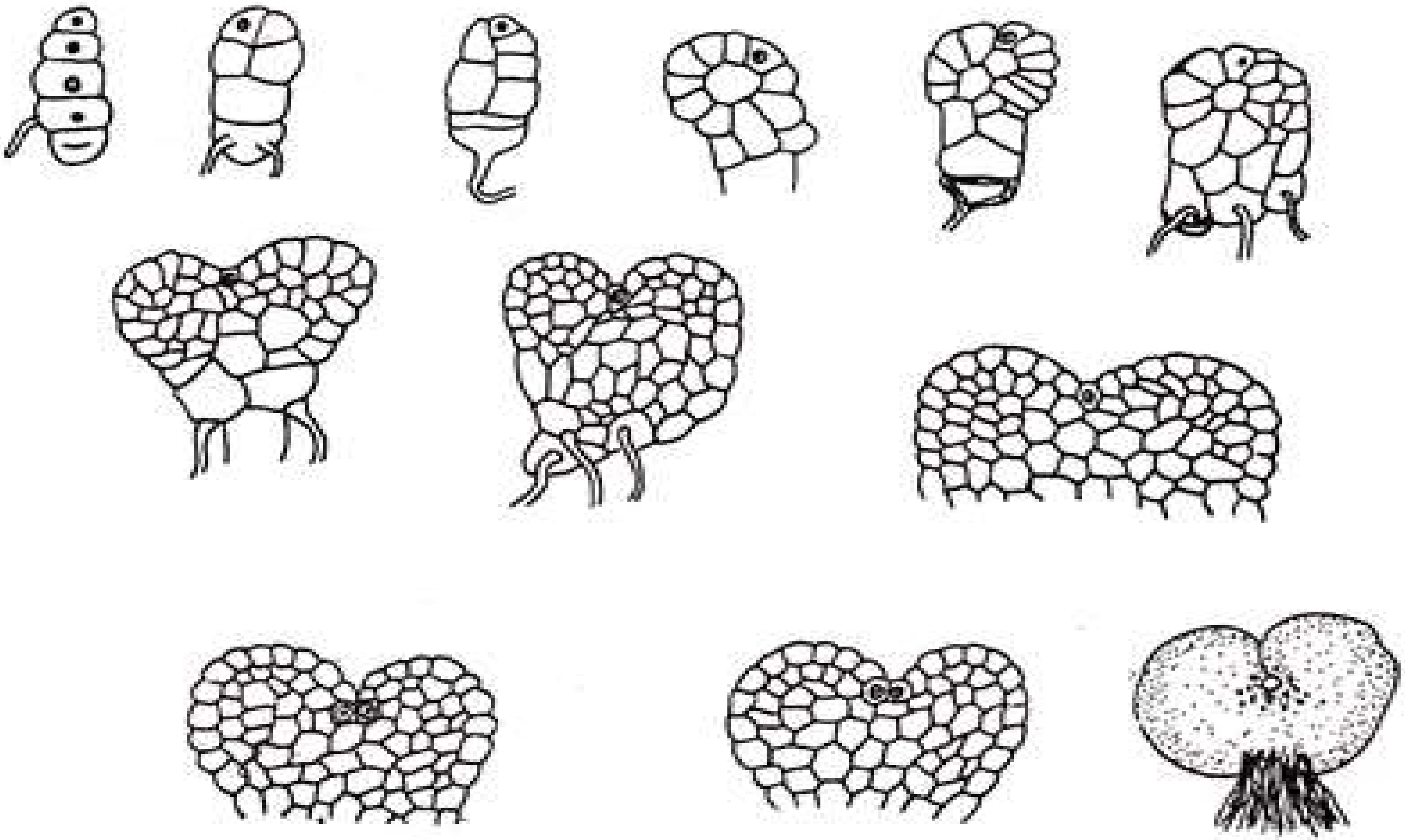


Fig. 154. *Adiantum* : Germination of Spore and Development of the Gametophyte
A-K. Developmental Stages, L. Mature Gametophyte

Antheridia

- These are male sex organs developed and mature earlier than archegonia. These are small, sessile and globular structures.
- Its wall consists of three tabular celled jacket.
- These cells are 1st ring cell that covers the basal portion of antheridial body, 2nd ring cell that covers the middle portion of antheridial body and cap cell that covers the apical portion of the antheridium. The cap cell forms the lid.
- Apart from these cells, there is a 4th cell at the base that can be considered as single celled stalk.
- The wall encloses 32 spermatocytes.
- Each one is metamorphosed into long, spirally coiled, multiciliate, motile antherozoid. • Each spermatozoid has prominent posterior vesicle of homogenous substance, coiled nuclear part covered cytoplasmic sheath and motor apparatus from which the cilia arise. • Dehiscence of mature antheridium takes place in the presence of water. • Jacket cells and androcytes absorb water, swell and exert pressure due to which the cap cell is either tilted upwards or thrown off.
- The antherozoids covered by androcyte membrane extrude out en masse. This extrusion is further assisted by the inward swelling and shortening of the wall cells. The membrane around the spermatozoids is dissolved and the male gamets become free to swim.

Development of Antheridium and Archegonium in Adiantum

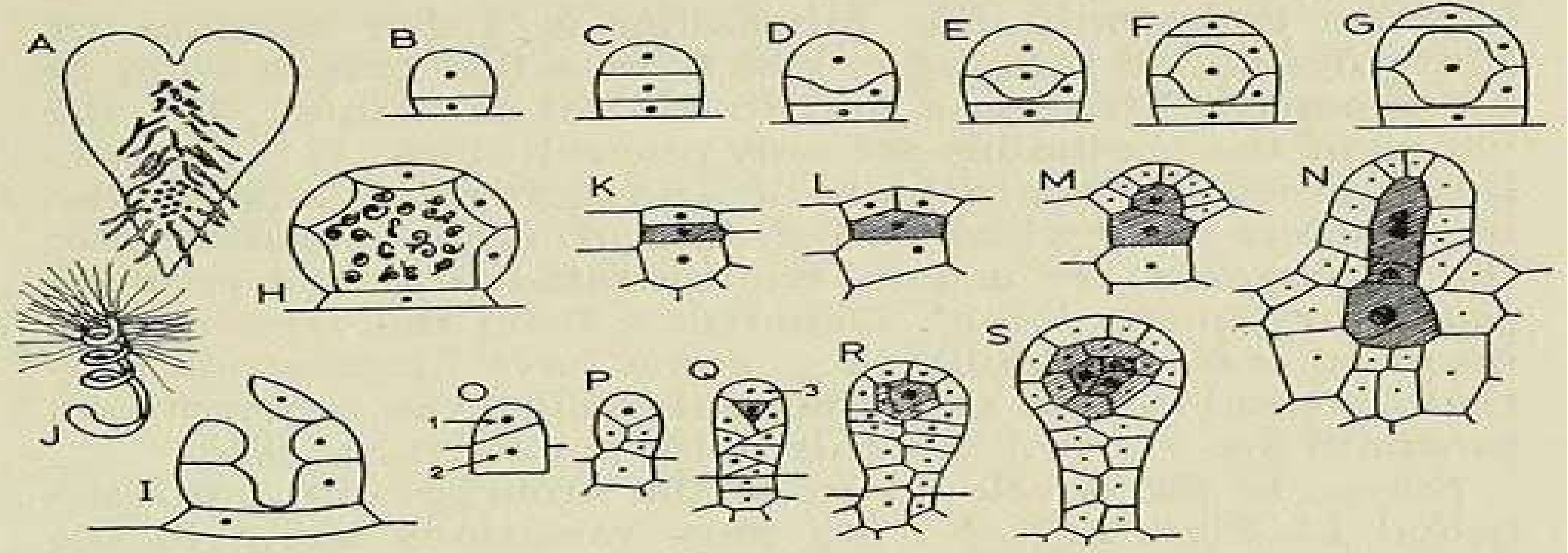


FIG. 22

Development of gametangia and sporangia as found in leptosporangiate ferns. A, typical gametophyte. B-H, stages in development of antheridium (diagrammatic). I, dehiscing antheridium. J, antherozoid of *Pteridium*. K-N, stages in development of archegonium. O-S, stages in development of sporangium of *Polypodium*

Archegonia

These are developed later than antheridia nearer to apical notch of prothallus.

It is flask shaped with swollen embedded venter in the prothallus and projected short, slender, slightly curved neck.

It has no venter wall or jacket. It consists of basal naked egg cell and above it a small ventral canal cell.

Neck consists of a single layered jacket with 4 vertical rows of cells with each row having 4 cells. So the total number of jacket cells is 16. Opercular cells or lid cells are absent.

Interior to jacket of neck, a single dikaryotic neck canal cell is present.

At maturity, the ventral canal cell and neck canal cell degenerate and form a sugary mucilaginous substance rich in malic acid.

This substance exerts pressure at the distal end of archegonium due to which the distal tier of neck cells are ruptured and the neck cells are far separated to establish a passage and the substance comes out in the form of droplet

Fertilisation and Embryogeny

- Fertilization takes place in the presence of water between the lower surface of prothallus and soil. • Malic acid of archegonial secretion helps in attracting the male gametes by chemotaxy. • The male gamets enter into the archegonium and one of the male gametes fuses with the egg to form the diploid zygote with its own wall. • Fertilisation is oogamous. • Out of several archegonia of the prothallus, usually only one is fertilised. In some cases even 2 or more archegonia may be fertilised. • With the act of fertilisation, the growth of prothallus is arrested. The archegonial venter forms a cap like calyptra around the fertilised egg.
- **Embryogeny**:
- The first division of the zygote is vertical (Fig. 155b). The epibasal half (next to the archegonial neck) forms the leaf and root while the hypo basal half forms the stem' apex and foot (Fig. 155c). Embryogeny is essentially similar to what is seen in Pteris.
- Generally only one sporophyte is formed per pro-thallus. During embryogeny the root and juvenile leaves make their appearance first, with the stem differentiating late. The primary root penetrates the soil and establishes itself. Apogamy has been reported in A.philippense.

Embryo

- Zygote develops into 8 celled embryo that later develops into adult sporophyte.
- The first division in the zygote is vertical and forms two cells. • The second division is also vertical but perpendicular to the first division to form 4 cells. • The third division is transverse to form 8 cells. • At this 8 celled stage the embryo gives out the primary root from its lower tier region, that pierces the calyptra and establishes contact with the soil.
- Later the first leaf emerges through the apical notch of the prothallus. It turns green and performs photosynthesis.
- The shoot grows slowly to become an underground rhizome. At this stage the primary root perishes and in its place many adventitious roots arise from the rhizome

Adiantum – Embryo Development

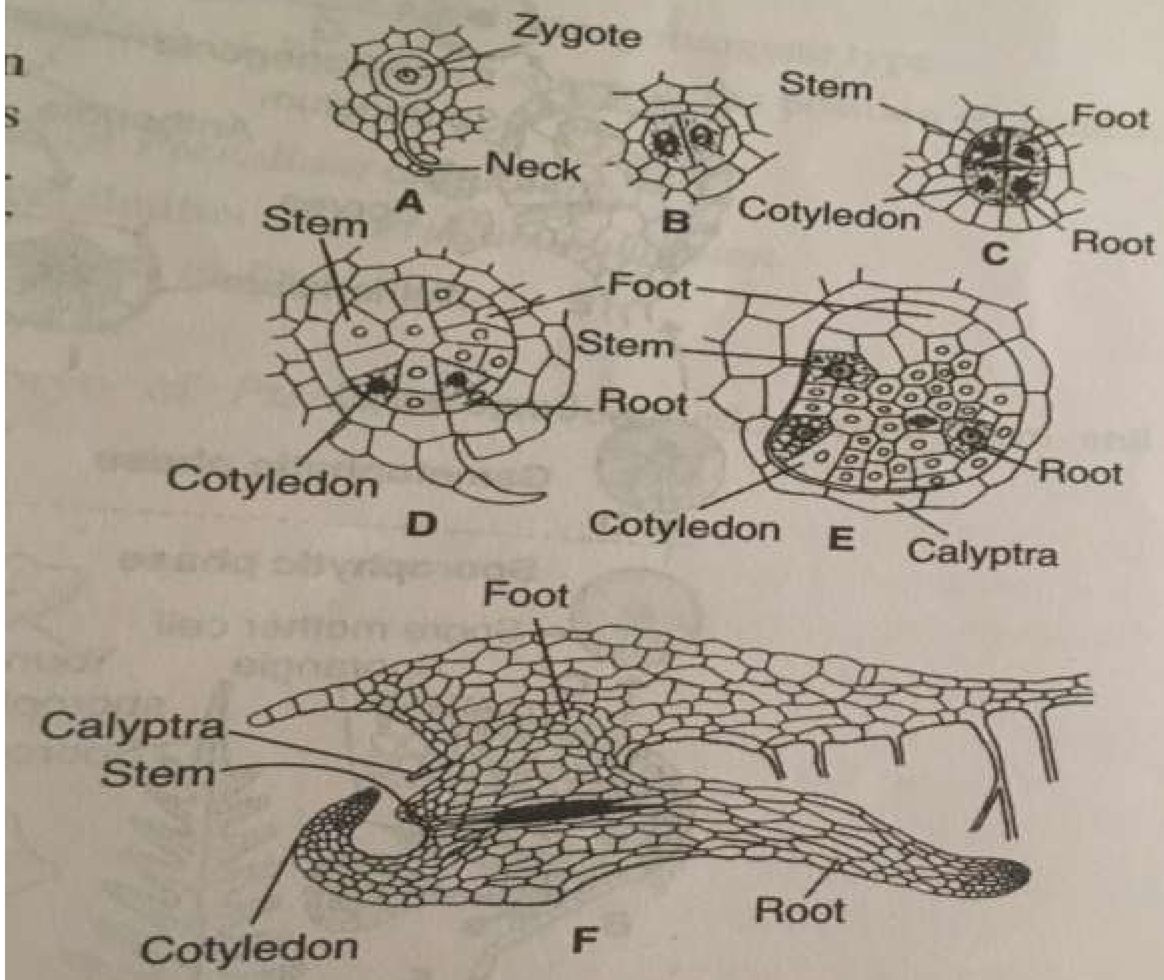
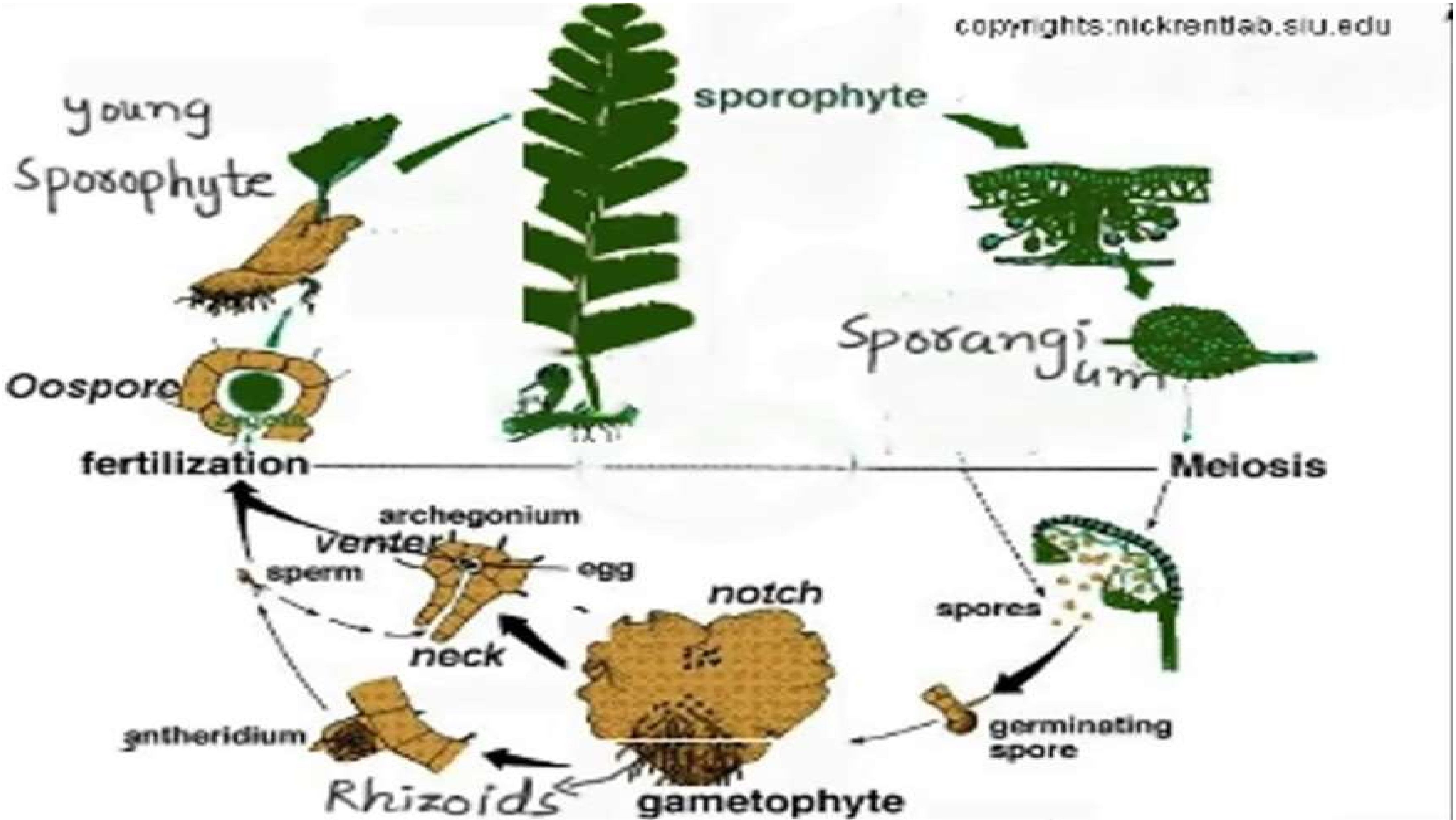


Fig. 21.12 (A-F) Some stages of embryo development.

- **Apospory**
- It is formation of diploid prothallus from diploid cells of sporophyte without the involvement of spores. • It can be induced in some species of Pteris. • In Adiantum, aposporous formation of prothalli can be induced from petiole, laminar surface or from juvenile leaves
- **Apogamy**
- It is development of haploid sporophyte from haploid cells of prothallus without the involvement of gametic union and sex organs. • It is common is Adiantum.
- **Life cycle** • The dominant stage is diploid independent sporophyte that produces spores in its coenosorus. The haploid gametophyte is highly reduced, short lived and independent. Hence the life cycle is diplohaplontic. • Since both gametophyte and sporophyte are morphologically different, its alternation of generations are described as heteromorphic..

Adiantum – Life Cycle



MARSILEA

MARSILEA – CLASSIFICATION/SYSTEMATIC POSITION

CLASS :	PTERIOPSIDA
SUB CLASS:	LEPTOSPORANGIATAE
ORDER:	MARSILEALES
FAMILY:	MARSILEACEAE
GENUS:	MARSILEA

Marsilea is commonly known as "pepperwort" or "water fern" (although it is a fern but hardly resembles a true fern). It is represented by about 53 species which are cosmopolitan in **distribution** but abundantly found in tropical countries like Africa and Australia. About 9 species have been reported from India.

Marsilea

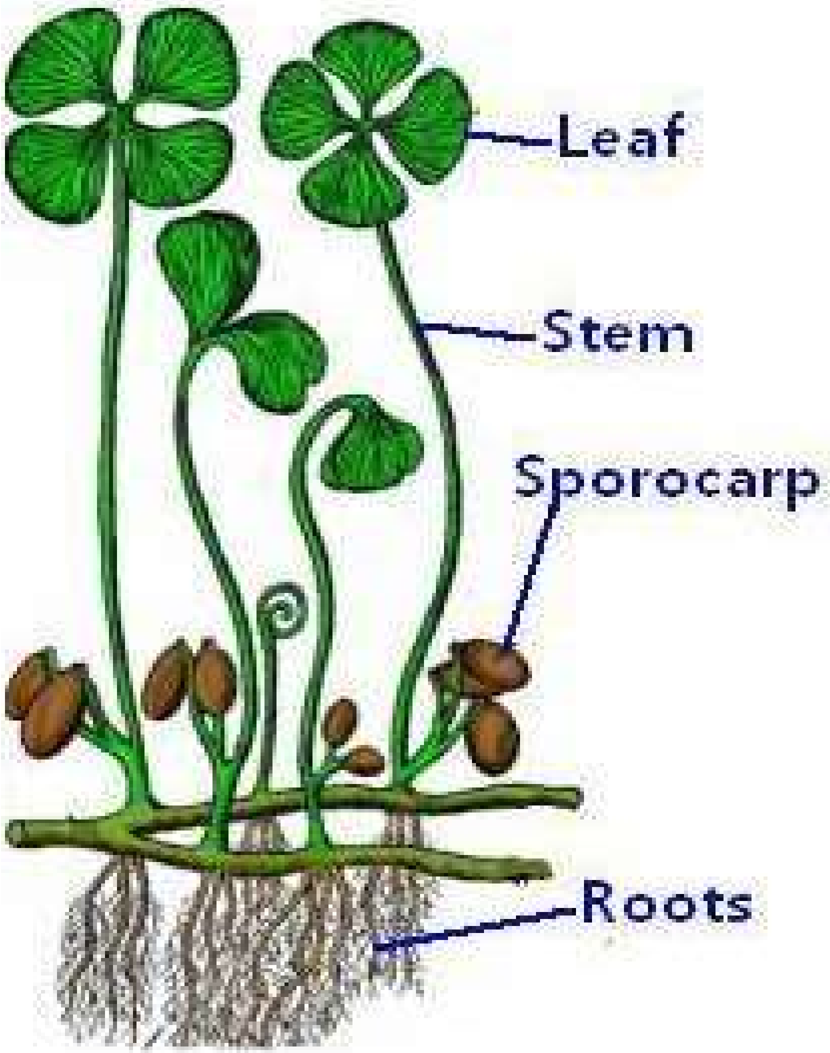
Marsilea

- **Occurrence**

Marsilea is an aquatic or semi aquatic plant. It is common in the temperate regions. It grows in fresh water ponds and ditches in Punjab. *Marsilea quadrifolia* and *M. minuta* are commonly found in Pakistan.

Sporophyte Morphology

- The vegetative plant is a sporophyte. It is differentiated into roots, rhizome and leaves.
- **1. Rhizome:** The stem is in the form of a rhizome. Rhizome has unlimited growth. Therefore, it covers a very large area. The rhizome is dichotomously branched. It has nodes and internodes. A number of adventitious roots arise at each node on the ventral side. But a single leaf arises at each node from the dorsal side.
- 2. The roots are adventitious, arising from the underside of the node of rhizome, either singly or in groups. In certain cases the roots are given out even from the internodes (M. aegyptiaca).
- **3. Leaves:** The leaves are compound. Each leaf has a long petiole and four :carats. The kallets are arranged in cross-like manner at the tip of the petiole. Each leaflet is triangular. Veins form reticulate arrangement Stomata arc located on the dorsal side and ventral side of the leaflets.


Leaf
Stem
Sporocarp
Roots

Internal Structure of the Rhizome

T. S. Rhizome (stem): Young rhizome shows a protostelic structure

T. S. of the old stem is somewhat circular in outline and shows the following structures:

i) Epidermis: It is the outermost limiting layer of single celled thick parenchymatous cells.The stomata are absent.

(ii) Cortex: It is differentiated into three regions – the outer cortex, the middle cortex and the inner cortex.

(a) Outer cortex: below the epidermis (hypodermis)-Parenchymatous - one to several cells thick , may contain tannin.

(b) Middle cortex: Aerenchyma-below the hypodermis - consists of large air spaces (chambers) separated by one cell thick parenchymatous septa.

(c) Inner cortex: It is a solid tissue of several cells thickness. The outer layers are thick walled (sclerenchymatous) while the inner layer of cells is thin walled (parenchymatous) and compactly arranged. Some of these cells are filled with starch or tannin.

(iii) Stele: Amphiphloic siphonostele i.e., in the centre there is a pith which may be either parenchymatous (aquatic species) or sclerenchymatous (terrestrial muddy species). Xylem is present in the form of a complete ring which is surrounded on both sides by a complete ring of inner and outer phloem, pericycle and endodermis.

T. S. of the nodal region shows an amphiphloicsolenostelic condition and is provided with one leaf gap.

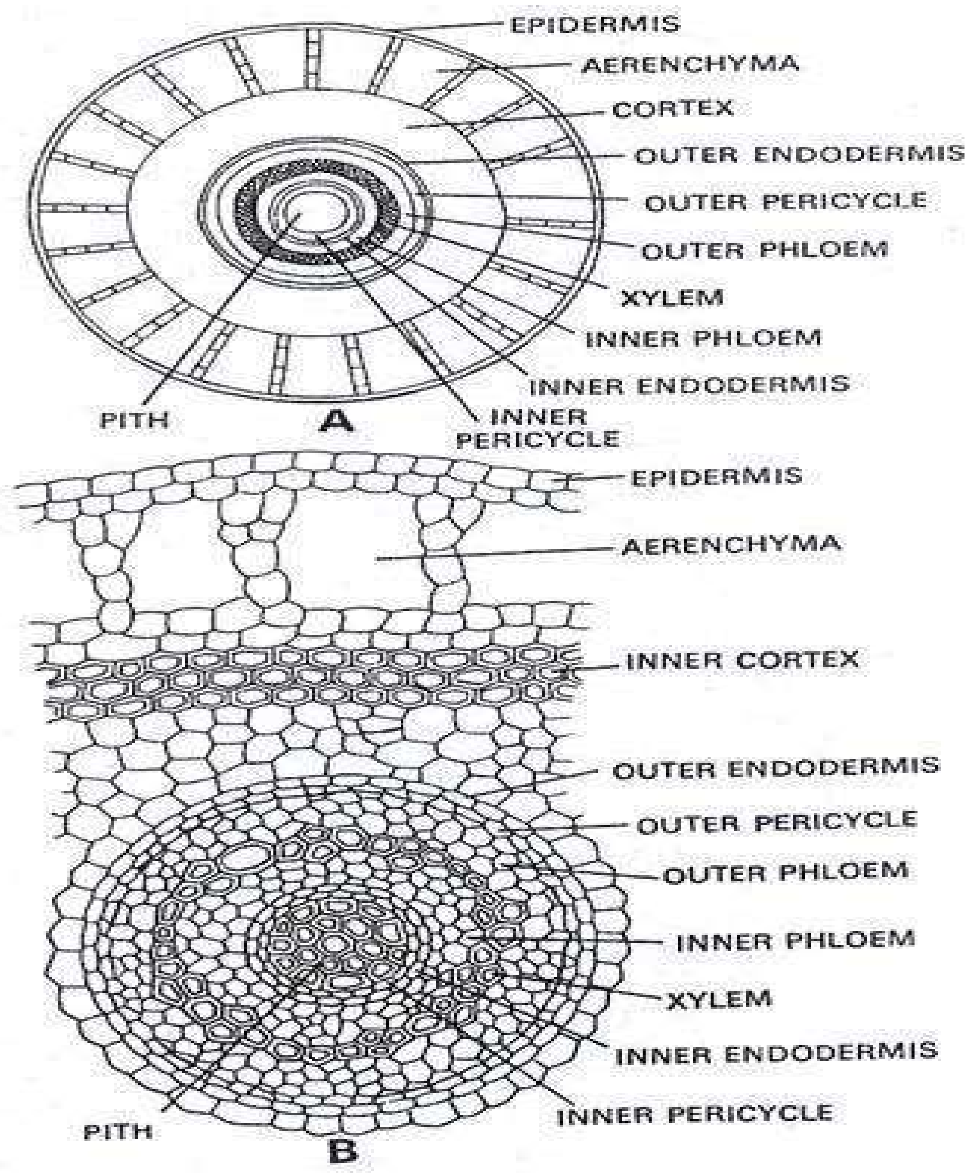
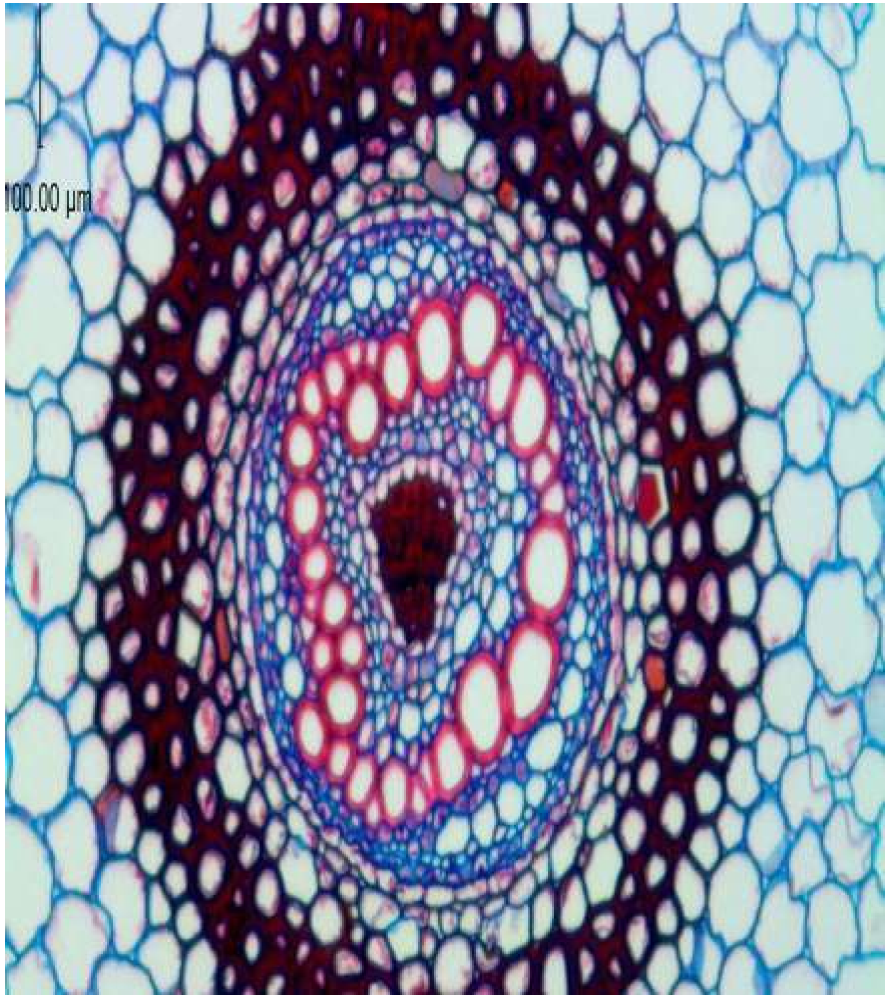


Fig. 30.3. *Marsilea quadrifolia*. Anatomy of rhizome. A, T.S. of rhizome (diagrammatic); B, T.S. of rhizome (detailed).



T. S. of the petiole

T. S. of the petiole is somewhat circular in outline and is differentiated into epidermis, cortex and stele.

Epidermis:

It is the outermost layer of single cell thickness. The cells are parenchymatous and slightly elongated.

(ii) Cortex:

It is differentiated into three regions: The outer cortex, the middle cortex and the inner cortex.

(a) Outer cortex:

It is present just below the epidermis, (also called hypodermis). It is made of thin walled cells (parenchymatous).

(b) Middle cortex:

It lies below the hypodermis and called aerenchyma. It consists a ring of air chambers. The air chambers are separated by single layered partitions of thin-walled parenchymatous cells.

(c) Inner cortex:

It is a solid tissue of several cells thickness. The cell layers are parenchymatous and contain starch and tannin filled cells. In *M. minuta* few sclerenchymatous layers are also present just inner to middle cotex.

(iii) Stele:

It is somewhat triangular in outline and is of protostelic type i.e. pith is absent. Xylem is "V" shaped with 2 distinct arms. Each arm is provided with metaxylem elements in the centre and protoxylem is situated at both the margins i. e., protoxylem is exarch. The xylem is surrounded on all sides by phloem. Phloem is externally surrounded by a single layer of parenchymatouspericycle which, in turn, is bounded by a single layered endodermis.

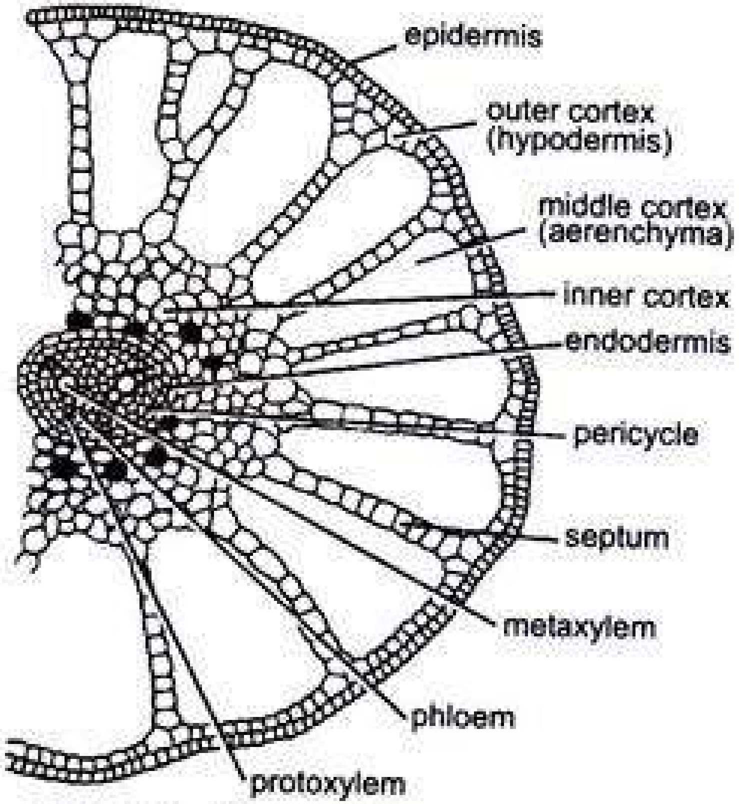


Fig. 3. *Marsilea quadrifolia.* T.S. of petiole

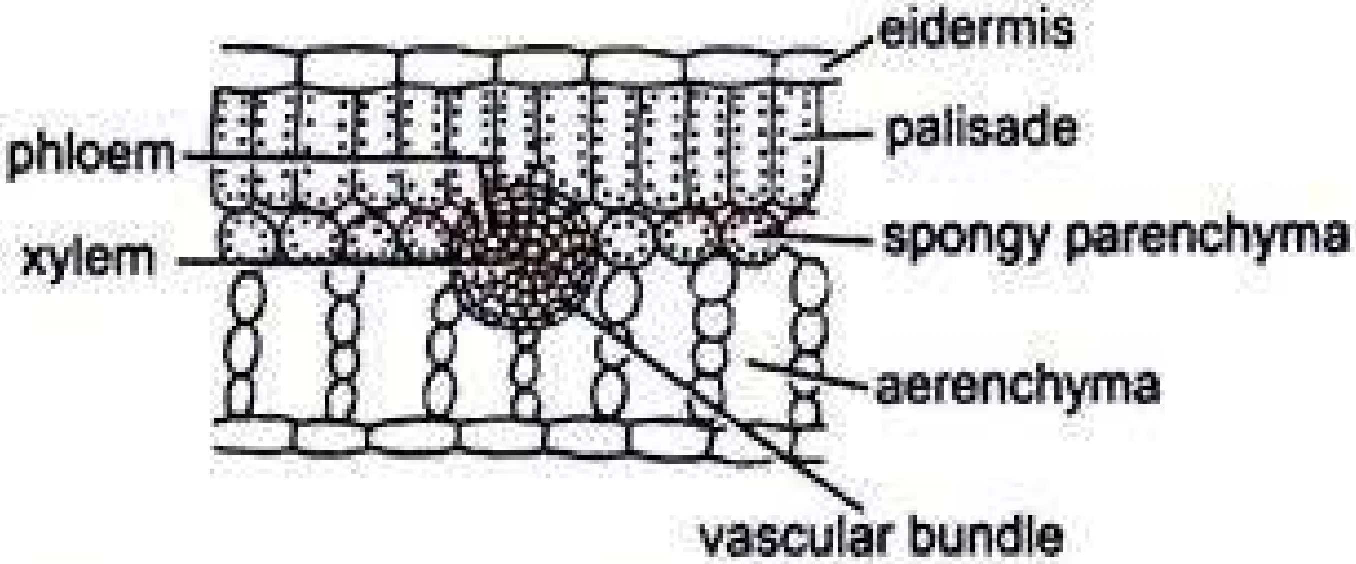


Fig. 4. *Marsilea quadrifolia.* V.S. of leaflet or pinna

T. S. of the leaflet shows epidermis, mesophyll and vascular bundles.

(i) Epidermis:

It is the outermost surrounding layer and is only one cell in thickness. It is differentiated into upper and lower epidermis. In floating leaflets the stomata are present on the upper epidermis but in case of plants growing in mud or moist soil where the leaves are aerial, the stomata are present both on upper as well as lower epidermis.

(ii) Mesophyll: It occupies a wide space between upper and lower epidermis. It is usually differentiated into an upper palisade tissue and lower spongy parenchyma. The palisade tissue is made up of elongated cells provided with chloroplast. The spongy tissue is made up of loosely arranged parenchymatous cells with large air spaces separated by single layered septa. In submerged species, however, the mesophyll is not differentiated into palisade and spongy parenchyma.

Vascular bundles: In between the mesophyll tissue are present several vascular bundles. Each vascular bundle is concentric and amphicribal type i. e., made up of a centrally situated xylem, surrounded on all sides by phloem. The phloem is enclosed by a single layered thick endodermis.

T. S. Root:

Epidermis: It is the outermost, parenchymatous, single layered covering.

(ii) Cortex: It can be differentiated into two parts: outer cortex and inner cortex. The outer cortex consists of large air chambers arranged in the form of a ring (parenchymatous). These chambers are separated from each other by longitudinal septa. The inner cortex is differentiated into outer parenchymatous and inner sclerenchymatous regions. The inner cortex is delimited by single layered thick endodermis.

(iii) Stele: It is of protostelic type and occupies the central position. It is devoid of pith. Xylem is situated in the centre which is diarch and exarch. It is surrounded by phloem. The phloem is bounded externally by a single layer of pericycle.

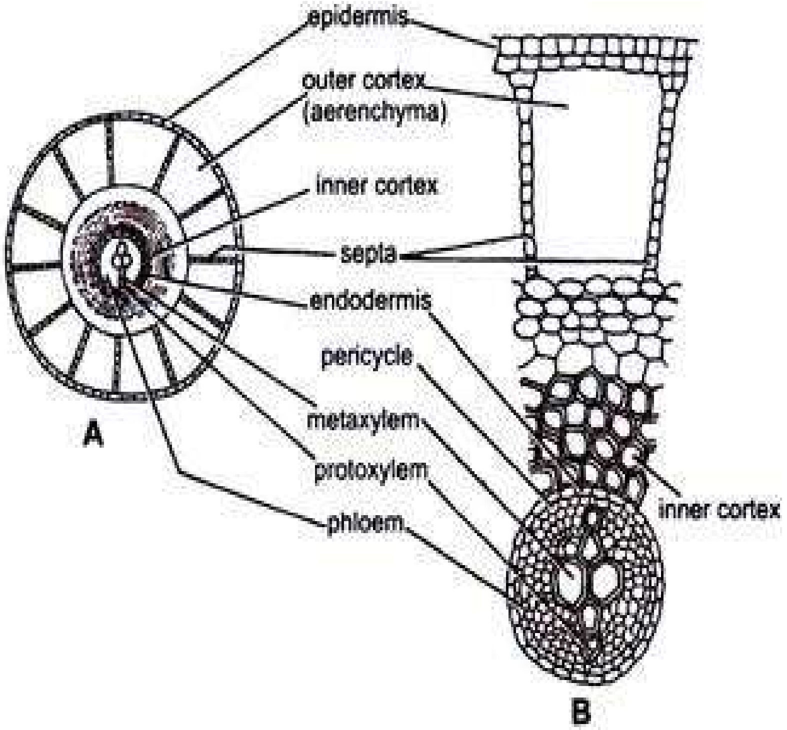


Fig. 5. (A, B) *Marsilea quadrifolia*. Internal structure of root. A. Diagrammatic, B. A part cellular.

Reproduction in Marsilea

Vegetative reproduction:

It takes place by means of tubers which are produced in dry conditions from the rhizome. First a branch is given out from the rhizome, which later on swells up due to the accumulation of food material. The structure is termed as tuber and is capable of tiding over the unfavourable conditions. On the return of favourable conditions it germinates to produce a new sporophytic plant, e.g. ,M. hirsuta, M. quadrifolia.

Sexual Reproduction:

1. Sporophytic Phase: Spore producing organs: Marsilea is heterosporous i. e., it produce two types of spores—microspores and megaspores. These spores are produced in microsporangia and megasporangia, respectively. These sporangia are borne in special type of spore producing organ called sporocarp. The sporocarp are born laterally on the short and lateral branches of the (called the peduncles or pedials) petiole of leaf either near the base or a little higher up.

They arise solitary or in clusters. The peduncle is usually unbranched but it may be branched also. Number of sporocarp differs in different species and varies from 1 to 20 or more. In M. vestita sporocarp arises single, in M. quadrifolia the peduncle is dichotomously branched bearing 2-4 sporocarps, in M. polycarpa several sporocarps arise in a linear row. The attachment of the pedicel sporocarp varies in different species.

Sporocarp Morphology

Each sporocarp is an oval or bean shaped biconvex, flattened structure. It is green and soft when it is young but at maturity it becomes very hard and brown in colour. It is made up of a short stalk like structure known as peduncle and the body.

The point of attachment of peduncle with the body is called raphe (Fig. 7A). Slightly above the raphe in a median plane are present 1 or 2 protuberances called tubercles. They are unequal in size and lower one is stouter than the upper one. In some cases the tubercles are absent e.g., M. polycarpa.

Internal Structure of Mature Sporocarp:

The sporocarp is a bivalved structure. It can be split open in the dorsiventral plane into two halves (valves).

If we split open the sporocarp, we can see the following structures:

Wall of sporocarp:

It is very hard, thick and highly resistant to mechanical injury. It can be differentiated into three zones—outer epidermis, middle hypodermis and inner parenchymatous zone. Epidermis is single layered made up of broad and columnar cells. Its continuity is broken by the presence of sunken stomata

Some of the epidermal cells develop into multicellular hairs. Hypodermis consists of two layers of radially elongated palisade like cells. Both the layers are without intercellular spaces and have chloroplast in their cells. Next to hypodermal layers is the parenchymatous zone. In mature sporocarp the cells of this zone gelatinise and form a gelatinous ring which helps in the dehiscence of the sporocarp.

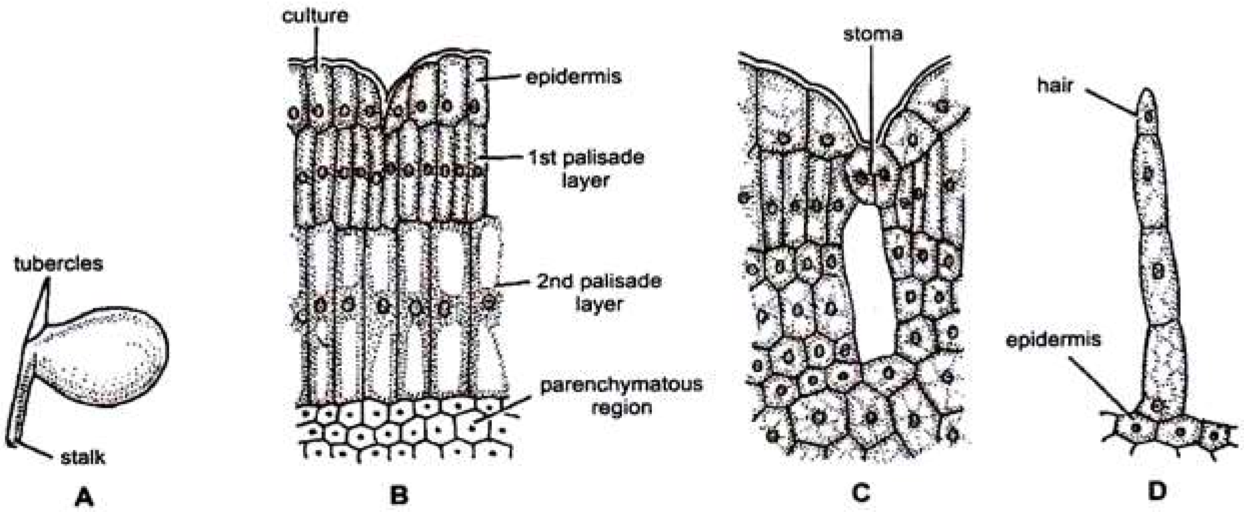


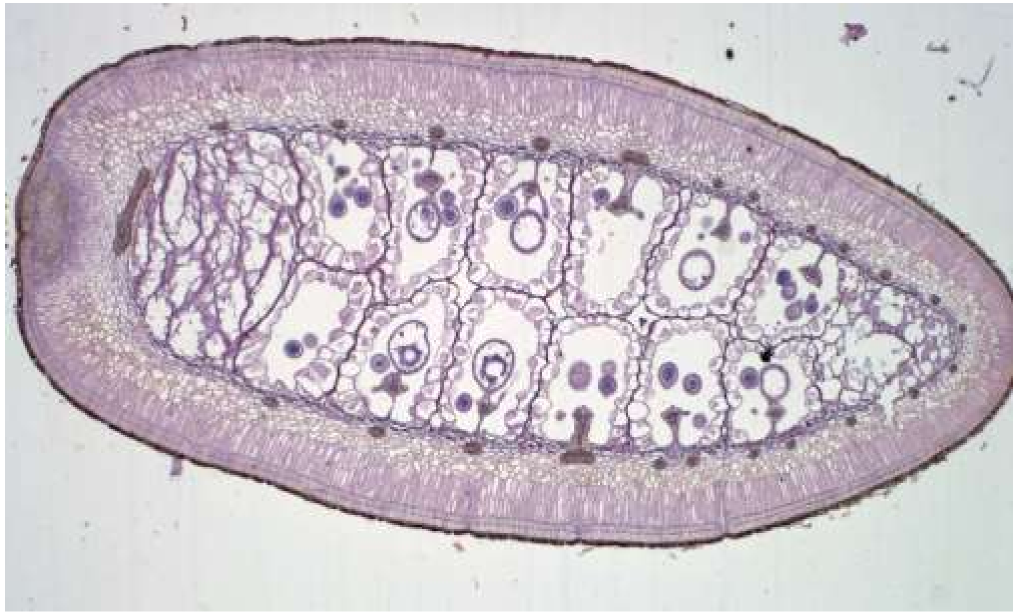
Fig. 7. (A-D). ***Marsilea.*** **Structure of sporocarp. A. sporocarp, B. Wall structure of sporocarp in T.S., C. sunken stoma in the wall of sporocarp, D. A multicellular hair.**

Cavity of sporocarp:

The alternating rows of sori (sing, sorus, a group of sporangia is called sorus), one along each side lies transversely-dorsiventrally to the long axis of the sporocarp. The sori on either side alternate with each other. The number of sori inside the sporocarp varies from species to species. It may be from two (e.g., M. aegyptiaca) to twenty (e.g.,M. vestita). Each sorus bears both microsporangia and megasporangia.

Their number also varies from species to species. In M. minuta a sorus has 4-8 megasporangia and 8-13 microsporangia. In M. aegyptiaca each sorus has 5-16 megasporangia and 9-19 microsporangia.

In M. minuta, M. vestita, M. rajasthanensis, sometimes megasporangia are absent in sorus. Each sorus arises on a ridge like placenta or receptacle formed on the sporocarp wall. Each sorus is surrounded by a thin, membranous two layered true indusium. The indusia of adjacent sori are partially fused.



The entire internal structure of the sporocarp can be best seen in section cut in three plains:
(i) Horizontal Longitudinal Section (H.L.S.): Section is cut horizontally but the sporocarp is cut longitudinally.
(ii) Vertical Longitudinal Section (V.L.S.): Section is cut vertically but the sporocarp is cut longitudinally.
(iii) Vertical Transverse Section (V.T.S.): Section is cut vertically but the sporocarp is cut transversely.

Horizontal Longitudinal Section (H.L.S.):
The section passes through the peduncle and cuts it transversely. Peduncle shows characteristic 'V' shaped xylem (Fig. 9 A, B). A H.L.S. of sporocarp shows the usual wall layers. The gelatinous ring is cut transversely and it appears in the form of dorsal and ventral mass at its proximal and distal ends.
The dorsal mass is more prominent than transversely along with their two layered inducia. Sori show their alternate arrangement in the two rows. Each sorus has a receptacle which has a central terminal megasporangium and two lateral microsporangia, one on either side. The lateral bundle is also cut transversely below each sorus.

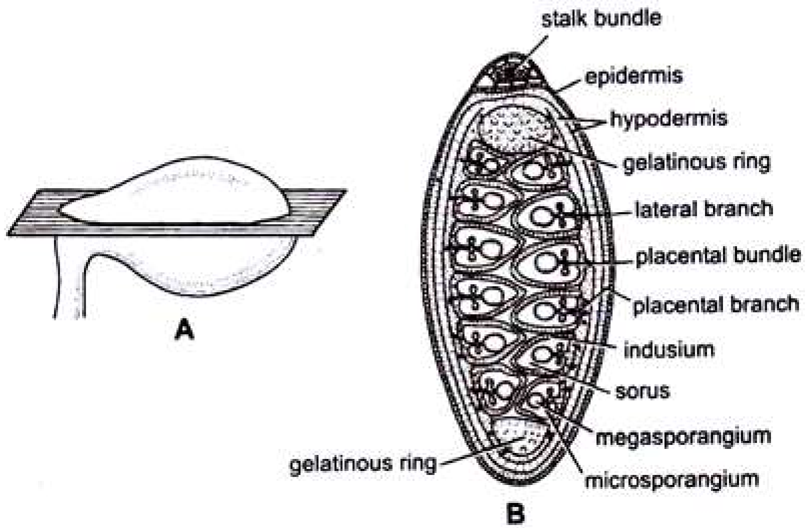


Fig. 9 (A, B). ***Marsilea.*** **B. Horizontal longitudinal section (H.L.S.) of the sporocarp as shown in plane A.**

(ii) Vertical Longitudinal Section (V.L.S.):

A V.L.S. of the sporocarp shows the usual wall layers. The peduncle along its vascular bundle is cut longitudinally. The entire gelatinous ring is cut vertically and it appears as a complete ring around the sori. The section cut the sori longitudinally, which are arranged in many vertical rows. If the section passes strictly through the median plane of sporocarp, only megasporangia are visible (Fig. 10A, B) but if it passes slightly away from the median line, only microsporangia are visible.

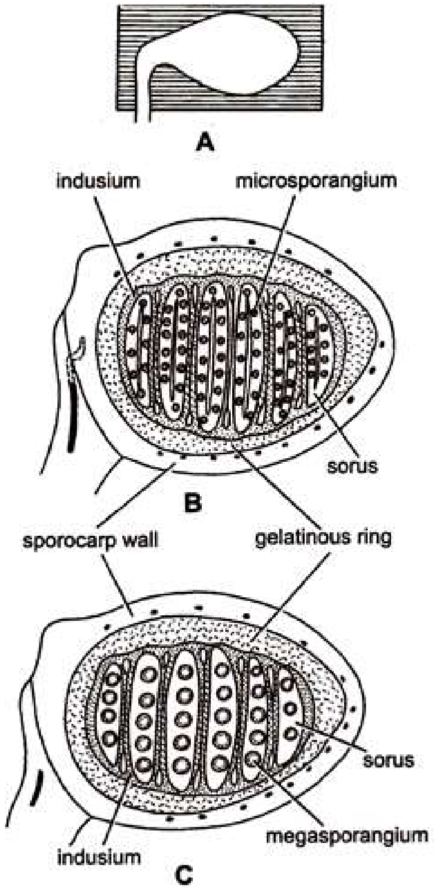


Fig. 10 (A-C). ***Marsilea.*** **Vertical longitudinal section (V.L.S.) of the sporocarp as shown in plane A., B. Section passing slightly away through the median plane (showing microsporangia), C. Section passing strictly through the median plane (showing megasporangia).**

iii) Vertical Transverse Section (V.T.S.):

A V.T.S. of the sporocarp shows the usual wall layers. Peduncle is not cut in the section. The gelatinous ring appears in the form of dorsal and ventral mass (as in H.L.S.). The gelatinous mass on the dorsal side is much more prominent. In V.T.S. only two sori covered with indusia are visible on the inner side and attached to the placental ridge on the outer side The sori reveal many megasporangia and only two or three microsporangia at the sides. The dorsal bundles, the lateral bundles and the placental bundles are clearly visible.

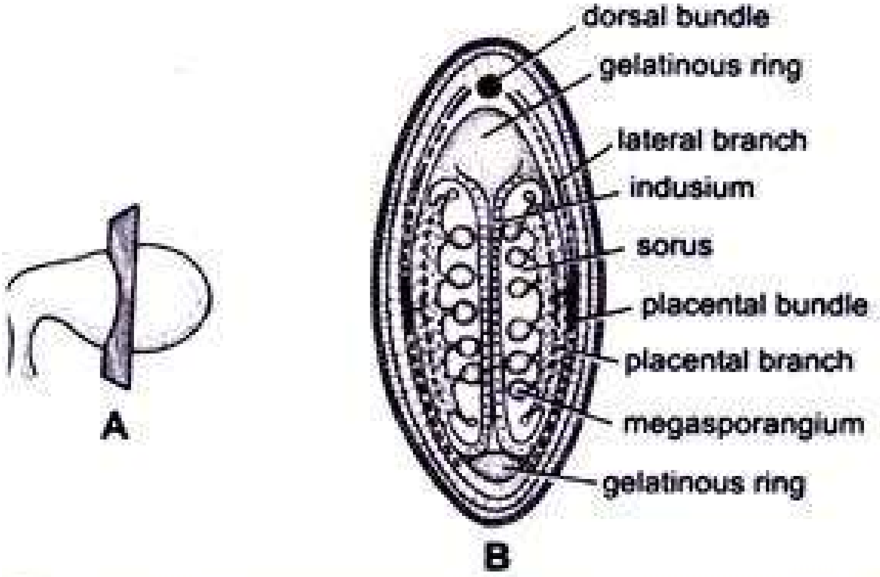


Fig. 11. *Marsilea.* (A, B). B. vertical transverse section of the sporocorp as shown in plane A.

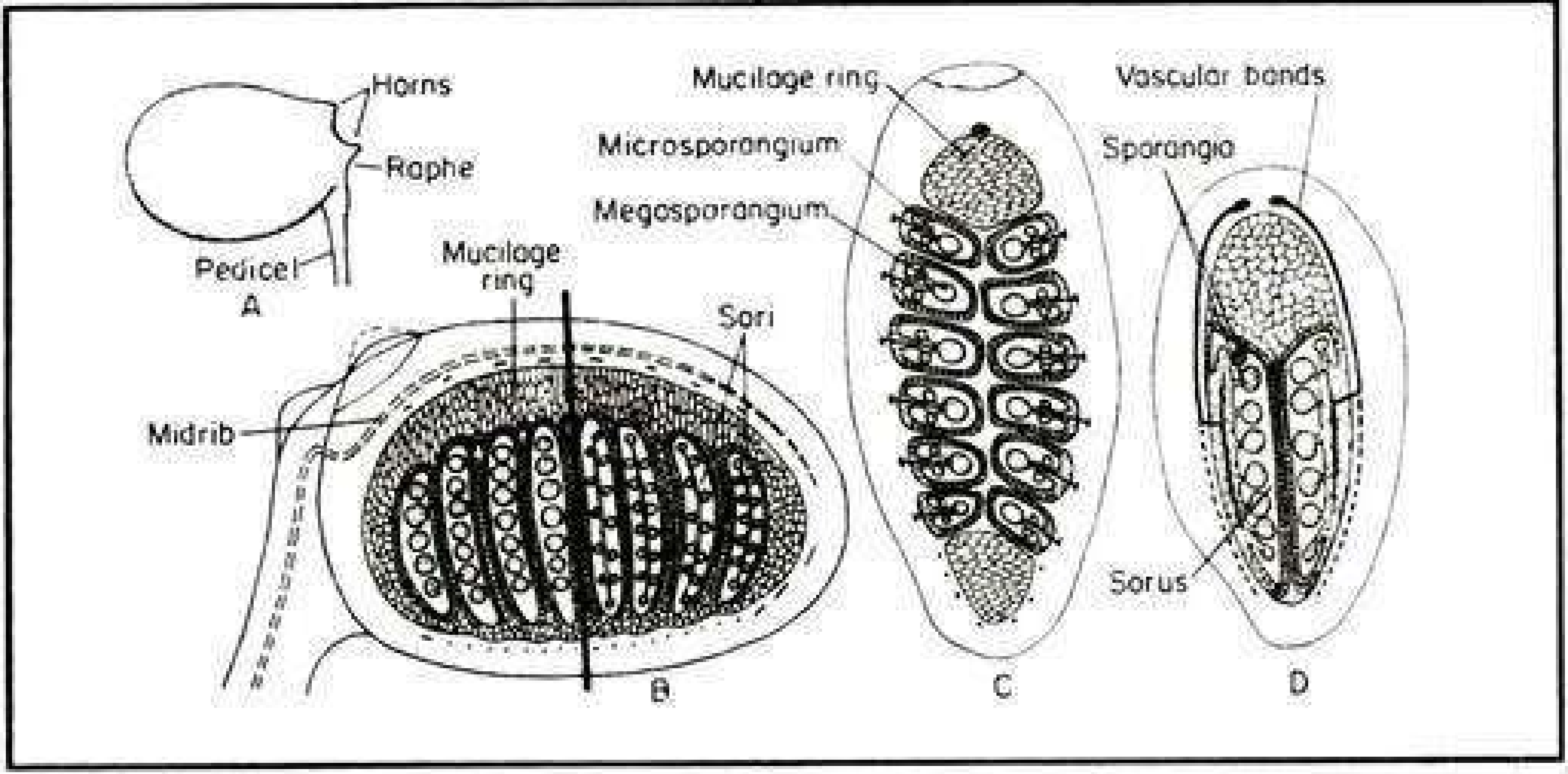


Fig 6.35. Marsilea Sp. : A – A sporocarp, B – V.S. through sporocarp, C – T.S. through sporocarp, D – L.S. through sporocarp.

Development of Sporocarp:

The leaf arises from a bifacial apical leaf cell. It cuts off a pair of segments. When the leaf primordium is 6-7 cells high, the sporocarp initial develops at its base (Fig. 13 A, B).

This cell behaves as a two sided apical leaf cell and cuts off segments on either side.

The second sporocarp initial appears in the same way as the first sporocarp initial appears.

Similarly, the third sporocarp initial arises. This means that these sporocarps are the branches of the leaf.

The sporocarp initial forms a mass of undifferentiated cells by cutting segments on both lateral sides. It grows into sporocarp. Two rows of soral mother cells appears on ventral side of the young sporocarp.

Formation of inoculations takes place due to undifferentiated growth of soral mother cells and their derivatives. These soral mother cells form two alternating rows of canals. These are called soral canals (Fig. 13 C-E).

Each soral canal is lined on its inner surface by a two layered tissue called indusium (Fig. 13 D, E). The receptacle of the sorus faces the indusium in each canal and the sporangia arise upon the receptacle in basipetal manner (Fig. 13 F).

The first sporangial initial appears at the tip of the receptacle and develops into megasporangia. Subsequently the two initials develop on the lateral side of the megasporangium. These are microsporangial initials and develop into microsporangia (Fig. 14A).

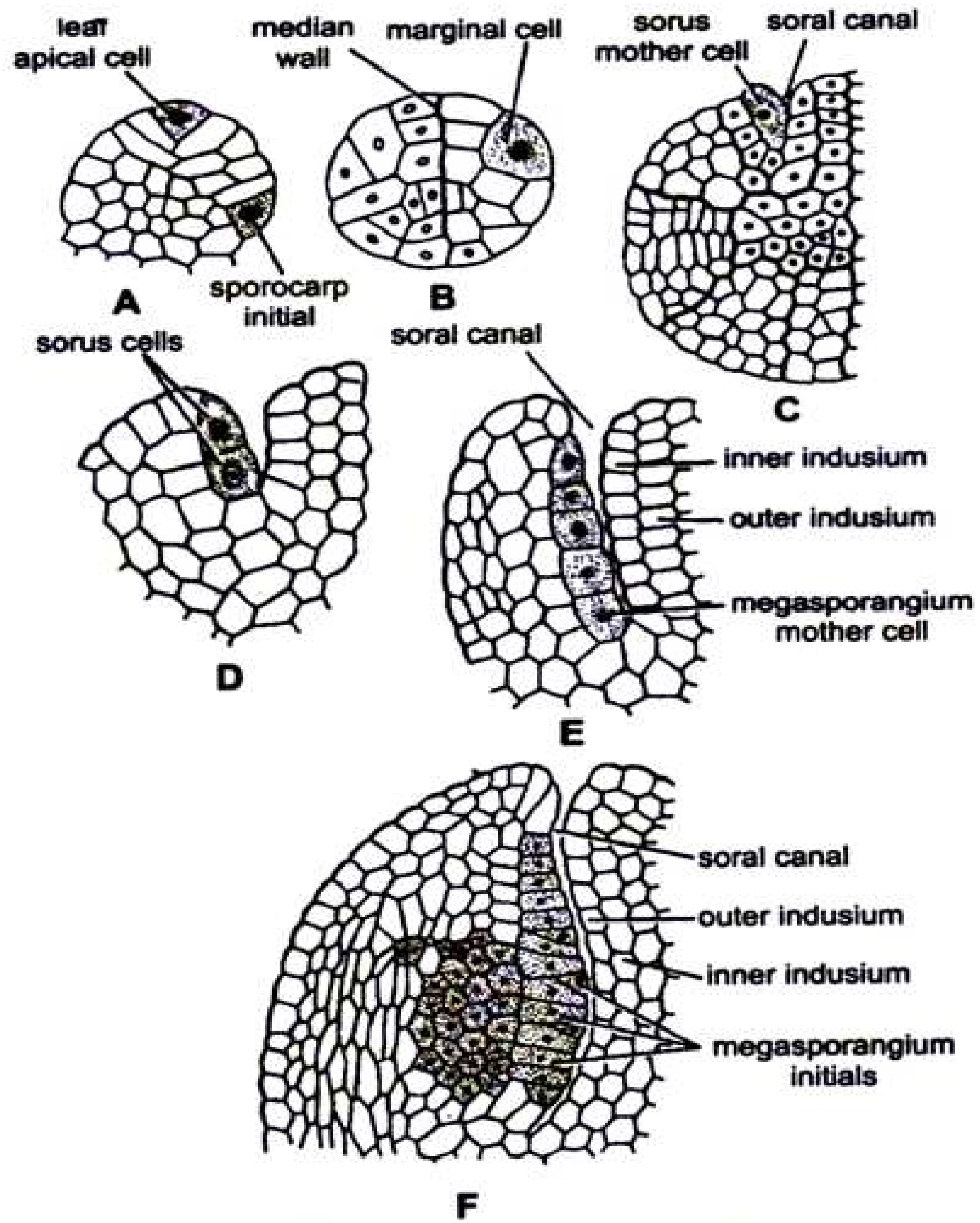
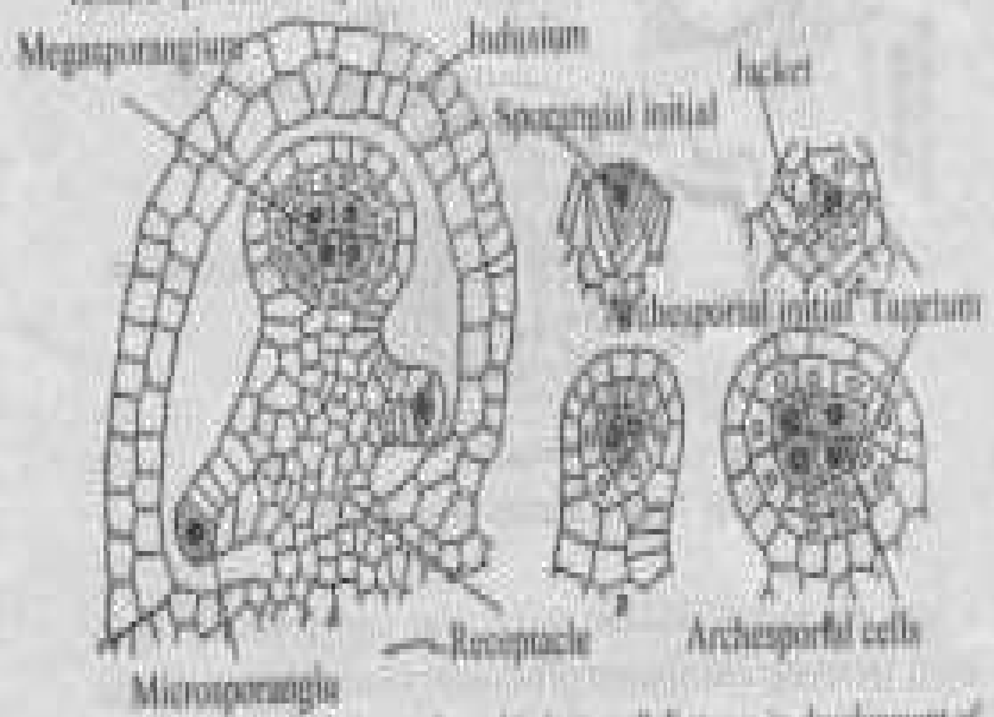


Fig. 13. (A-F). ***Marsilea.*** **Successive stages in the development of sporocarp.**



A-Vertical section of receptacle and indusium, B-E stages in development of microsporangia.

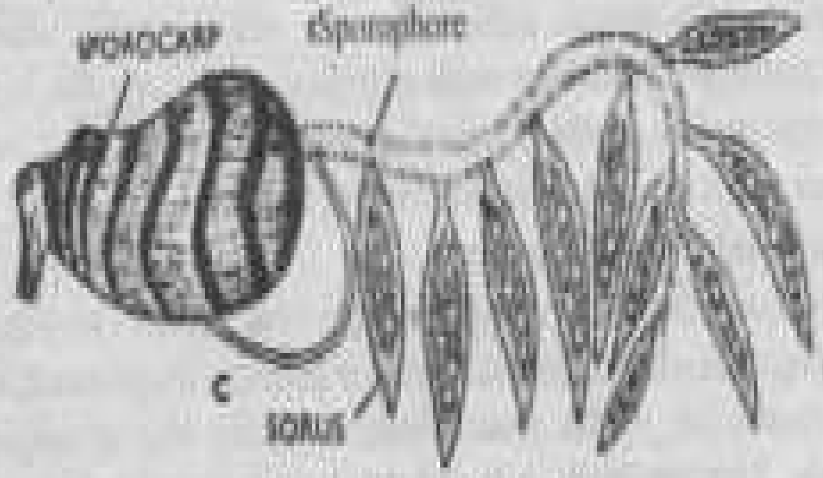


Fig: Dehiscence of sporocarp

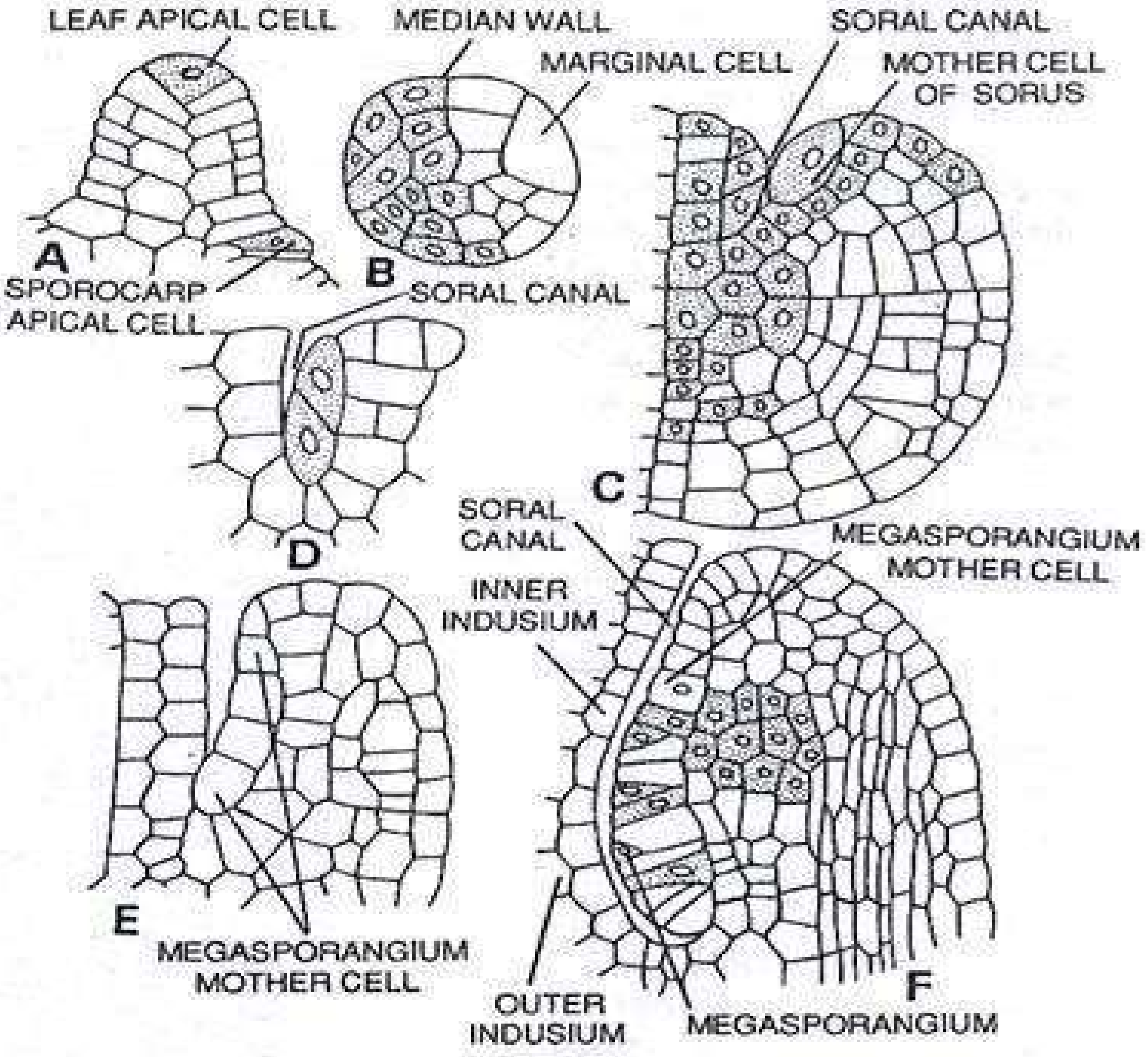


Fig. 30.6. *Marsilea* sp. Development of sporocarp. A, young leaf; B, T.S. of young sporocarp; C, development of one half of leaf; D-F, stages of development of sorus and soral canal.

Structure of Microsporangium:

It is somewhat oval structure with a long stalk and is present laterally on the receptacle. It is smaller in size. It has a single layered jacket followed by two layers of tapetal cells. In the centre is present a cavity filled with microspore mother cells (Fig. 14H).

At maturity the tapetal cells disintegrate and each microspore mother cell divides reductionally forming 4 haploid microspores (Fig. 141). The microspores are usually 32-64 in number and are liberated by the disintegration of the microsporangial wall (Fig. 14J).

Development of Microsporangium:

It takes place from a superficial cell situated laterally on the receptacle. This cell is called as sporangial initial. It divides transversely into an outer and inner cell (Fig. 14 B, C). The outer cell later on gives rise to the whole of the sporangium i. e., stalk, wall, tapetum and microspores. It divides by three successive diagonal divisions to form a tetrahedral apical cell (Fig. 14D) with three cutting faces.

This apical cell cuts off two cells from its each face which helps in the formation of stalk. Now a periclinal wall is formed towards the outer face of the apical cells forming an outer smaller primary jacket cell and an inner archesporial cell (Fig. 14J). The primary jacket cell divides only anticlinally to form a single layered jacket.

The archesporial cell again divides periclinally to form an outer primary tapetal cell and inner primary sporogenous cell (Fig. 14F, G). The primary tapetal cells divide periclinally as well as anticlinally to form a two layered tapetum. The primary sporogenous cell divides to form 8-16 microspores mother cells (Fig. 14H). Now each microspore mother cell divides reductionally to form a tetrad of spores as a result of which 32-64 microspores are produced (Fig. 14J).

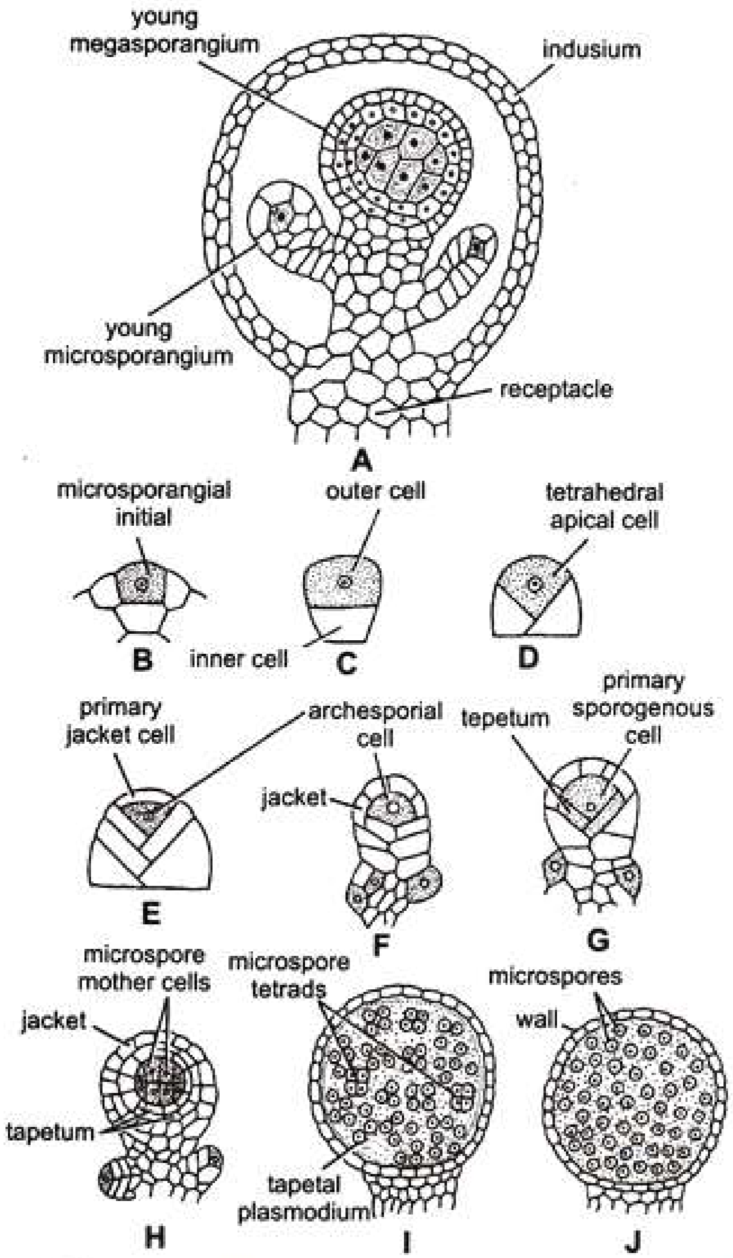


Fig. 14. (A-F). ***Marsilea.*** **A-H. Successive stages in the development of microsporangium and megasorangium, I. Microsporangium with spore tetrad. J. A mature micrposporangium with microspores.**

Structure & Development of Megasporangium

It is a spherical structure with a short stalk and is present on the top of the receptacle (Fig. 14A). It is bigger in size than the microsporangium (Fig. 14A). Its structure is similar to microsporangium except that only one megaspore is present per megasporangium at maturity. The megaspore is liberated by the disintegration of the megasporangial wall.

The development of megasporangium is exactly in the same way as that of microsporangium except that out of the total number of megaspores formed, all degenerate leaving except one which behaves as a functional megaspore (x). It increases in size.

Dehiscence of Sporocarp and Liberation of Spores:

The decaying of the wall of the sporocarp takes place due to bacterial action and thus the sporangia and spores are liberated. The sporocarp bursts open only in water in valvecular manner along the ventral side and apex. The gelatinuous ring absorbs water and extends greatly through the open margins of the sporocarp thus dragging out sori along with it.

It straightens and behaves as sporophore. The gelatinous ring bears two alternating rows of sori. The delicate mucilage wall of the sporangia (micro-or mega) opens in water and the spores (micro-or mega are liberated which germinate soon (Fig. 15 A, E).

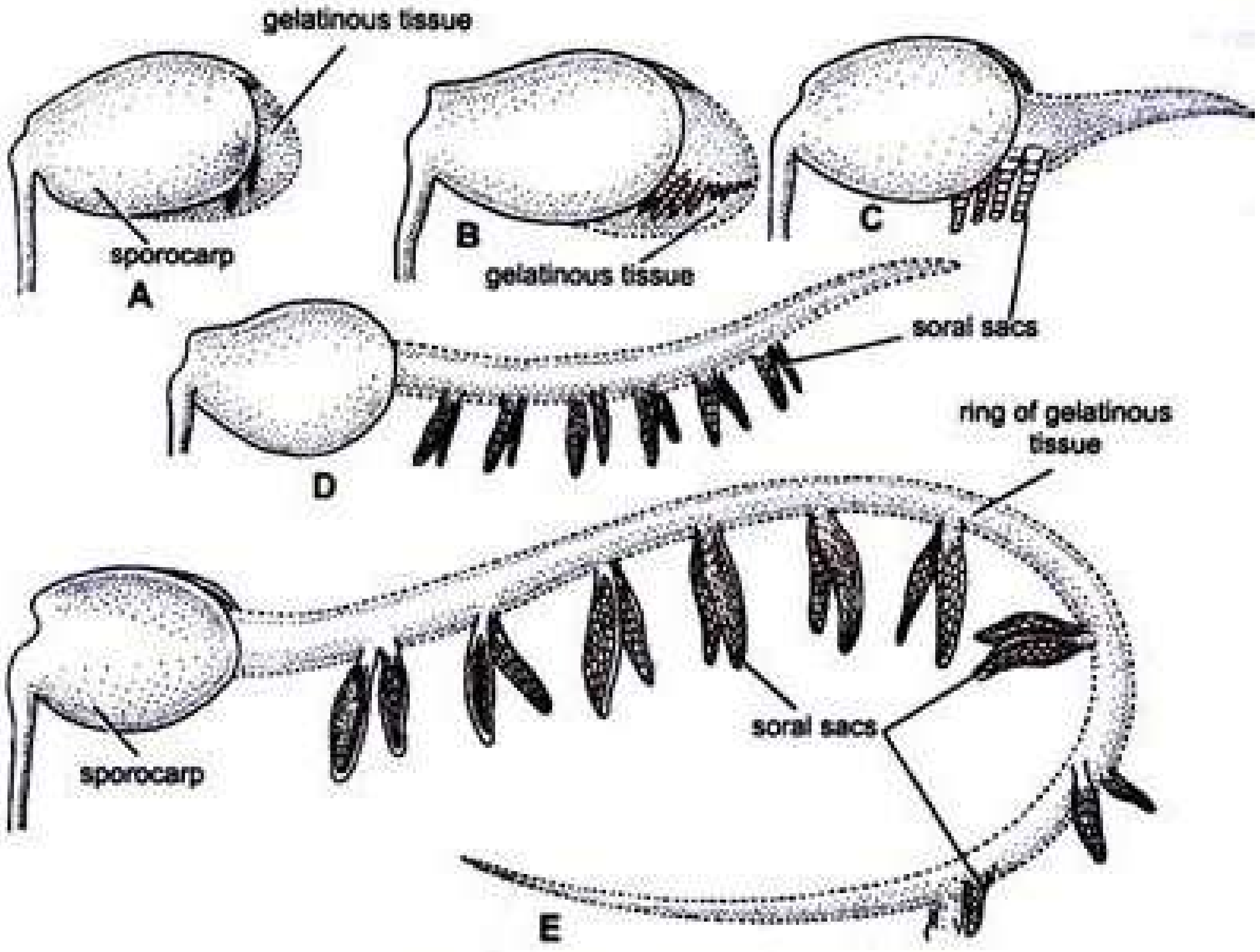


Fig. 15. (A-E) *Marsilea*. Successive stages in the dehiscence of the sporocarp

Gametophytic Phase:

The microspores and the megaspores are the unit of male and female gametophytes respectively.

They germinate to produce the respective gametophyte in the following ways:

Development of male gametophyte:

The microspore is the initial stage in the development of male gametophyte. Each microspore is a unicellular, uninucleate, thick walled globose and haploid structure, ranging from 0- 060 to 0- 075 mm in diameter.

The cytoplasm is surrounded by inner wall called endosporium and outer wall called exine or exosporium. The microspore germinates just after its liberation. The first division is in a lenticular plane to form a small lens shaped prothallial cell and a apical cell (Fig. 16A, B).

The apical cell divides transversely to form 2 equal antheridial initials (Fig. 16C). Each antheridial initial divides periclinally to form an outer first jacket cells (initial) and inner wedge-shaped sister cells (3-3) (Fig. 16D). The inner cell further divides by periclinal division to form a second smaller jacket cell and a large outer cell (Fig. 16E).

The large cell again divides by a periclinal wall to form an outer or peripheral third jacket layer and a central cell or the primary androgonial cell (Fig. 16F). Each primary androgonial cell divides to form 16 androcytes (Sperm mother cells) and finally metamorphosises into antherozoids. In all 32 antherozoids are produced (Fig. 16 G-I).

The male gametophyte is developed inside the microspore and produces 32 antherozoids with usually one prothallial cell. Sometimes 2 prothallial cells are also produced. By breaking of the jacket cells and disintegration of male gametophytic tissue the antherozoids are liberated.

Each antherozoid is a cork screw shaped, spirally coiled multiflagellate, structure (Fig. 16 J, K). It is characterised by the presence of a prominent terminal vesicle. The cilia are attached only to the posterior coils. The coiling looses at the time of fertilization.

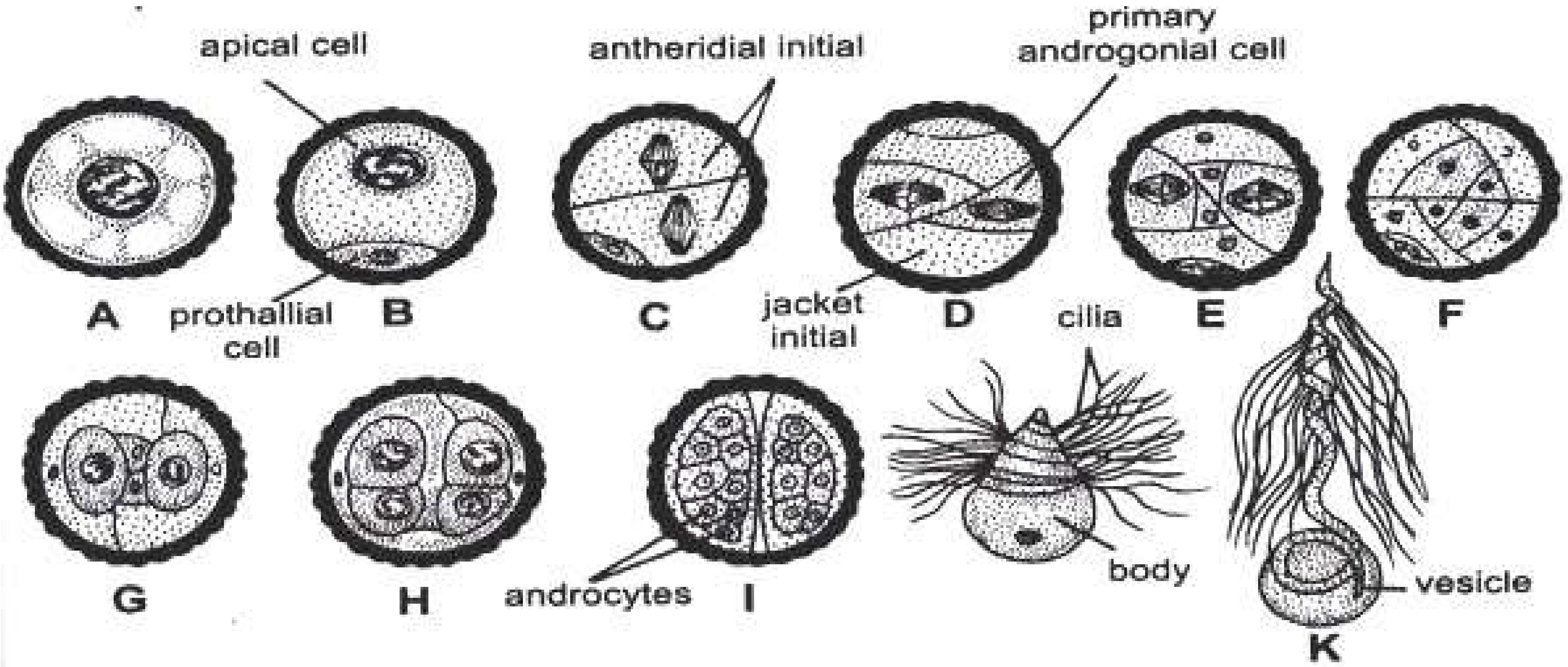


Fig. 16. (A-K). *Marsilea.* A-I. Successive stages in the development of male gametophyte, J.K. Antherozoids.

Development of the Female Gametophyte

The megaspore is the initial stage in the development of female gametophyte. Each megaspore is a unicellular, uninucleate, ellipsoidal structure with an apical papilla (Fig. 17A). The mucilaginous wall is a thick structure except in the papillate region. The wall has 2 covering layers, outer one is known as exospore and inner one as endospore. The nucleus lies in the apical papilla (Fig. 17A). The rest of the basal portion of the megaspore contains granular starch, oil globules and albuminous substances. The first division is in a transverse plane at the base of papilla, thus forming an upper small cell and a basal bigger prothallial cell (Fig. 17B).

The prothallial cell serves as a nutritive cell and provides nutrition to the developing gametophyte while the apical cell forms the female gametophyte. The upper smaller cell again divides transversely to form an upper apical cell and lower basal cell (Fig. 17C). The apical cell divides by three vertical divisions so as to form 3 lateral cells surrounding a central cell or archegonial initial (Fig. 17D).

The archegonial initial divides by a periclinal wall forming an outer primary cover cell and an inner central cell (Fig. 17E). The 3 lateral cells and a basal cell by further horizontal and vertical divisions form a jacket round the archegonium. The cover cell divides vertically by 2 divisions at right angle to each other to form 4 neck initials (Fig. 17F) which by transverse division forms a neck of 2 tiers of 4 cells each.

The inner cells first divides transversely to form an upper primary- neck canal cell and lower primary venter cell. The former may or may not divide to form 1 or 2 neck canal cells. The latter divides to form an upper ventral canal cell and a basal egg. Thus, at maturity the mature archegonium has 8 celled neck, 1 neck canal cell, a small venter canal cell and a large egg. Each megaspore produces a single archegonium (Fig. 17G).

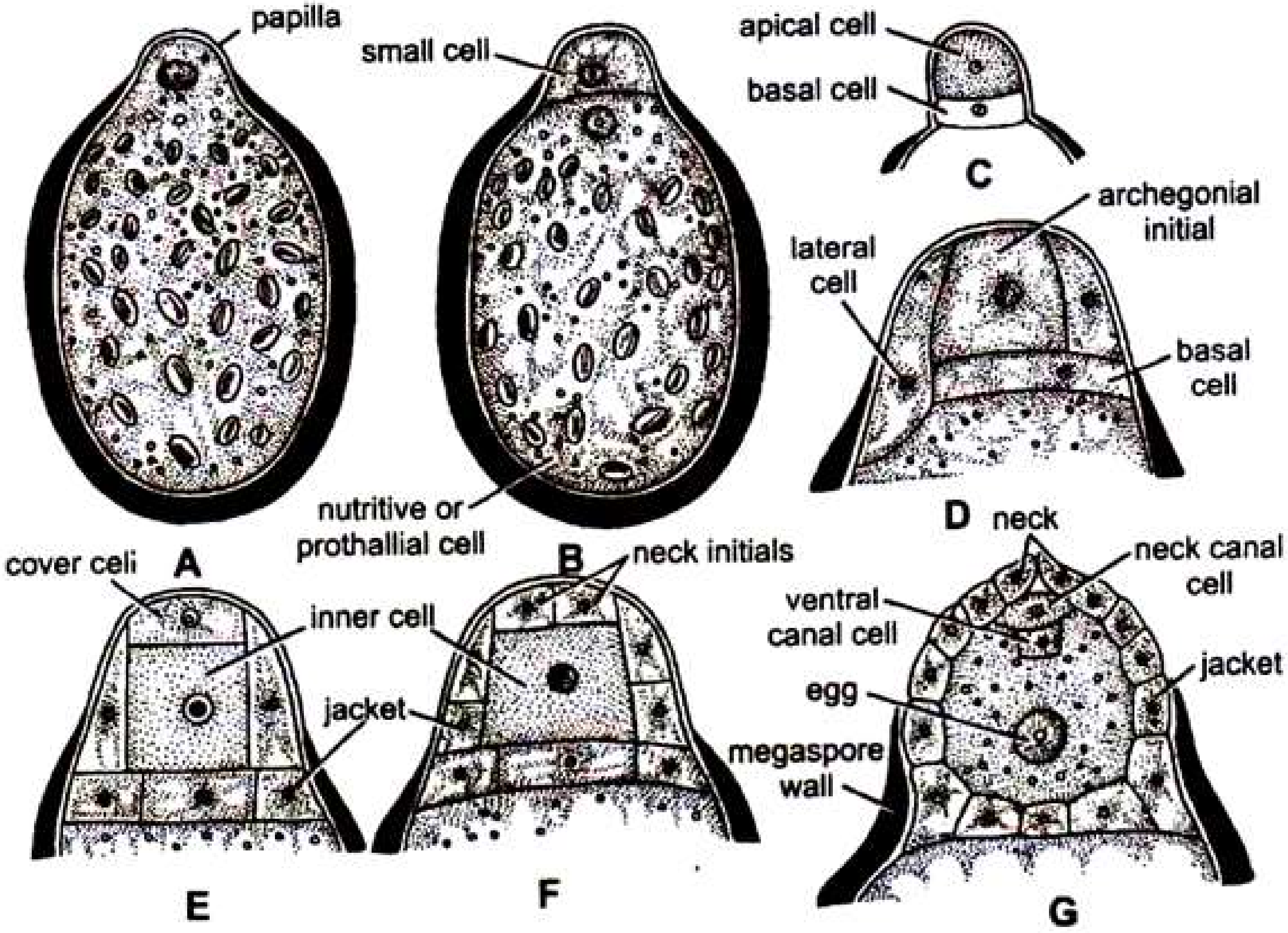


Fig. 17. (A-G). ***Marsllea.*** **A-F successive stages inthe development of female gametophyte G. a mature archegonium.**

Fertilization

Each megaspore is enveloped by a layer of mucilage. Several antherozoids enter into this mucilaginous. One of these antherozoids enters the archegonium and fertilizes the egg to produce oosphere.

Development of the Embyro & Young Sporophyte

The oospore divides to produces four cells. Two sister cells develop stem and cotyledons. The other two cells develop into foot and root. The vegetative cells of the gametophyte form a calyptra**.** It is two to three cells in thickness. This calyptra forms envelop around the developing embryo.

The surface cells of the calyptra produce long rhizoids. Cotyledon and the root grow faster than calyptra and conic out of it. The root enters the soil. Cotyledon expands to form the first simple leaf. Primary root is replaced by adventitious roots. 1 he stem grows horizontally on the soil and form the rhizome.

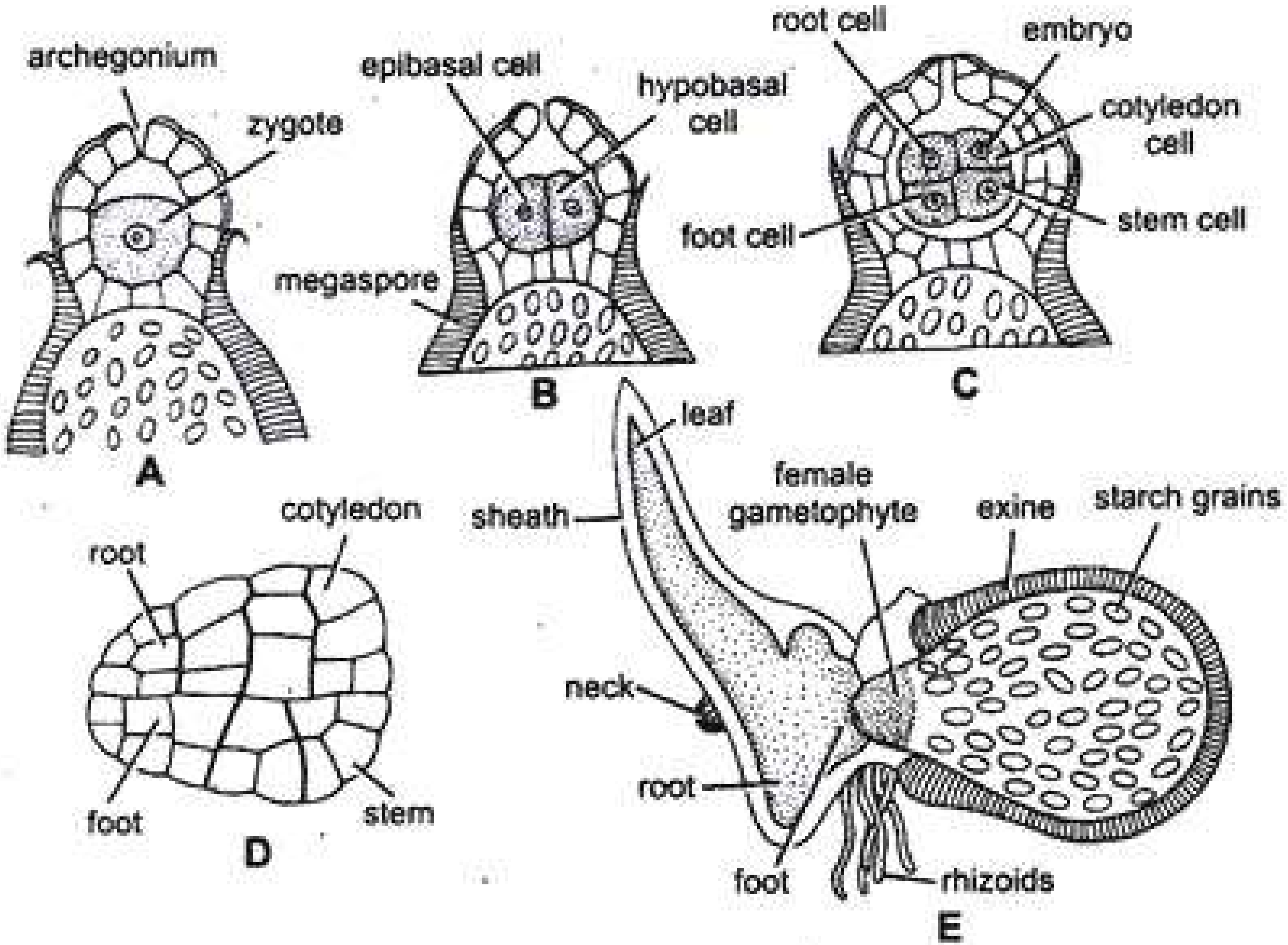


Fig. 18. A-E. Marsilea. Successive stages in the development of embryo.

Alternation of Generation

The sporophyte and gametophyte generations alternates with each
other. Vegetative plant of Marsilea is *a* diploid sporophyte. It is hetrosporous. It produces mega and microsspores by meiosis. The spore germinates to form haploid gametophyte. The gametophyte of Marsilea is dioecious. The microspores give rise to the male gametophyte. The megaspore gives rise to the female gametophyte. Both male and female gametophytes complete their development within the spore walls. Both gametophytes produce male and temale gametes. Gametes fuse to form diploid oospcire. The oospore develops into the sporophyte again.

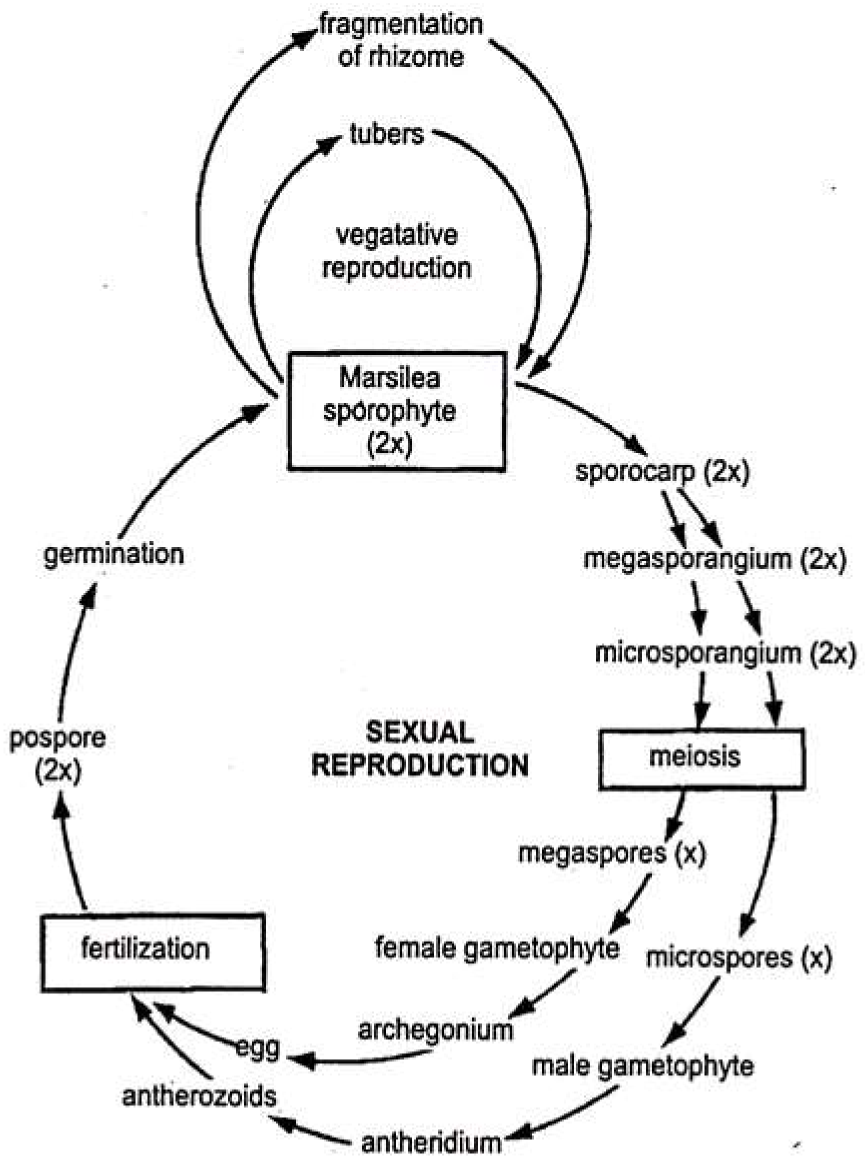


Fig. 20. ***Marsilea.*** **Schematic life cycle.**

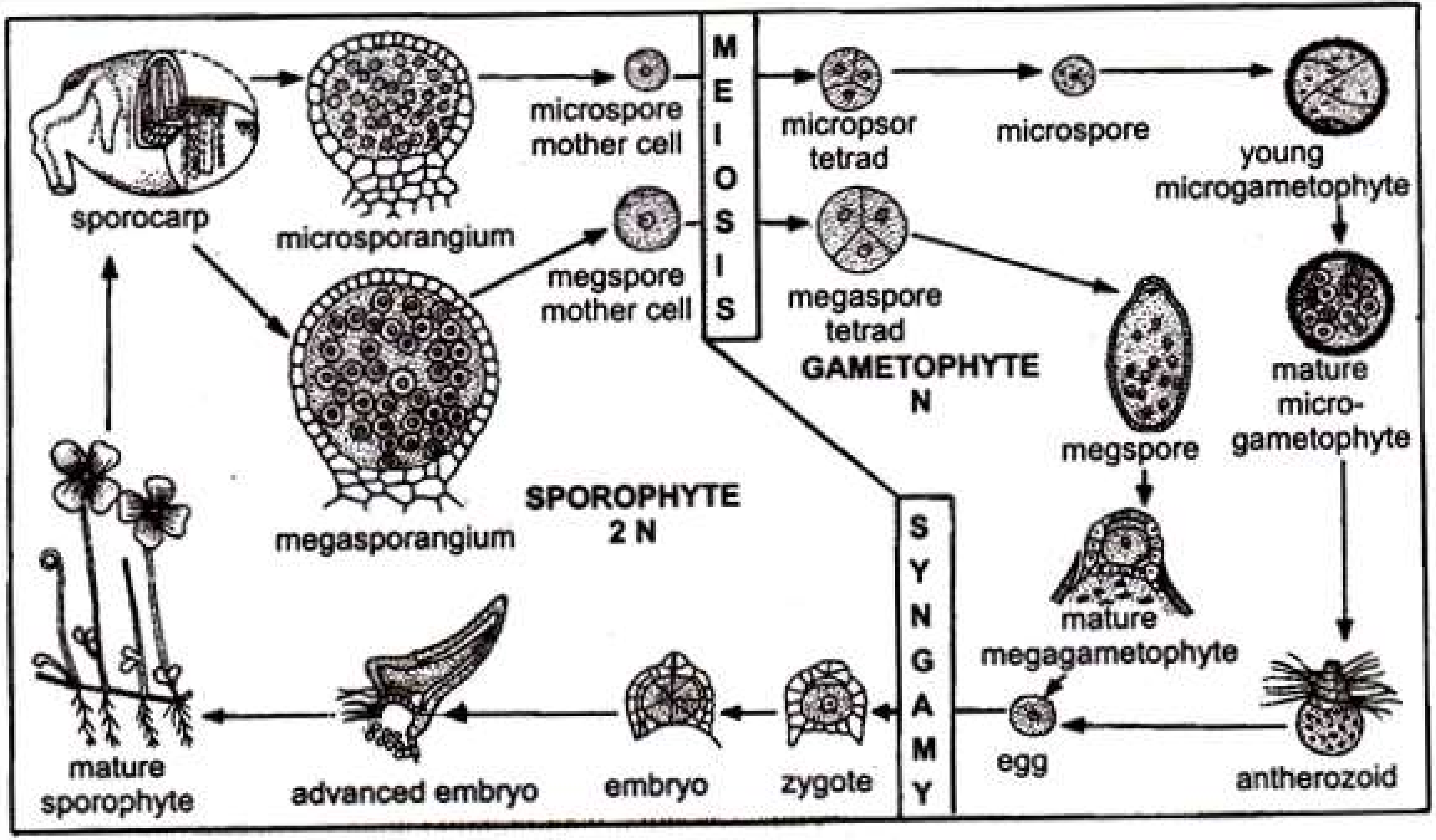


Fig. 19. ***Marsilea.*** **Diagrammatic life cycle.**