

Primary and Secondary Growth in Roots and Shoots

Vascular plants, which account for over 90% of the Earth's vegetation, all undergo primary growth—which *lengthens* roots and shoots. Many land plants, notably woody plants, also undergo secondary growth—which *thickens* roots and shoots.

Primary and secondary growth can occur simultaneously in a plant. While primary growth occurs in newer plant regions, secondary growth becomes apparent in regions that have completed primary growth. There are overlaps and distinctions between root growth and shoot growth.

Apical meristems enable the primary growth of both roots and shoots - with primary shoot growth beginning in the shoot apical meristem and root primary growth starting in the root apical meristem.

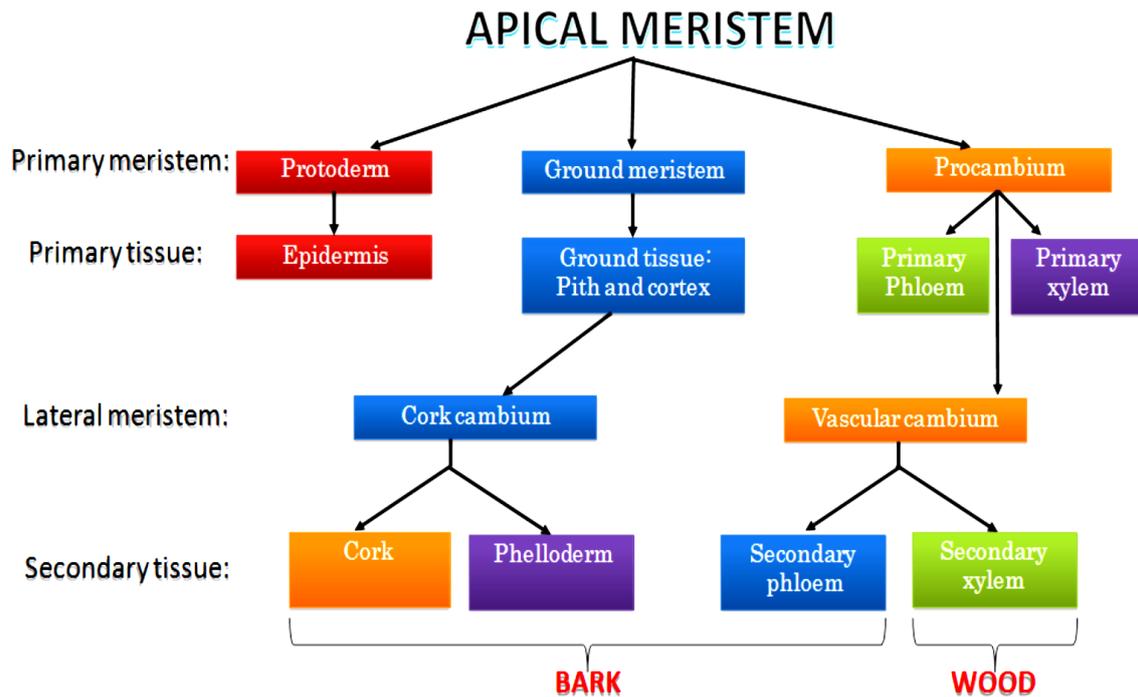
Dividing cells in the root and shoot apical meristems differentiate into the same primary meristems—the protoderm, ground meristem, and procambium. In both roots and shoots, these primary meristems develop into the same tissue types; the protoderm, ground meristem, and procambium respectively develop into dermal, ground, and vascular tissues.

However, there are differences between the specific tissues produced in roots and shoots. In roots, the epidermis contains roots hairs, which account for most of the root's surface area. Additionally, unlike the shoot ground tissue of eudicots—the most common flowering plants—root ground tissue is not divided into pith and cortex. Furthermore, the shoot apical meristem contains leaf primordia, which form leaves.

Compared to primary growth, secondary growth is more similar between roots and shoots. Secondary growth is enabled by two types of lateral meristems, which run along the lengths of roots and shoots.

The vascular cambium, between the primary xylem and primary phloem, creates a layer of secondary xylem (wood) and secondary phloem each year in roots and shoots.

The cork cambium, a component of bark, is located outside the vascular tissues. In both roots and shoots, it produces cork and phelloderm to form the periderm—which replaces the epidermis.



Secondary Growth in Dicotyledonous Stem

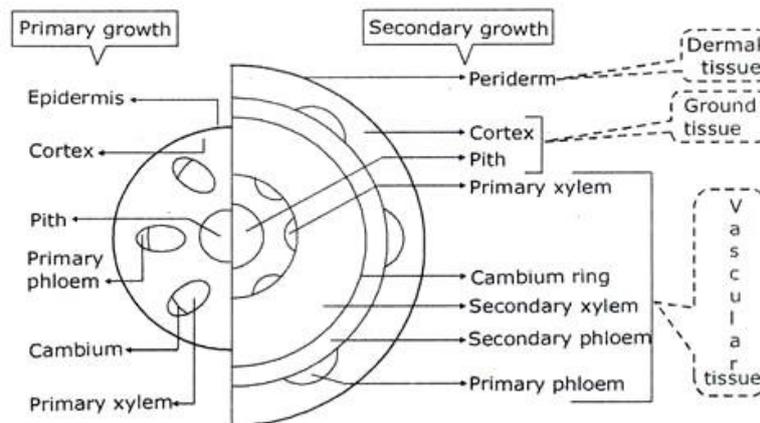
Secondary growth can be defined as a phenomenon where, after the completion of primary tissue formation, more secondary tissues are developed to supplement dermal, vascular and mechanical tissue system in certain plants.

The meristem of primary tissue divides. The daughter cells, after differentiation and maturation, form primary tissues of plant body. Primary tissues include epidermis, cortex, primary phloem, primary xylem and pith, which are observed in the cross section of young stems and roots.

In many plants, vegetative development is completed after the maturation of primary tissues. However, in many herbaceous and woody dicotyledons, formations of new tissues continue even after the maturation of primary tissues.

The production of these new tissues is attributable to the lateral meristem, which includes cork and vascular cambium. These cambia produce new tissues for effective protection, conduction and mechanical strength – a phenomenon termed as secondary growth.

Secondary tissues are formed by the cambium, which is normally present in dicotyledonous roots and stems. Though some monocot stems possess nonvascular cambia, which produce secondary tissues, it is regarded as anomalous. So normal secondary growth occurs in dicots only, and it causes increase in thickness both in intrastelar and extrastelar region of roots and stems.



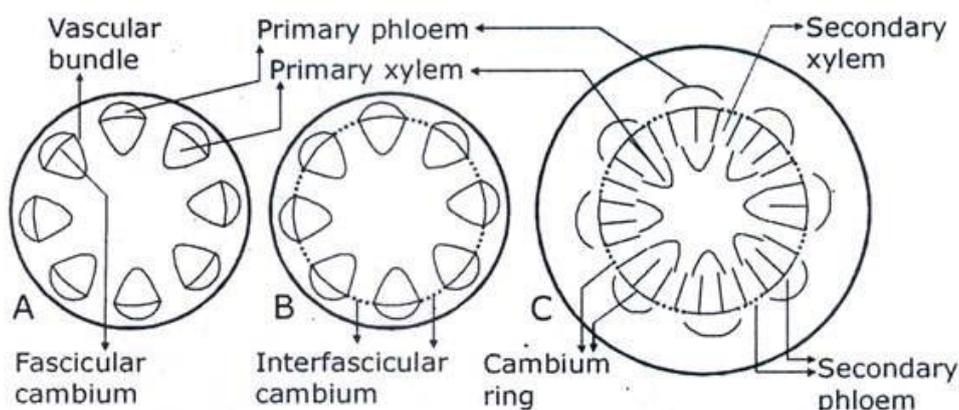
Intrastelar secondary growth in dicot stems

In dicotyledonous stem, the vascular bundles are arranged more or less in a ring. The bundles originate from procambium strand. The procambium cells divide; the inner derivatives are differentiated into primary xylem and the peripheral ones form primary phloem.

A strip of procambium remains in between primary xylem and phloem and this undifferentiated procambium is known as cambium. The cambium, along with peripheral primary phloem and inner primary xylem, forms collateral open vascular bundle of dicot stem.

At the onset of secondary growth, the union of fascicular and interfascicular cambium forms a normal vascular cambium ring. The cambium, which is normally present in between primary xylem and primary phloem is the fascicular cambium, which originates from procambium and so primary in origin.

The interfascicular cambium originates from primary permanent medullary ray cells, situated between the primary vascular bundles and so secondary in origin. The interfascicular cambium differentiates along the line of fascicular cambium and so their union produces a normal cambium ring.



The cambium ring divides tangentially and produces daughter cells on the peripheral and inner side. The peripheral cells are differentiated into secondary phloem, while the inner derivatives form secondary xylem. In between the two secondary tissues, i.e. xylem and phloem, the continuously dividing cambium is present.

Secondary tissues are produced both at fascicular and interfascicular region. Normally equal proportion of secondary xylem are differentiated in all segments of the cambium ring on the inner side while the secondary phloem are formed towards periphery in equal amount in all the segments of the cambium ring but they (secondary xylem and phloem) are not of equal quantity.

Generally, more amount of secondary xylem is differentiated in contrast to secondary phloem. The cells of cambium ring also divide radially to produce ray cells or medullary cells. The ray parenchyma cells are arranged radially in secondary xylem and phloem.

During secondary growth a large amount of secondary tissues are produced within the stele by the activity of cambium ring. As more and more secondary tissues are produced, the primary xylem gradually approaches to the centre and appears as small patches below the secondary xylem. The primary phloem occupies the peripheral position above the secondary phloem.

Extrastelar secondary growth in dicot stem or periderm formation

In intrastelar secondary growth a considerable amount of secondary vascular tissues are produced. As a result a pressure is developed within the stele and it is transmitted to extrastelar region when the endodermis is ruptured, cells of cortex are crushed; the epidermis is stretched and tends to be ruptured.

So to withstand this pressure a special protective tissue is formed usually replacing the peripheral tissues of stems. These protective tissues are known as periderm, which is formed as a result of extrastelar secondary growth.

Periderm originates from the permanent cells present in the epidermis, cortex or phloem and so secondary in origin. In these permanent tissues certain cells become meristematic, which is termed as cork cambium or phellogen. The cells of phellogen are uniseriate, polygonal or rectangular in shape, compactly set with little intercellular spaces.

They contain large nuclei, vacuoles and sometimes chloroplastid and tannin. In contrast to vascular cambium with ray and fusiform initials, phellogen consists of one type of cells. The cork cambium divides mainly tangentially or less commonly radially. The entire cork cambium ring may divide or the division may be restricted to certain cells only. The daughter cells, thus produced, lie at radial rows.

The peripheral derivatives of cork cambium are known as phellem. These cells are rectangular, compactly set without any intercellular spaces, lie at radial rows whose number ranges from two to twenty, and it varies according to species.

Phellem, also known as cork, is dead at maturity. The cell walls may contain suberin or lignin in addition to cellulose. It is the suberin and wax, the fatty substances, which make the phellem or cork impervious to water and gases, thus conferring upon it the protective properties. Sometimes non-suberized cells occur in the phellem - termed phelloids.

In plants different types of cork cells occur i.e. (i) Radially elongated, thin walled, empty and very light cork and (ii) Radially thin, thick walled, cell lumen is impregnated with dark staining materials like tannin or resin, ex. *Eucalyptus*. These two types may occur in the same plant, ex. *Betula*, *Arbutus*.

The cork cells protect the inner cells from any mechanical injury and owing to their suberized cell wall the inner cells are protected from desiccation. Phellem or cork cells are dead. They are resistant to pressure, acids and other chemicals. They are resilient and impermeable to gases and liquids.

The above features and the strength, elasticity and lightness give much commercial value to the cork. **The commercial cork is chiefly obtained from *Quercus suber*.** The bottle corks that are used as stoppers are made sizes by tangential unit to stop leakage from vertically oriented lenticels.

Secondary Growth in Roots

The roots of gymnosperms and most dicotyledonous undergo secondary growth. Most of the dicotyledonous roots show secondary growth in thickness, similar to that of dicotyledonous stems. However, the roots of extant vascular cryptogams and most monocotyledons do not show any secondary growth; they remain entirely primary throughout their life.

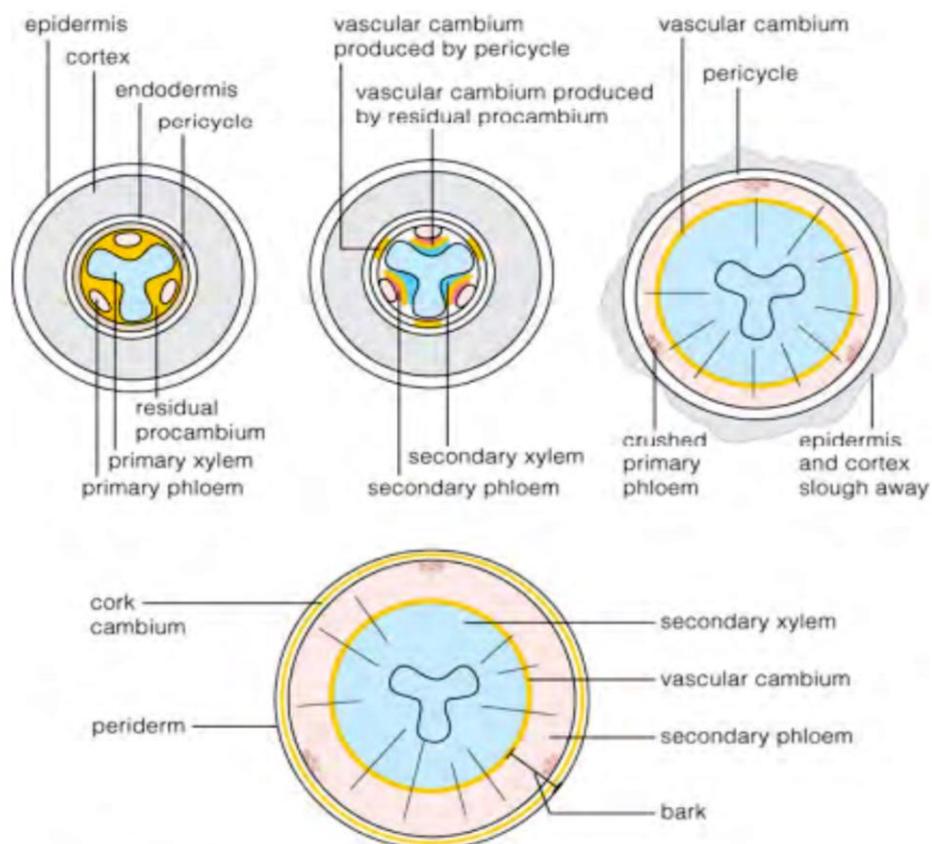
The secondary tissues developed in the dicotyledonous roots are fundamentally quite similar to that of dicotyledonous stems, but the process initiates in some different manner. Certain dicotyledonous roots do not show secondary growth. The secondary vascular tissues originate as a result of the cambial activity. The phellogen gives rise to the periderm.

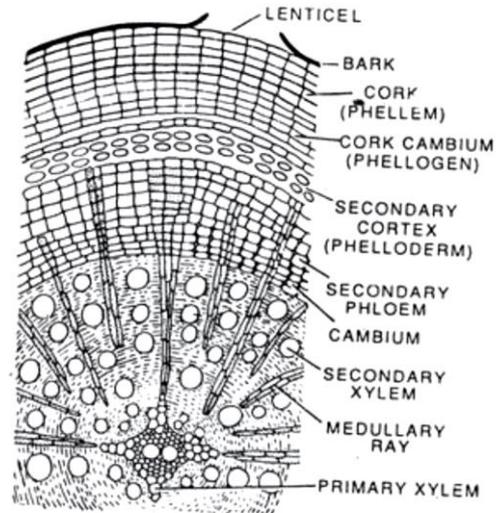
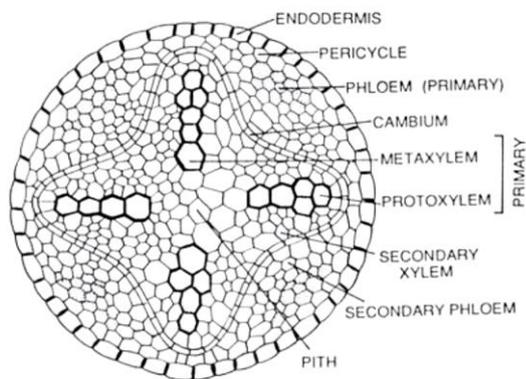
Formation of Cambium and Development of Secondary Tissues:

The dicotyledonous roots possess a limited number of radial vascular bundles with exarch xylem. Normally the pith is very little or altogether absent. On the initiation of secondary growth, a few parenchyma cells beneath each group of phloem become meristematic and thus as many cambial strips are formed as the number of phloem groups.

The cambial cells divide tangentially again and again and produce secondary tissues. Thereafter some of the cells of single layered pericycle become meristematic lying against the protoxylem groups, which divide and form a few layers of cells. The first formed cambium now extends towards both of its edges and reaches the inner most derivatives of the pericycle, thus giving rise to a complete ring of cambium.

The cambium ring is wavy in outline, as it passes internal to phloem and external to xylem groups. The cambial cells produce more xylem elements than phloem. The first formed cambium produces secondary xylem much earlier, and the wavy cambium ring ultimately becomes circular.





Now whole of the cambium ring becomes actively meristematic, and behaves in the similar way as in the stem, giving rise to secondary xylem on its inner side and secondary phloem towards outside.

The secondary vascular tissues form a continuous cylinder and usually the primary xylem gets embedded in it. At this stage distinction can be made only by exarch primary xylem located in the centre. The primary phloem elements are generally seen in crushed condition.

The cambial cells that originate from the pericycle lying against the groups of protoxylem function as ray initials and produce broad vascular rays. These rays are traversed in the xylem and phloem through cambium; this is characteristic feature of the roots. Normally, such rays are called medullary rays.

Periderm

Simultaneously the periderm develops in the outer region of the root. The single layered pericycle becomes meristematic and divides, giving rise to cork cambium or phellogen. It produces a few brownish layers of cork cells or phellem towards outside, and the phellogen on the inside.

The phellogen does not contain chloroplasts. The pressure caused by secondary tissues ruptures the cortex with endodermis, which is ultimately sloughed off. The epiblema dies out earlier. Lenticels may also be formed.