Text Book
Of Wood Science

— Anatomy, Properties and Uses of Wood

Guangxi University
Guangxi Nanning
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Luo Jianju
Professor of Wood Science &Technology
Guangxi University

Xu Feng
Associate Professor of Wood Science
Guangxi University

Li Ning
Lecturer of Wood Science &Technology
Guangxi University

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Preface

This book is compiled as the bi-language lecturing material for classes of undergraduate students in the field of Wood Science & Engineering. It can also be used as self-learning material for post-graduate students who are interested in Wood Science &Technology. The purpose of the authors of this book is to prepare a set of bi-language teaching material, and through bi-language teaching to improve teaching and learning quality in the course of Wood Science, and meantime to improve students' English level in reading English books and articles of wood science and technology.

The content corresponds with the teaching syllabus of wood science (i.e. the structure and properties of wood). The authors are grateful to the following for using their materials in the process of compiling this book:

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Chapter 1

Introduction

The progress of humanity from the primitive state to the present day's highly advanced technology has been closely associated with dependence on wood. The relative ease of working it and its almost universal availability has made wood an essential material for human survival. Wood has been used for shelter, fuel, weapons, and tools since prehistoric times. As technology developed, wood came to be used for boats, vehicles, bridges, and as fuel for smelting ores and working metals.

The greater the technological advances, the more diverse and sophisticated the uses that have been found for wood. Today, in spite of the availability of numerous new synthetic materials, even the most highly developed countries would find it difficult to maintain their high standard of living if deprived of access to wood products. It is easy to demonstrate that the higher the level of economic development, the greater is the dependence of men on wood, not only in many of its conventional forms but also in a variety of less readily recognizable items, such as paper, films, and other wood-pulp products which are the very mainstay of life. In fact, our dependence on wood is increasing because of its position as a renewable resource. The growing scarcity of petroleum in the world is forcing a reevaluation of the importance of wood as a fuel and as a source of basic chemicals to replace those now obtained from crude oil.

Since dependence on wood is of such antiquity, it is only natural that an extensive empirical background on its uses should have been accumulated. But, as is often true when heavy reliance is placed on tradition, it is not surprising to find that even today, though some of the information on wood is factual, much of it is colored with prejudice or is distorted by the rule-of-thumb approach, while some is no more than fantasy. As a result, its exceptional qualities have only too often been taken for granted, or have remained unappreciated, while its faults have been grossly exaggerated. Paradoxically, the reason for this situation is the extreme versatility of wood, coupled with its almost universal availability to peoples of different cultures and degrees of technical attainment. On the one hand its fabrication and many of its applications are so simple that they require no special skills or technical knowledge by the user; on the other hand wood is a substance of a greater complexity than any other major engineering material, and its utilization under the competitive conditions of modern technology calls for a degree of scientific and technical understanding not possessed by most of its consumers.

A comprehensive knowledge of the characteristics of any material is essential to its best utilization. This is especially true with wood because of the manner of its formation and its complex cellular and cell wall structure.

Ⅰ. Characteristic properties of wood

All wood, regardless of its botanical origin, possesses certain characteristics in common. These are summarized in the following paragraphs.

1. All wood is cellular in structure with cell walls composed of a characteristic mixture of polymers of cellulose, noncellulosic carbohydrates, and lignin, organized as a reinforced matrix. This accounts for a combination of elastic and plastic responses of the cell wall to applied forces.

2. Wood is anisotropic in nature; i.e., it exhibits different physical properties when tested along its three major directional axes. This behavior arises from the structure and organization of cellulose in the cell walls, the elongated shape of the wood cell, and their longitudinal-radial arrangement resulting from the radial symmetry of the tree trunk.

3. Wood is a hygroscopic substance; i.e., it loses and gains moisture as a result of changes in the atmospheric humidity and temperature. Because of its anisotropic nature these moisture variations produce dimensional changes in wood which are unequal in the three axial directions; they are quite small in the longitudinal and appreciable in the radial and tangential directions. In addition, the changes in moisture content and dimensions affect strength and a number of other physical properties such as electrical conductivity.

4. Wood is biodegradable; i.e., it may be reduced to its component simple sugars and lignin elements through attack by organisms such as fungi, bacteria, and certain insects, for instance, termites. It can also be degraded by hydrolysis and oxidation resulting from condition to which it is exposed.

5. Wood is combustible. This property makes wood one of the major sources of fuel in the world economy because of the relative abundance and the renewable nature of the supply. It also opens many possibilities for deriving basic chemicals from wood, such as alcohols and gaseous compounds that can replace similar materials now obtained from crude oil. On the other hand, combustibility of wood must be taken into account when it is employed in light construction.

6. Wood is remarkably inert to the action of most chemicals. For this reason it is well suited for many industrial applications where resistance to the disintegrating action of chemicals and to corrosion is important. However, when wood is exposed to atmospheric conditions, it will slowly erode under the action of weather as the rate of about 0.25 inch per century. This can be easily prevented by painting the surface; such protection carries the added advantages of decoration and reduction of surface porosity.

7. Wood is surprisingly durable when used under conditions which are not deliberately favorable to the wood-destroying agencies. Many instances are known of wood, protected from dampness and from attacks by insects, lasting centuries and even several millennia. Such extreme examples of the enduring qualities of wood were found, for instance, in the 2700-year-old wood beams in the tomb of King Gordius, near Ankara, Turkey. Sound beams, many centuries old, have recently been removed from ancient temples in Japan. In this country, perhaps less spectacular but nevertheless impressive, are the old colonial homes in New England and in South, with the original wood exterior and interior in a well-preserved state after 200 years or more.

There is no reason why, if properly used, wood should not last indefinitely. Decay and insect damage can be largely eliminated by following sound methods of design in construction and by using properly seasoned wood. In situations where biological wood-destroying agencies are especially difficult to control, wood can be made to last by impregnation with suitable preservatives.

8. Because of its fibrous structure and the quantity of entrapped air, wood has excellent insulating properties. With the exception of wood, the common building materials used in house construction are not good insulators. In comparison with wood, the heat loss through common brick is 6 times, and through a glass window 8 times as great. Concrete made with sand and gravel aggregate is 15 times as conductive as wood, steel 390 times, and aluminum more than 1700 times. Well-constructed wood windows provide a considerable advantage over highly heat-conductive metal windows by reducing heat transmission in and out of the building and minimizing vapor condensation in cold weather.

Wood provides thermal insulation the year around; i.e., wood insulation is effective not only in the winter against cold but also in the summer against heat. Finally, wood is the only major structural material that combines outstanding structural characteristics with effective thermal insulating properties.

Wood when reasonably dry is also a poor conductor of electricity. This is important in such uses as power line poles and ladders used in fire fighting, and may be significant in dwellings by minimizing the danger of shock from broken or exposed wires coming into contact with the structural members of a building.

Ⅱ. Variability of wood Properties

Wood is an inherently variable substance because of its origin as a product of metabolism of the living tree. As a result, its properties are subject to wide variations brought about by the physiology of the trees and the external factors affecting its growth. Therefore, wood characteristics may vary in different parts of the same tree as well as from tree to tree. Furthermore, wood is a product of not one but many species of trees with each kind of wood exhibiting its own anatomical, physical, and chemical properties. In consequence we have available a material with an almost infinite range of properties and characteristics from which to select for particular use requirements.

Ⅲ. Wood as an industrial raw material

Most of characteristics of wood that make it an outstanding industrial and construction material are traceable to one or more of its basic properties and to its manner of origin. Conversely its faults are derived from the same basic characteristics. A comprehensive knowledge of the structure of wood, its chemical and physical behavior, and the causes of its variability as they affect its utilization is therefore the basis of present and potential utilization.

The supremacy of wood as a raw material for pulp and paper is unquestioned. There is no other natural substance that can meet the ever-increasing demands of modern society for paper and other pulp products. At present it seems unlikely that a synthetic material could be produced economically to rival wood as a source of pulp, especially in light of the limited supplies of petroleum, which would have to provide the chemicals for production of competing materials. In fact the increasing cost of crude oil is causing a critical reevaluation of the importance of wood as a potential source of basic chemicals. Some methods of wood conversion into chemicals such as reduction of wood waste to alcohols, have already been developed, and other potentials exist for using wood as a raw material for producing chemicals that are now obtained from petroleum.

Ⅳ. Wood as a construction material

When wood is employed in its basically unaltered form in construction, furniture, containers, power transmission lines, transportation, and a host of other applications, it offers the greatest challenge and opportunity to the designer and user. This is true because wood is universally available in a large variety of shapes and sizes with greater diversity of unique characteristics than are found in other major structural materials.

1. Wood may be cut and worked into various shapes with the aid of simple hand tools or with power-driven machinery. It therefore lends itself well not only to conversion in a factory but also to on-the-side fabrication. It is the latter fact that largely keeps conventional wood-frame construction fully competitive with any method of complete prefabrication of houses yet employed.

Wood can be joined with nails, screw, bolts, and connectors, all of which require the simplest kinds of tools and produce strong joints. Wood can also be joined with adhesives, which can produce a continuous bond over the entire surface to which they are applied and develop the full shear strength of the wood. This use of adhesives provides a means of fabricating wood members of differing shapes and almost unlimited dimensions. Prefabrication of large wood trusses, laminated beams and arches, and stressed-skin panels have made wood construction competitive in building.

2. Flexural rigidity in relation to the weight of the material, traceable to the nature of the cell wall material and its distribution as a system of thin-walled tubes, is one of the outstanding mechanical properties of wood. For instance, when Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] is compared with low-carbon structural steel on an equal weight basis, even if the design stresses are reduced to allow for the presence of defects in wood, it is apparent that Douglas-fir is superior to steel in bending by a ratio of 2.6 to 1. The high flexural rigidity of wood is most effective in members in which the length is far in excess of depth of the cross section, such as in beams and long slender column. For example, an 8×4 inch “I”-section steel column 20 feet long and a Douglas-fir pole with an effective circular cross section 10.5 inches in diameter will have equal weights, but the wood pole will carry 32 percent more load as column.

3. Wood structures can be designed to carry impact loads that are twice as great as those they can sustain under static loading. This can be contrasted with steel and concrete for which no increase in loads is allowed under similar conditions. The exceptional impact strength of wood gives it a considerable mechanical and economic advantage for structures designed to resist earthquakes or for situations where abrupt loads are imposed, e.g., in aircraft carrier decking, since wood is at least nine times as good an energy-absorbing material as steel. Unlike steel, wood also possesses excellent vibration-damping characteristics. This property is of utmost importance in bridges and other structures subject to dynamic loads.

4. Dimensional changes that may take place as a result of rise in temperature are less significant in wood construction than they are in construction utilizing metal structural members. When heated, wood expands across the grain as much as or more than metals, but only little in the longitudinal direction, which is important in construction. Moreover, in wood, increase in dimensions with rise in temperature is frequently balanced to a considerable degree by shrinkage caused by drying, with a corresponding increase in strength. There is no such compensating effect in metal structural members, which expand and lose strength progressively when heated.

For instance, if during a fire room temperature rises from 70℉ to 100℉, or higher, a wood beam of a cross section adequate to span 60 feet would increase in length by about 1.5 inches. In fact, this elongation would be considerably less because of the concurrent shrinkage induced by the moisture loss. Furthermore, the stated amount of elongation is predicated on the assumption that the wood beam would have reached a uniform temperature across the entire section. Because of the low conductivity of wood and the insulating properties of the charred surface, this would not be the case.

Under similar conditions, a steel beam of the same length will elongate approximately 4.95 inches. If by then the side walls of the building have not yet collapsed from the effect of steel elongation, the steel beam will sag because it is unable to support even its own weight when heated to that temperature or beyond.

Ⅴ. Knowledge of wood and better use

Certain characteristics of wood are sometimes cited as detrimental to its use for particular purposes. However, when its properties are well understood, these supposed disadvantages may be minimized and in some cases even turned to advantage. For instance, the essentially tapered cylindrical shape of the tree trunk causes some losses in sawing straight-grained, rectangular lumber from logs, but this very shape of trunk offers a maximum stress resistance for a minimum of material used.

Problems arising from differential dimensional changes in wood may be serious. They may be reduced, however, by choosing a kind of wood that has not only low shrinkage but also a minimum difference between radial and tangential dimensional changes. Also, the simple rule should be followed that where dimensional changes may cause a significant problem, wood must be dried, before it is used, to the average moisture content it is expected to attain in service. The difficulties of unequal transverse shrinkage and swelling in flooring may be minimized by use of quarter-sawn lumber, so that the minimum dimensional changes occur in the radial direction, i.e., across the wide faces of the boards. Additionally, wood can be stabilized by several methods. It may be converted to plywood in which the anisotropic dimensional properties of wood are so distributed in alternate layers that shrinkage and swelling, as well as strength properties of the sheet of plywood, are approximately equal in the two principal directions of the face of the sheet. Stabilization can also be achieved by impregnating wood with a chemical compound, such as polyethylene glycol, which will occupy the absorption sites within the cell wall, which are normally taken by water, thus maintaining the original dimensions of the wood.

Combustibility of wood is valued when wood is used as a fuel, but is regarded as a fault when wood is used for construction. In reality the low thermal conductivity of wood allows only a gradual internal loss of strength from external heating, if the wood members are used in large enough sizes. In contrast to structural steel constructions which collapse in ordinary building fires, wooden structures with adequately sized members will not collapse. In fact, buildings framed with heavy timbers in the style known as "heavy mill construction" have the most advantageous rating by fire underwriters of any type of building commonly erected.

These few examples do not by any means present an exhaustive treatment of all the outstanding characteristics of wood. Rather they serve to illustrate the unlimited possibilities that exist when advantage is taken of the available technical knowledge. However, in spite of its many proved advantages as a construction material, or as a raw material in its many other industrial applications, adherence to antiquated methods of construction and failure to understand and to make full use of its outstanding technical qualities frequently place wood at a disadvantage in competition with other products. Many of these disadvantages, real or implied, could be overcome by intelligent use of wood, based on comprehensive knowledge of its properties.

Finally, it should never be forgotten that wood is the only major raw material with a wide range of industrial uses, which is renewable, and hence capable of meeting the needs of a nation in perpetuity. It is therefore inconceivable that this priceless material should be either grown or used without due consideration of the known scientific facts concerning its nature.

We may use wood with intelligence only if we understand wood.

Chapter 2

Tree Stem And Its Growth

Ⅰ. The plant origin of wood

Wood is plant origin. Not all plants, however, possess woody stems, and not all that do possess woody stems produce timber suitable for use as an industrial material. The following criteria serve to distinguish woody from nonwoody plants:

- Woody plants must be vascular plants; i.e., they must possess specialized conducting tissues consisting of xylem (wood) and phloem (inner bark). The xylem is lignified and is the wood of the mature plant. Plants devoid of vascular tissue cannot produce wood.
- They must be perennial plants; i.e., they must live for a number of years.
- They must possess a stem that persists from year to year. Many perennials fail to be classed as woody plants because their stems die back to the ground each autumn, the roots persisting through the winter and producing a new stem the following spring. Some plants possess persistent creeping stems and hence fall into the category of woody plants, even though they appear to be herbaceous.

- Typical woody plants, which include all the commercially important timber trees, exhibit secondary thickening; i.e., they have a means of thickening their stems by subsequent growth in diameter, not traceable to terminal growing points. This is achieved through the activities of a growing layers, called cambium, which is situated just outside the last formed layer of wood and beneath the inner bark (phloem); new wood and new phloem are thus produced yearly and are developed between the previously formed wood and bark. In this manner, in the case of trees, the trunk eventually attains a diameter of sufficient size to be converted into lumber or other useful products.

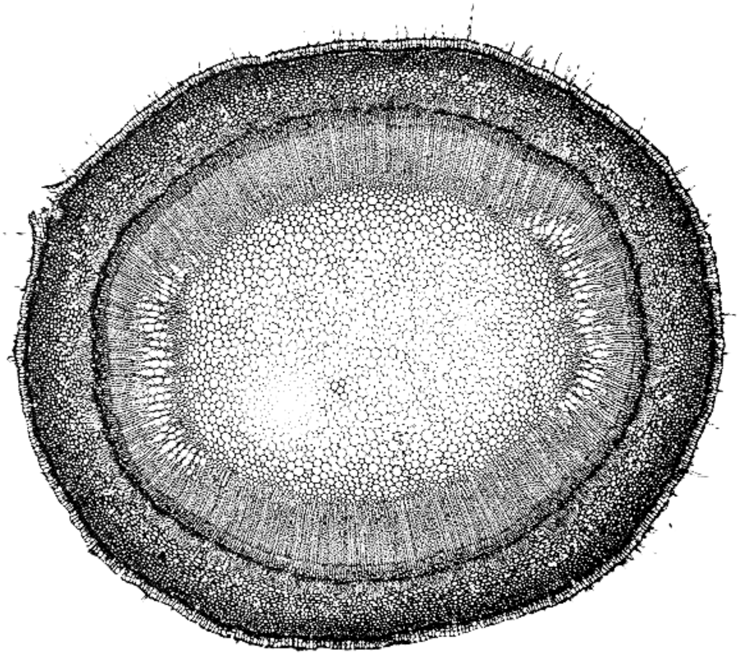

Fig.1 Transverse section of a 1-year dicotyledonous stem, *Fraxinus pennsylvanica* Marsh., showing a vascular cylinder (xylem, cambium, and phloem) surrounding the pith. The cylinder is bounded by cortex, periderm, and epidermis, in the sequence stated. (25×.)

Ⅱ. Parts of a tree

A tree has been defined as a perennial, vascular, woody plant which attains a height at least of 20 feet and usually (not always) has a single, self-supporting stem. Although trees, like other vascular plants, exhibit a surprising range of variation in size, form, and structure and are, in reality, complex organisms, they are constructed according to a simple, uniform plan. The plant body consists of a continuous cylindrical axis, which bears lateral appendages.

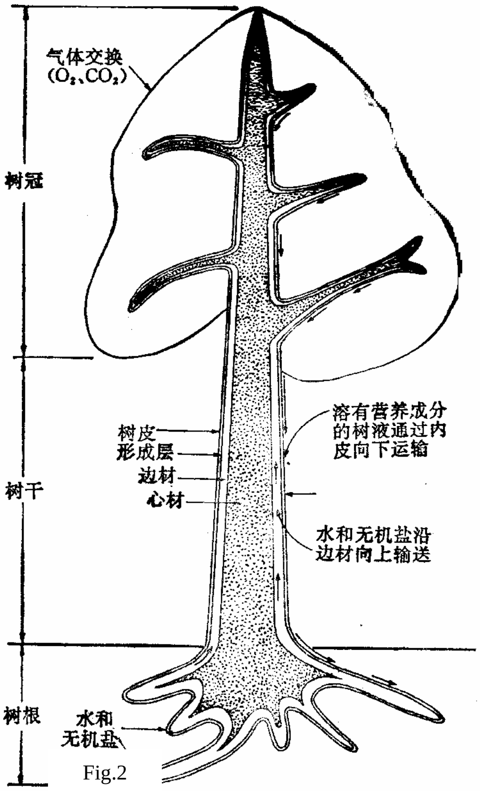

Fig.2

图 1-1 树木的各部分和作用

The main portion of the axis above ground is the stem, trunk, or bole; this divides successively into limbs, branches, and branchlets, often in a manner characteristic for the tree species. The remainder of the axis is embedded in the earth; like the portion above ground, it divides again and again, and forms the root system. The stem provides mechanical support for the crown, serves as an avenue for conduction between the crown and the roots, and, on occasion, may store appreciable amounts of reserve food. Roots, in contrast, are organs of anchorage and support, which in addition perform the functions of absorption by means of root hairs or mycorhiza, of conduction, and of storage. Both roots and stems exhibit radial symmetry when cut transversely i.e., the various parts are arranged around a common center. Trees are different from the higher animals in which bilateral (right and left) symmetry is the rule.

Ⅲ. How a tree grows

Wood on a commercial scale is obtained only from trees of some maturity. Since the processes of growth in length and in thickness in trees are identical with those that take place in the production of seedlings from seeds, and trees from seedlings, a discussion of the manner in which growth proceeds in the mature tree will serve the purpose of this text.

A tree, as previously noted, consists of a branched cylindrical axis to which appendages of various sorts are attached. The trunk and much-branched crown compose the portions of this above the ground; below the surface of the ground, the axis divides more or less abruptly into a wide spreading root system, which in size and bulk compares favorably with the crown. Until the tree attains maturity, enlargement of the crown and root system proceeds at a fairly rapid pace, in later years undoubtedly more sluggishly. But elongation, at least in some parts of the crown and root system, never stops during successive growing seasons, i.e., as long as the tree lives.

Elongation of the branches on cylindrical axis is traceable to apical growing points, and to these alone. Through growth proceeding in these, the axis increases in length, branches according to the plan characteristic of the species, and adds new appendages acropetally (toward the apices), meanwhile (and sometimes in season-leaves) casting its older appendages. Tissues arising from such apical growing points are termed primary tissues.

But little thickening would occur in the branched cylindrical axis of the tree were it dependent upon primary growth alone. Obviously, the growing points, as they forge ahead, leave tissues to the rear, which alter to varying degree as they mature. However, the number of cells that can arise in an apical growing point is limited, which means in turn that the volume of tissue derived from it must be restricted, in fact, too restricted to insure the necessary strength to support the crow of the tree. In trees, growth in thickness is traceable to a cambium (growing layer) between the bark and the wood throughout the tree; the cambium continues to live for a good many years and annually produces new wood and bark between the old bark and wood. Growth of this sort from a lateral cambium is responsible for most of the thickening of the stem; it is designated as secondary growth or secondary thickening, to distinguish it from growth in length traceable to apical growing points. Tissues originating laterally through secondary thickening are known as secondary tissues. Such tissues add to the bulk of the plant body, especially of the vascular (conducting) tissue, and strengthen the stem; they do not, however, fundamentally alter its structure, nor are new types of cells usually formed.

Ⅳ. Orientation of the tissues in a young tree stem (twig)

The massive trunk of a tree is but a main stem in which primary growth (growth in length) has ensued each year at the apex and in which secondary growth (growth in thickness) has proceeded through its length. Once secondary growth is initiated, it continues periodically as long as the tree lives. Hence, a proper understanding of the manner in which a tree bole is built up, year by year, entails knowledge of the tissues present in a young stem and their orientation as regards one another, this prior to and after secondary thickening is under way.

The figure that is abbreviated illustrates diagrammatically the tissues present in four segments of a 1-year twig, “as is ” at different heights; the tissues are depicted in longitudinal sectional view. Segment A is obviously through the twig-tip; toward the apex, there is a region of persisting initiating cells, the promeristem, in which cell division

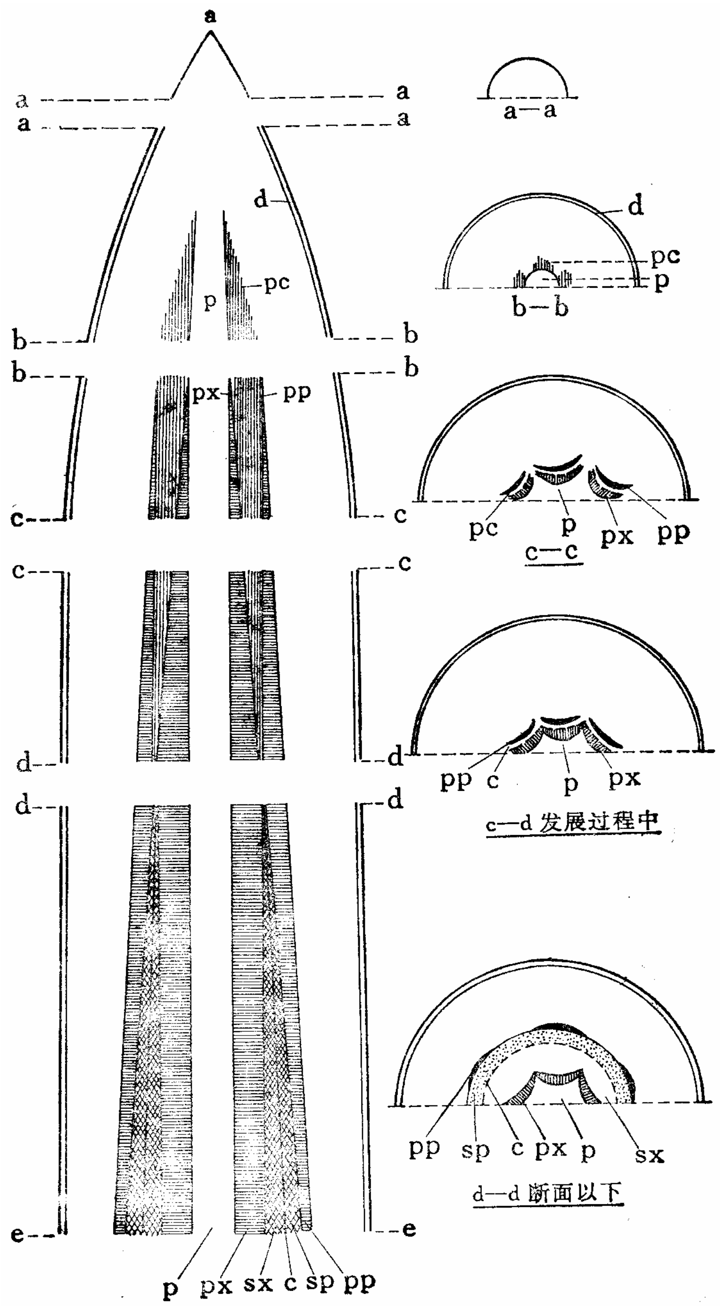

Fig. 3

proceeds rapidly. The cells cut off to the rear continue to divide, but the tissues composed of them remains wholly undifferentiated; in this zone growth takes place by increasing in the number of cells rather than by increasing cell size. But already, in the sides of segment A toward the base, the eventual formation of an epidermis is presaged; the outermost layer of the promeristem has differentiated into a dermatogen.

In segment B, farther back from the apex, the cells arising from the promeristem have undergone further differentiation. The dermatogen, which made its appearance first toward the base of segment A, has been continued as an outer limited layer. Meanwhile, changes in cell size, cell shape, cell contents, and in the arrangement of cells have resulted in the differentiation of two additional regions, a central core or plerome and a region between it and the dermatogen, the periblem. These three regions of meristematic tissue shown in segment B have little physiological or morphological significance; they do serve, however, to indicate the origin of the mature tissues depicted at the next lower level.

In segment C, the tissues (primary tissues) resulting from primary growth have now become fully mature. The stem is covered on the outside by an epidermis that has arisen by the further differentiation of the cells of the dermatogen. The core of plerome visible in segment B has been replaced by a rectangular area of tissue directed lengthwise of the twig. In reality, this zone of tissue is cylindrical in shape; it is a sort of column which is known technically as a stele (from Greek, post). The tissue between the stele and the epidermis, i.e., the tissue derived from the periblem shown in segment B, is the cortex.

The epidermis of a young stem forms a continuous layer over the entire stem in segment C. it is rarely over one cell in thickness. The cells are living but are devoid of chloroplasts, except the guard cells at the stomatal openings. The chief function of the epidermis is to serve as a covering layer that prevents excessive loss of water from deeper lying tissues. In most instances it is the better equipped to perform this because the outer surfaces of the cells are usually waterproofed with a layer of waxy material (cutin), which acts as a varnish.

The stele in evidence in segment C consists of central pith that appears unusually large at this stage. It is bounded on the flanks by a narrow zone of primary vascular tissue. The pith, like the entire stele, is actually cylindrical and is completely sheathed by vascular tissue.

The cylinder of vascular tissue in the stele depicted is composed by primary xylem (primary wood) and primary phloem. The primary xylem forms a continuous layer around the pith. The primary phloem is situated outside the primary xylem and, like it, is arranged in a continuous layer.

The chief functions of vascular tissue, both of primary vascular tissue and of secondary vascular tissue, are conduction and support, although, on occasion, it may assume a third function, i.e., storage. Xylem conducts water and substances in solution absorbed from the soil upward; the tissue is rendered woody, and for this reason, most of the stiffness of the stem is traceable to it. The phloem carries food previously elaborated in the leaves downward.

The pith inside the xylem is composed of tissue that is usually soft and quite deferent in nature from the vascular tissue; in twigs, the pith may store appreciable amounts of food, but in the mature tree-trunk, its cells are dead and no longer participate in the vital processes of the tree.

The cortex between the stele and the epidermis varies from a few to many layers of cells in thickness and is essentially parenchymatous although the cells composing it vary greatly in nature. Frequently they are thickened at the corners (collenchymatous) and serve to some extent as mechanical tissue. Fibers, grit (stone) cells, and oil or storage cells are often present. In many twigs, the cortical cells immediately under the epidermis are strongly lignified (sclerenchymatous) and occur in sheets or strands. In such cases, they supplement the epidermis as an additional protective layer and form a hypodermis; they also provide the necessary strength in the twig prior to the time when sufficient wood has accumulated through secondary thickening to meet this need.

It remains to indicate how secondary growth proceeds in a twig following the maturation of the primary tissues depicted in segment C. This situation is portrayed in segment D. The diameter of the stem has now increased appreciably owing to the formation of secondary xylem and secondary phloem between the primary xylem and the primary phloem. These secondary tissues trace their origin to the activities of the cambium. The cylinder of pith and the zone of primary xylem continue to occupy the same positions and the same space as previously. The cambium meanwhile has moved outward, and a wide band of secondary xylem surrounds the primary xylem, bounded on the outside by the cambium. The cambium is likewise responsible for a zone of secondary phloem underlying the primary phloem, and this last-mentioned tissue has meanwhile been pushed farther to the outside. The cortex is still intact, which means that it has been enable to adjust itself to the expanding girth of the stele. Not so the epidermis. This has been ruptured since there was no provision for its areal expansion; it has been replaced by a protective layer of periderm, the origin and functions of which are subsequently described on next paragraph.

Ⅴ. Bark structure

Even the layman is conversant with the fact that the trunk of a mature tree is composed of core of wood covered by a layer of bark on the outside. The manner in which wood accumulates in the bole through periodic growth of a lateral meristem (cambium) has already been explained. The significance of bark formation in trees now deserves attention.

For a short time, the young stem (twig) is protected from desiccation, and to some extent from mechanical injury, by the epidermis. The outer surface of this is more or less cutinized to prevent undue loss of moisture, and it is generally pierced by stomatal openings, which ensure the proper aeration of deeper lying tissues. But in the great majority of woody plant no provision is made for the areal increase of the epidermis as the twig enlarges in girth through secondary thickening. It soon ruptures (usually during the first year) and is sloughed off promptly in most cases. Were the twig left without an insulating layer on the outside, it would soon dry out and die, but this contingency does not.

Before the epidermis is ruptured, a new protective layer, the first periderm, is formed under it. This serves to protect the stem desiccation after the epidermis is ruptured. It is provided with lenticels (breathing pores) in lieu of stomates.

Structurally, a periderm consists of three layers: (1) the phellogen (cork cambium), (2) the phellem (to the outside) which is composed of layers of cork cells, and (3) the phelloderm (to the inside) composed of one or more layers of thin-walled, nonsuberized cells. The phellogen occupies the medial position, and the other two layers originate from it through cell division. In stems, as a rule, it arises from mature, living parenchymatous cells underlying the epidermis that have remained thin-walled and begin dividing, cutting off cells parallel to the outer surface of the twig. The insulating qualities of the periderm are traceable to the phellem layer, which is heavily suberized to prevent or at least inhibit the passage of moisture and gases.

The first periderm in twigs is more or less cylindrical and in transverse sections is usually annular, underlying the surface. It may arise (1) in the epidermal layer (Ex. Acer pennsylvanicum L.), (2) in the primary cortex, which is the usual condition (Exs., Tilia app., Juglans app., Platanus spp.), or (3) in the pericycle (Exs., Thuja spp., Juniperus spp.). The evidence available points to the fact that, in the first two instances, it is initiated under or near the stomates, the segment thus formed spreading laterally and coalescing to form a layer that is uninterrupted except for the lenticels.

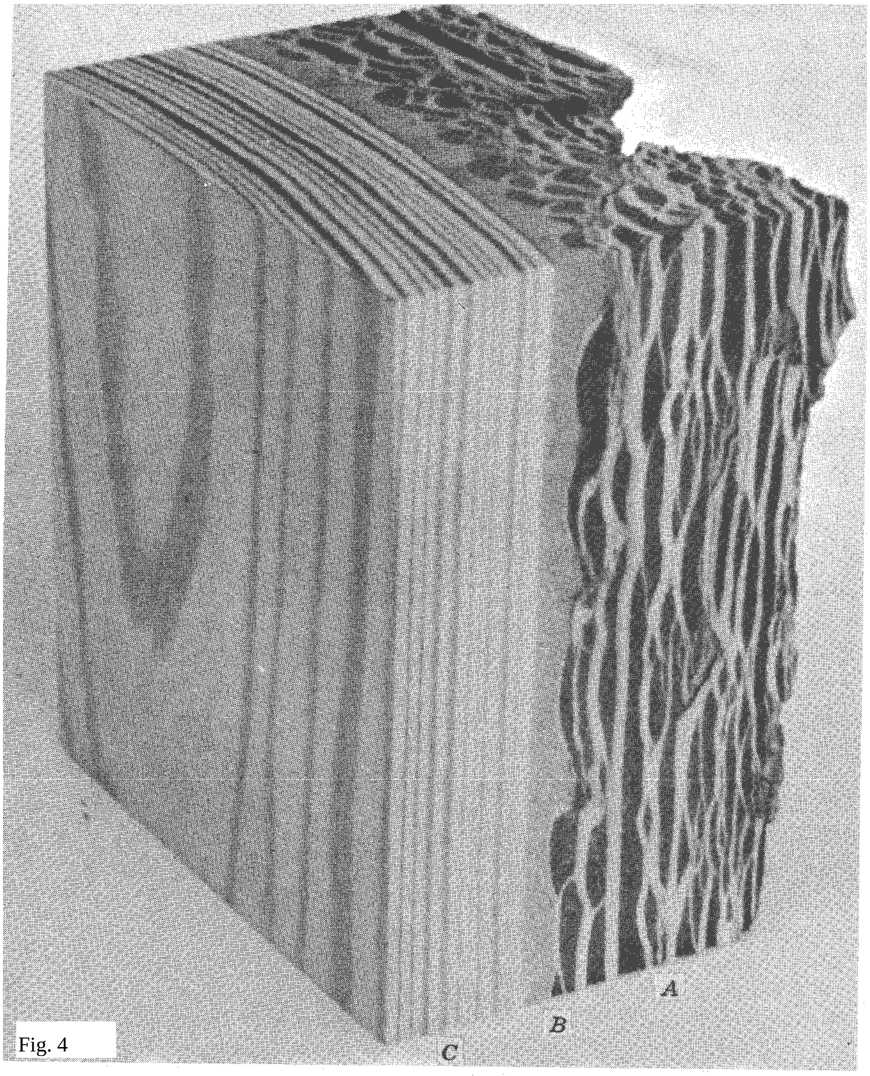

Fig. 4

FIG. 2-19 A block of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco].
A. The outer dead bark.
B. The inner living bark.
C. Wood

Once establish in the tree, the phellogen producing the first periderm may continue to function for many years, i.e., it is perennial like the true cambium, becoming active in the growing months and remaining dormant during the winter. Most of the cell divisions are in the periclinal plane (parallel to the outer surface of the twig), but occasionally anticlinal divisions take place, which permit the phellogen to increase in girth (as seen in transverse sections) and provide for its retention without rupturing near the outer surface of the twig. The tissue (epidermis, cortical cells) to the outside is cut off from the physiological activities of the tree, dies, and eventually sloughs off.

Thereafter, the stem is encased by the primary periderm for some years and remains comparatively smooth. Roughening of the bark indicates the inception of deep cork formation, a feature that will be discussed subsequently.

During this period while the primary periderm is functioning, secondary thickening proceeds from the true cambium in the normal manner; each year, layers of new xylem and of new phloem are inserted between older layers of the same sort, and the stem increases in girth. In this way, the volume of vascular tissue (xylem and phloem) steadily mounts, but it still remains enclosed within the first periderm. The layers of xylem are lignified (woody) and accumulate in the tree, forming a permanent part of the bole. Not so the phloem which is formed year by year outside the cambium; this tissue is pushed farther and farther to the outside, as new phloem forms under it, and eventually is cast off as bark.

The bark on a mature tree is never so thick as the wood, for three reasons:

1.The layer of xylem formed a given year is usually six to eight times as the thick as corresponding layer of phloem; for this reason, wood in a tree stem does not accumulate in direct proportion to the phloem but much faster.

2. Phloem always contains sieve tubes, accompanied by one or more of the following longitudinal elements: companion cells, phloem parenchyma, and bast fiber. Bast fibers possess lignified walls and hence do not crush easily; phloem parenchyma may become lignified on occasion. But the walls of sieve tubes and companion cells are never woody and, in trees, generally function for 1 year only. During this period while the sieve tubes are fluxed with protoplasmic contents, they retain their shape, but, when bast fibers are not present, they usually collapse the second year, owing to bark pressure. In such instances the older phloem tissue is compressed radially and no longer occupies as formerly.

Finally, old phloem tissues, where these have accumulated to such an extent as to be an impediment to further growth, are shed. This process consists in the formation of secondary periderms which, in transverse and radial sections, take the form of short arcs or lunes, that branch off (a) first from the inside of the primary periderm and (b) subsequently from the last-formed secondary periderms, cutting off patches of tissue. If the primary periderm is situated in the outer part of the cortex, which is the usual situation in the stems of timber trees, the remainder of cortex is the first tissue to turn brown, as it is cut off from participation in the vital processes of the tree. New lunes of secondary periderm continue to form ever deeper in the tissues, and sooner or later the older (outer) portions of the phloem are invaded. In the phloem, the new phellogens arise from living phloem parenchyma which, unlike the sieve tubes, has continued to function. The invasion of the phloem by lunes of periderm marks the beginning of deep cork formation in trees; it is at this time that the outer surface of the bark becomes rough.

At this stage, and this holds for mature trees, the bark consists of two parts: an outer, dead (dark) bark which in transverse or radial sections can be seen to consist of islands of dead phloem (and possibly of cortical tissue on the extreme outside) bounded by anastomosing lunes of periderm; an inner, living (light-colored) bark composed of accumulated phloem in which the sieve tubes are no longer functioning except in the layer immediately contiguous to the cambium but in which the phloem parenchyma is still living. The width of these two layers varies greatly in different kinds of trees, in individuals of the same species growing under different conditions, and at different heights in the same tree.