# SOME SOURCES OF VARIATION IN STRUCTURAL CHARACTERISTICS OF DOUGLAS-FIR BARK[1]

*William D. Ross*[2] and *Robert L. Krahmer*
School of Forestry, Oregon State University, Corvallis 97331

ABSTRACT

This study examines variations in structure and formation of Douglas-fir bark. Development of a classification system based on the external appearance of the bark surface that would correlate with anatomical characteristics of the bark was not possible. Modification of bark by fungi was observed to occur in several specific ways, such as attacking cell walls of sclereids, removing contents from lumina of various cell types, and affecting formation of cork layers in regions associated with radial checks and fissures in the bark.

## INTRODUCTION

Transverse sections of bark from Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) show that considerable differences occur in the relative amounts of various bark components. Also, external appearance of the bark surface of Douglas-fir is quite variable. We have undertaken this study to examine sources of variation in structure and formation of bark, and to relate these sources to the appearance of the surface of the outer bark. Observations and measurements were made on the total bark, that is, both inner bark (phloem) and outer bark (rhytidome).

## PREVIOUS WORK

Variations in bark might arise from influences classified into the following general categories:

1. Growth patterns that were inherited.
2. Growth patterns that resulted as living tissue responded to environmental stimuli.
3. Alterations in bark form that resulted as dead tissue was modified by environmental factors.

Differences in bark anatomy among species of trees have been used to explain differences among species in appearance of external bark (Eames and MacDaniels 1925); for example, the outer surface of bark of ponderosa pine (*Pinus ponderosa* Laws.) often breaks up in much the same pattern as drying mud at the bottom of a lake bed. Secondary phloem of this species lacks any type of fibrous cells, and the cork layers cut off discrete flakes of phloem tissue that are not strongly tied together by fibers or sclereids. Bark from redwood (*Sequoia* spp.), however, has large amounts of very long fibers originating from the vascular cambium, and has very thin cork layers. Thus, the effect of fibers is predominant in redwood, and the bark breaks up into long stringy furrows. Because Douglas-fir produces fairly thick cork layers and has many short, fiberlike cells (sclereids) in the secondary phloem, the bark tends to show flaky patches of cork bound together in furrows by the fibrous phloem.

Few studies have been made to correlate variations in bark structure caused by tree growth with differences in the external appearance of the bark surface *within* a species. Hofman and Heger (1959) classified young Douglas-fir trees from 14 different plantations into three bark classes. Classes were based on fissure width and overall roughness of the bark. Their results

[1] This study was supported partly by Federal funds from the McIntire-Stennis Act, with substantial financial support and technical assistance also provided by the Pacific Northwest Forest and Range Experiment Station, Forest Service, U. S. Dept. of Agriculture, Portland, Oregon. Paper 730, Forest Research Laboratory, Forest Products Department, School of Forestry, Oregon State University, Corvallis 97331.

[2] Presently with Division of Plant Science, University of Wyoming.

TABLE 1. *Description of sampling area in Northern California*

| Plot | Elevation | Number of trees | Avg age of plot | Avg site index |
|---|---|---|---|---|
| | *Feet* | | *Years* | |
| 1 | 2,200 | 9 | 217 | 166 |
| 2 | 2,900 | 10 | 153 | 175 |
| 3 | 3,000 | 10 | 81 | 138 |
| 4 | 2,500 | 10 | 210 | 138 |
| 5 | 3,000 | 10 | 330 | 148 |
| 6 | 2,500 | 8 | 216 | 95 |
| 7 | 3,700 | 10 | 244 | 108 |
| 8 | 500 | 10 | 48 | 189 |
| 9 | 1,000 | 10 | 235 | 191 |

indicated that trees with the roughest bark and widest fissures generally grew taller than trees with the smoothest bark. Also, trees with the smoothest bark were more resistant to fungal attack.

Grondal (1942) separated Douglas-fir bark into four classes based on cork grades determined by cork thickness and quality as observed on transverse sections of the bark. From his study, the quantities of bark available in the various cork grades from the forests of Washington were estimated.

Some instances have been noted in which growth patterns of bark have been altered in response to environmental stimuli. Kaufert (1937) noted that aspen growing on good sites in the Lake States usually retained smooth bark regardless of age, but aspen on poor sites often had rough bark. Rough-barked trees formed deep layers of cork in response to fungal attack by *Macrophoma tumefaciens*. These deep layers of cork, which are abnormal for aspen, disrupted radial transport of food materials to the outer surface of the bark and caused death of cells and roughness of the outer bark. When smooth-barked trees were inoculated with this fungus, rough bark developed. Similarly, Bramble (1936) found that deep cork layers in chestnut became lignified and distorted in the path of mycelial fans of the fungus *Endothia parasitica*. Struckmeyer and Riker (1950) described formation of wound periderm in white pine trees resistant to blister rust. Lignified stone cells formed along with suberized cork to separate the invading pathogen from living phloem.

## METHODS

### *Field sampling and photography*

Bark was collected from 87 trees in northern California. These trees were part of a tree and log-grade study of coast-type Douglas-fir, which was being conducted by the Pacific Northwest Forest and Range Experiment Station in Portland, Oregon. The study area contained nine plots of about 20 trees each. Bark was collected from about half the trees on each plot (Table 1).

For purposes of classifying bark into groups based on external bark appearance, photographs were taken of all sample trees. A stereo pair of colored photographs was taken of the northeast side of the standing trees. Photographs were taken of positions along the stems where bark was sampled after trees were felled.

Samples of bark up to one foot square were removed from the northeast side of trees at a height of 4.5 ft (breast height), 16 ft above the stump, and from the top merchantable log. Generally, a sample of bark also was collected from the southwest side of trees at breast height. All samples were placed immediately in plastic bags for storage in a cold room.

### *Bark classification*

All trees sampled for bark could be classified into seven visual classes formulated by us and based on fissure patterns and bark roughness. This classification was made with the photographs of butt logs only, as upper logs were difficult to segregate into particular visual classes. There were from 5 to 20 trees in each of the seven bark classes.

### *Laboratory analysis*

Variations in size, amount, and distribution of cell types in bark were used as criteria for measuring overall variation in structure. Grillos (1956), Grillos and Smith

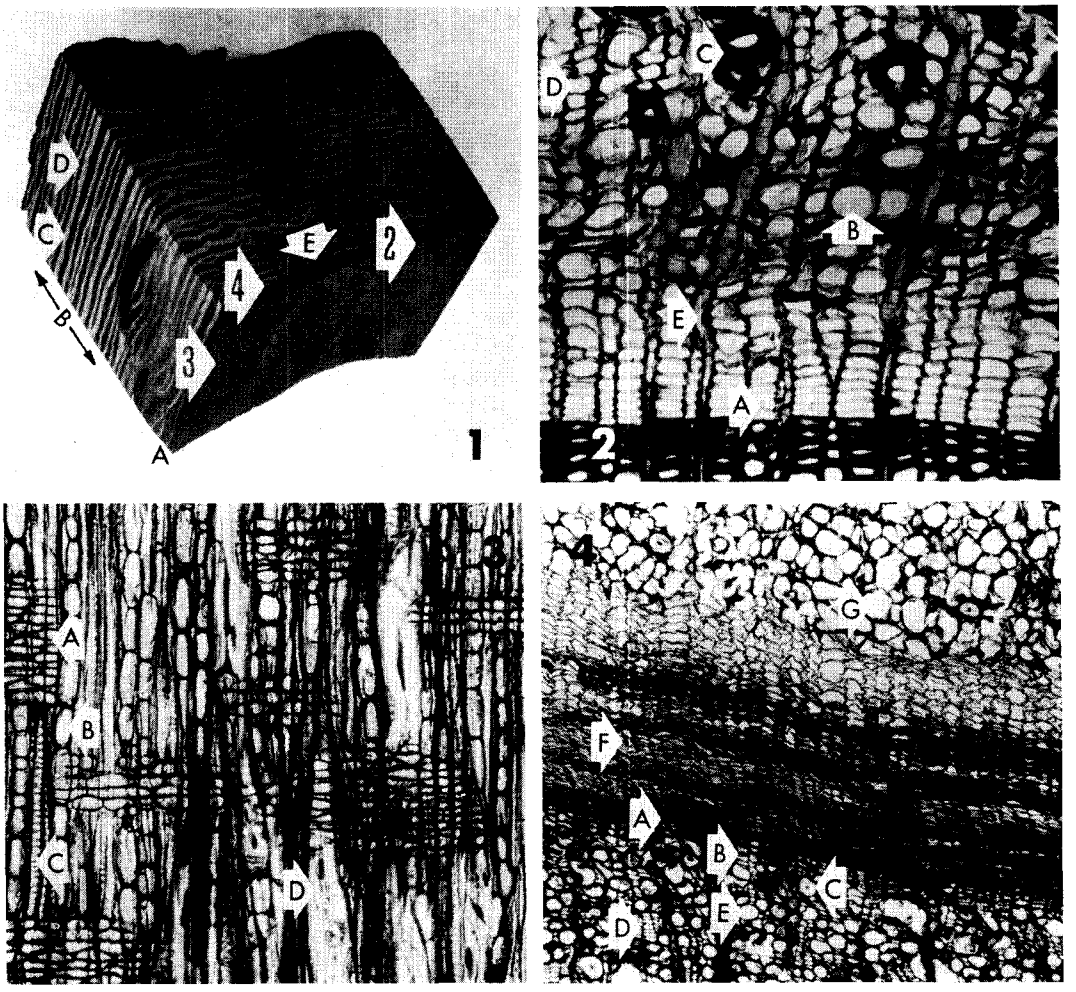


FIG. 1. Structure of Douglas-fir bark: 1. Mature bark; A, inner bark (phloem); B, outer bark (rhytidome); C, cork layers (periderms); D, dead phloem tissue; E, last deep cork layers formed from dividing and differentiating parenchyma cells in the inner bark; positions for micrographs shown by numerals 2, 3, and 4. 2. Transverse section through the vascular cambium including xylem and phloem; A, vascular cambium zone; B, parenchyma cells in tangential bands; C, sclereid; D, sieve cell; E, phloem ray. 3. Radial longitudinal section of inner bark tissue; A, part of phloem ray; B, axial parenchyma strand; C, sieve cell; D, sclereid. 4. Transverse section of bark showing the transition from inner bark at the bottom to outer bark at the top; A, cork cambium zone (phellogen); B, radial row of 4–5 phelloderm cells; C, sclereid; D, sieve cells; E, inner bark parenchyma cell; F, cork cells (phellem) differentiated from cork cambium and showing four growth rings; G, dilated outer bark parenchyma cell—note that outer bark sieve cells have been crushed.

(1959), and Chang (1954) have given detailed descriptions of the anatomy of Douglas-fir bark; Fig. 1, however, has been included here to show the arrangement of cell types that make up its structure. Lengths of sieve cells and sclereids, and diameters and number of sclereids were measured in inner bark. Differences in relative amounts of sclereids, cork, and fines between trees and plots were determined from bark samples that were ground and screened into these three fractions. Information on thickness and formation of cork layers was also obtained, as well as micro-

scopic observations on changes in bark that might have been caused by growth or environmental conditions.

### *Cell length measurements*

Lengths of sieve cells and sclereids were measured from macerated samples of inner bark at breast height, at 16 ft, and from the top log for five trees from each of five plots. Bark was macerated by cooking 25 g (wet weight) in 40 ml of Kraft pulping liquor and 90 ml of water at 340 F for 2 hr in small digesters (250 ml) at 105 lb pressure. A sample of the macerated bark was shaken in about 30 ml of alcohol and spread over the surfaces of microscope slides. Cells were stained with fast green, and 60 sieve cells and 60 sclereids from each sample were measured to the nearest 0.01 mm.

### *Sclereid diameter and number*

The tangential diameter of sclereids was measured on transverse sections from inner bark cut with razor blades. Every second sclereid was measured with a micrometer eyepiece as the sections were traversed in a straight line with a mechanical stage on the microscope. Diameters of 10 sclereids were measured for each bark sample.

A measure of the number of sclereids differentiated in a unit of cross-sectional area of inner bark was obtained by counting all sclereids that appeared in a microscope field of 317 $mm^2$. Sclereids were counted by polarized light because the sclereid cell walls are strongly birefringent and easily distinguished from the surrounding parenchyma cells.

### *Bark fractionation*

About 500 g of whole bark were taken from breast height, at 16 ft, and from top logs of five trees from each plot. This bark was dried overnight at 105 C and then ground in a coffee grinder. Each batch of ground bark was oven-dried, and two samples of 10 g each were removed from each batch for screening. The 10-g samples were screened on a Syntron shaker for 15 min with Tyler Standard screens of sizes 20, 28, 35, 80, 100, 150, and 170 mesh. Bark retained on screens of 20–35 mesh was considered cork and that passing through 170 mesh was considered fines. Bark retained on the 80- and 100-mesh screens was largely sclereids with some cork, and these fractions were suspended in water to separate the cork from the sclereids. Fractions retained on the 150- and 170-mesh screens were largely sclereids and fines, and these were also purified by flotation.

The sclereid fraction and the cork fraction were quite pure. The fine fraction consisted mainly of broken pieces of axial and ray parenchyma cells and sieve cells, although small amounts of finely broken cork and sclereids also were present.

Relative percentages of the amount of cork, sclereids, and fines in each of the 10-g samples were based on the oven-dry weights of each fraction. If more than 8% of the bark was lost during fractionation, the operation was repeated until a minimum of 92% of the 10-g sample was recovered.

### *Patterns of cork (periderm) formation*

Patterns of cork formation were studied on all bark samples taken from the 87 trees. The following measurements were made: average number of cork layers in a centimeter of outer bark thickness; average radial thickness of individual cork layers; average number of growth increments in a cork layer; and average number of cork cells in each growth increment of cork. The reasons for growth increments appearing in the cork tissue have not been established, but some kind of growth periodicity is evident. In cross section, the phellum cells of cork layers are arranged in concentric bands (Fig. 1), much like the growth rings of wood.

Only approximate measurements of cork thickness can be made, because cork cells exist in the outer bark in various states of collapse. If a thin section is made of a cork layer that measures ¼ inch while in the bark tissue, often it may be stretched to ½ inch or more after the section has been cut and placed on a glass slide. As the average

thickness of cork layers was measured on transverse surfaces of blocks of bark, the degree of collapse of cork layers was not considered. A radial line was drawn from the inner bark to the outside surface of each sample at the point of maximum sample thickness, and all cork layers crossing this line were measured. Because many samples showed noticeable differences in thickness of cork between the inner and outer halves of the rhytidome (outer bark), a separate average for cork thickness was calculated for each half of the rhytidome. This was done to determine whether cork thickness varied with increasing age of the trees.

### *Histological examinations*

Histological techniques were applied to study a large number of microscope sections of inner and outer bark. These techniques were necessary both for specific measurements we made and for observations on the effect of fungal attack in the outer bark. Several stains were used, depending on the type of inquiry. Sudan IV was used for suberin and fats, $I_2KI$ and 75% $H_2SO_4$ for cellulose, phloroglucinol in HCL for lignin, and $FeCl_3$ with $NaCO_3$ for a general tannin stain (Johansen 1940). Crystals were observed under polarized light. Razor blade sections of fresh material were used in these histochemical studies.

## RESULTS AND DISCUSSION

Results of observations and measurements of components of inner and outer bark, and information on fractionation of bark into sclereids, fines, and cork are presented below. During the course of this study, certain relations appeared possible between variability in bark structure and other growth or environmental factors, and these are mentioned. These possible relations were not statistically analyzed here because our sampling provided a wide range of bark forms in terms of external appearance, and sample sizes were usually small when trees were stratified by other growth or environmental factors. Factors such as site and elevation were available from the Pacific Northwest Forest and Range Experiment Station.

### *General bark measurements*

Averages for total bark thickness were 3.05 inches at breast height and 0.83 inch at the sampling position in the top log (Table 2). The inner bark had uniform thickness in the tree; it averaged 0.33 inch at breast height and 0.26 inch at the sampling positions at 16 ft and on the top log.

### *Inner bark variation*

Length of sclereids and sieve cells and diameter and number of sclereids were measured in the inner bark.

### *Cell length*

The average length for all sclereids measured was 1.1 mm, but sieve cells were about four times longer than sclereids, averaging 4.6 mm (Table 2). Grillos (1956) indicated that sieve cells were about the same length as the fusiform initials of the wood cambium, and he and Smith (1959) found that the average length of fusiform initials in Douglas-fir was about 0.8 mm in one-year-old trees and 4.5 mm in 200-year-old trees. This same trend in sieve cell length was evident in our study, where the youngest trees had the shortest sieve cells.

Length of sclereids ranged from about 0.5 to 2.0 mm. Inner bark of young trees appeared to have longer sclereids than older trees. As sclereids develop from parenchyma cells some distance into the inner bark from the vascular cambium, their ultimate length depends on the extent of apical intrusive growth of the differentiating sclereid cell. Young, vigorous trees might be expected to produce longer sclereids than older, less vigorous trees, because active synthesis of walls is required for sclereid elongation.

### *Sclereid diameter and concentration*

Diameter of sclereids, which averaged 55.4 $\mu$m, was quite uniform within plots, with the standard deviation about 2.5 $\mu$m

TABLE 2. *Averages and standard deviations for measurements on Douglas-fir bark. The standard deviation is in parentheses following the average value*

| | Height in tree | | | | | |
|---|---|---|---|---|---|---|
| | 4.5 ft | | 16 ft | | Top | |
| *Bark thickness* | | | | | | |
| Total thickness of bark samples (inches) | 3.05 | (1.54) | 1.72 | (0.89) | 0.83 | (0.42) |
| Inner bark thickness of bark samples (inches) | 0.33 | (0.10) | 0.27 | (0.07) | 0.26 | (0.08) |
| *Length of sclereids and sieve cells* | | | | | | |
| Sclereid length (mm) | 1.11 | (0.19) | 1.11 | (0.20) | 1.05 | (0.15) |
| Sieve cell length (mm) | 4.34 | (0.52) | 4.93 | (0.47) | 4.66 | (0.53) |
| *Diameter and number of sclereids* | | | | | | |
| Sclereid diameter ($\mu$m) | 55.4 | (6.5) | 56.4 | (6.7) | 54.3 | (6.8) |
| Number of sclereids/cm$^2$ | 459 | (134) | 489 | (128) | 432 | (156) |
| *Cork measurements* | | | | | | |
| Thickness of cork layers (mm) | 1.82 | (1.33) | 0.68 | (0.47) | 0.34 | (0.17) |
| Cork layers/cm outer bark | 2.92 | (0.74) | 3.46 | (0.71) | 3.45 | (0.81) |
| Growth increments in one cork layer | 7.0 | (3.1) | 5.4 | (2.4) | 3.3 | (1.5) |
| Cork cells in one growth increment | 15.8 | (4.0) | 12.4 | (2.9) | 10.6 | (2.5) |
| *Percentage of cork, sclereids and fines* | | | | | | |
| Cork (%) | 44.8 | (9.1) | 34.9 | (8.6) | 26.9 | (7.1) |
| Sclereids (%) | 20.3 | (7.4) | 31.8 | (7.9) | 35.6 | (7.6) |
| Fines (%) | 33.8 | (6.2) | 32.3 | (5.1) | 37.5 | (6.5) |

(Table 2). There was little difference in average diameter of sclereids between positions within individual trees. Sclereids are not uniform in diameter along their length, but are pointed at the ends (Fig. 2). Average diameters given in Table 2 are smaller than would be the average maximum diameter of sclereids, because our measurements were made on transverse surfaces of bark and most measurements would not occur at the position of maximum diameter of the sclereid.

The average number of sclereids in a cross-sectional area of one square centimeter of inner bark was quite variable within sample plots as well as between plots. Our data indicated that trees less than 100 years old and over 350 years old had fewer sclereids in the inner bark than trees between these ages. Also, trees from dry sites generally had the greatest number of sclereids.

### *Periderm (cork) measurements*

Cork layers ranged in thickness from about 2.0 cm to less than 1.0 mm at root collars of trees. In old-growth trees, the cork layers were often thick at the root collar but the layers usually were considerably thinner at breast height and averaged about 1.8 mm (Table 2). Above 16 ft in the tree, most of the cork layers were less than 1.0 mm thick. There was a trend toward higher numbers of cork layers as site quality decreased, but thickness of cork layers also decreased. Cork layers showed the greatest variation in thickness at breast height (Table 2). They were more uniform in thickness at 16 ft and in top logs. Cork layers usually were thinner in the outer portions of bark, although in some samples of young bark at breast height or older bark at 16 ft, the outer cork layers were thicker. Where this occurred, the outer layers contained no more cork cells in a growth increment, or more growth increments in a cork layer, than the narrower layers deeper in the outer bark tissue. Perhaps these particular surface cork layers were under less compression from surrounding tissue and were able to expand more.

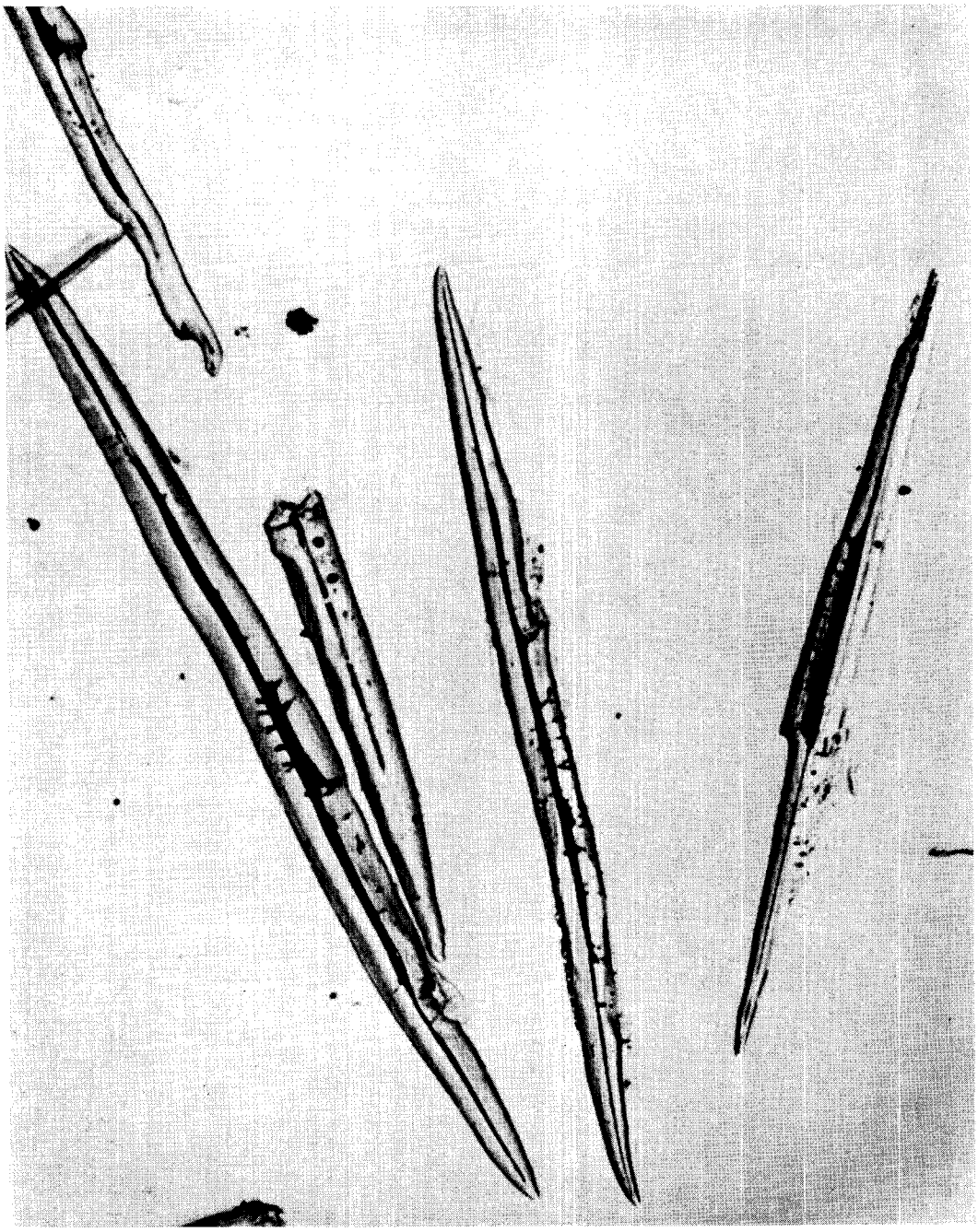

FIG. 2. Sclereids from the bark of Douglas-fir. They are thick-walled fibers with narrow lumens and pointed ends. Magnification: 150×.

The number of cells counted across individual growth increments in cork layers ranged from over 40 to less than five (Table 2). A few samples showed large variations, but differences in number of cells in a growth increment were usually small between the oldest and youngest cork layers within a single sample. Number of cork

cells produced in each increment appeared higher for trees on good sites than on poor sites.

The number of growth increments in individual cork layers decreased as samples were taken higher along the stem. The number of growth increments of cork often is far less than the age of the tree stem at any particular height in the tree.

### *Fractionation of whole bark*

Relative percentages of sclereids, fines, and cork were studied as a measure of gross anatomical variation in bark (Table 2). Cork content varied greatly within and between trees on sample plots, and a statistical analysis indicated that there was no significant difference at the 1% level of probability in cork content between sample plots. Percentage of fines varied the least of the tree fractions. Sclereid content, however, was significantly different at the 1% level among sample plots for samples at breast height and 16 ft.

Sclereid content was lowest in trees on good sites, which was the same result obtained from data on the number of sclereids counted in a square centimeter of transverse surface of inner bark. Because variation in content of fines was small, the content of cork was generally higher on good sites, particularly in samples taken at breast height.

### *Bark classification*

There are at least three major considerations that might justify development of a procedure for bark classification. Forest managers possibly could predict potential for tree growth on the basis of external bark form. Manufacturers could accurately estimate wood quality on the basis of bark form, and they could determine bark quality for conversion to bark products.

Two attempts were made to correlate bark form with factors such as site, age, growth rate, elevation, geographic location, crown position, crown length, and the bark measurements. First, the seven visual classes, in which photographs of external bark surfaces had been separated on the basis of fissure patterns and bark roughness, were examined for match with these factors. Unfortunately, large variations in measurements on bark structure and tree descriptions often were found in the same visual class. We decided that these seven classes served no meaningful purpose. Second, photographs were placed into groups according to individual factors such as site, age, average number of sclereids in a square centimeter of inner bark, and other measured factors. Uniform appearance classes then were sought. The only trees that segregated into a group with fairly uniform appearance were the youngest trees, which generally showed the lowest number of sclereids in the inner bark and the greatest diameter growth of the tree.

Hofman and Heger (1959) correlated bark form of young Douglas-fir with height and diameter growth, so their findings were compared with those obtained in this study. Their three bark classes were based mainly on fissure width, and they concluded that trees with the widest fissures and roughest bark grew taller and larger in diameter than smooth-barked trees. We used site index to compare rates of height growth between bark classes, because site index is the estimated height of a tree corrected to 100 years of age. When we examined extremes in bark appearance, young trees of site class I and II generally had wide fissures, and those in site class IV had narrow fissures. However, there was a considerable range of bark forms even within classes I and IV, and fissure width and roughness were not sufficient criteria by themselves. When older trees were considered, fissure width and roughness were completely unreliable criteria for determining site index of individual trees.

Even though we found variations in structural components of Douglas-fir bark, these could not be correlated with the external configuration of the bark. In young trees, cortical tissue is responsible for surface configuration and masks patterns of cork and phloem beneath. On older trees, we ob-

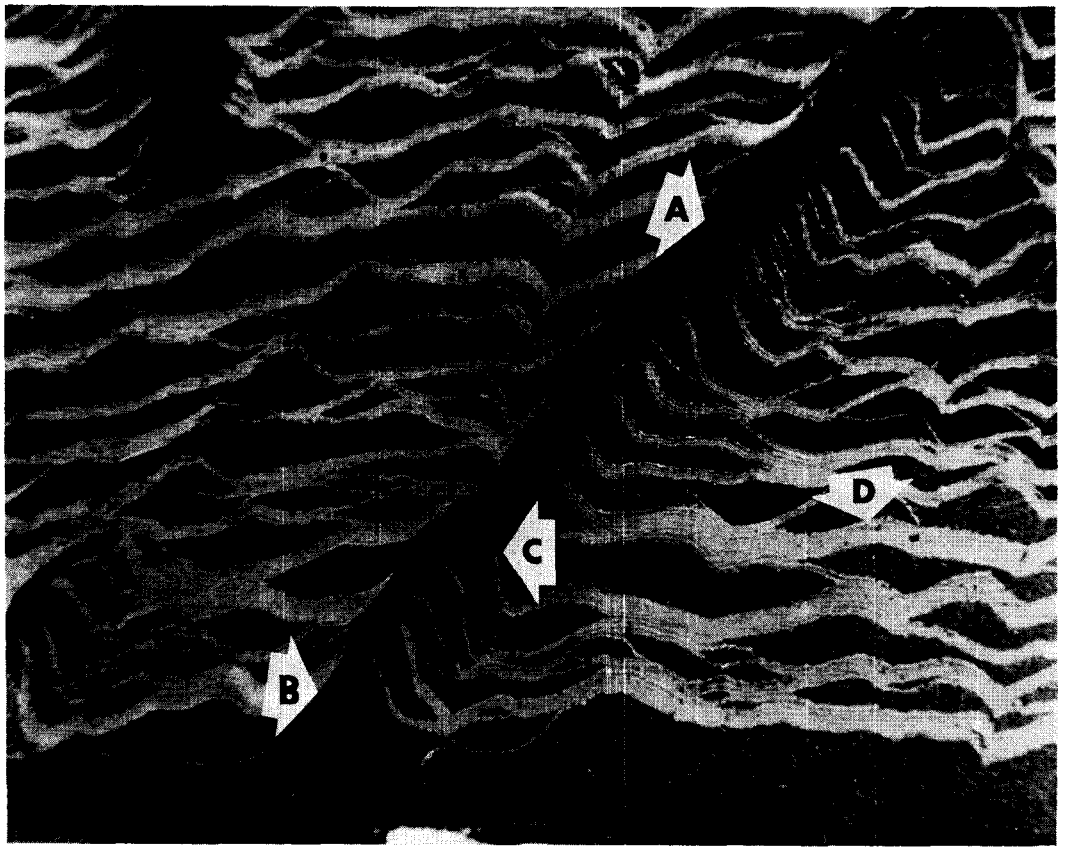


FIG. 3. Transverse section of 350-year-old bark showing a large number of cork layers per inch of bark thickness. A radial crack (A) having fungal attack at the innerbark-outerbark boundary (B) is lined on the lower side with distorted cork layers (C); but farther from the crack the cork layers are thicker and fairly regular (D).

served considerable alteration of outer bark by environmental factors. Probably no one factor is dominant in determining external bark form, and in fact, it is the interaction of many separate factors that makes the explanation of bark form difficult.

### *Histological and other observations*

A factor that we observed as contributing to the variation in structural characteristics of Douglas-fir bark was the apparent effect of fungi on the formation of cork layers and fissures in bark, and the specific degradation of bark components by fungi. When periderms (cork layers) are formed in regions of bark that lack deep cracks or fissures, the layers are generally straight and form regularly repeating concentric bands, as seen in transverse section (Fig. 3). Regions of bark lacking radially oriented checks or fissures usually are small, however, and rarely would they extend more than a few inches around the circumference of any tree. Cork layers formed in bark between these checks also are fairly straight and unmodified, but they become greatly distorted adjacent to the under (inner) side of each check (C of Fig. 3). In Fig. 3, the deepest checks have extended radially across more than 25 cork layers, and every layer is distorted. The thicker, unmodified cork layers between the checks appear to become divided into several thin, distorted layers adjacent to the checks. Because there is phloem tissue be-

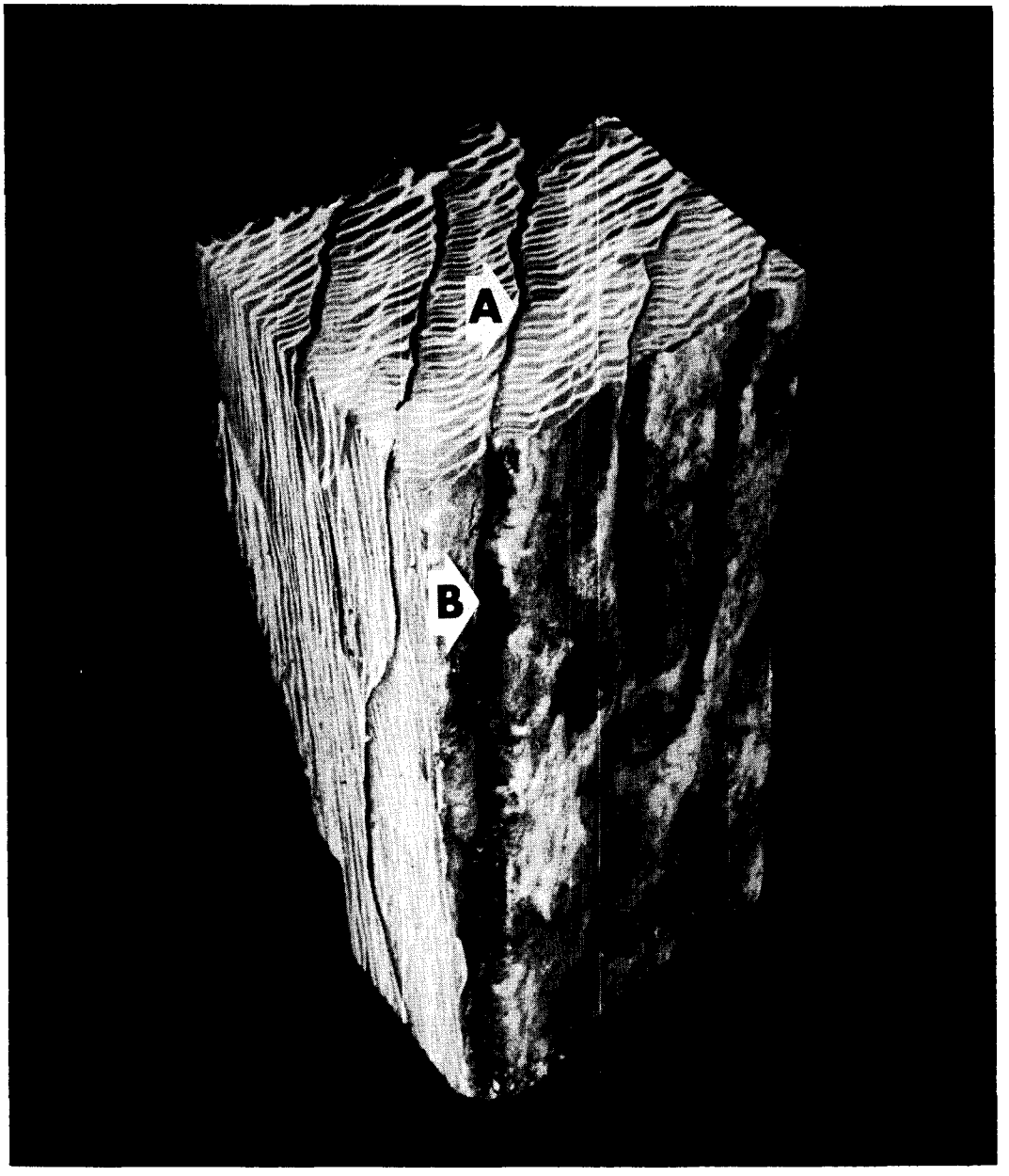


FIG. 4. Douglas-fir bark having checks (A) extending to the innerbark-outerbark boundary (B) where there are pockets of fungal mycelium that have penetrated the last-formed cork layer.

tween each of the thin, distorted cork layers, new cork cambia had to be formed frequently in the living phloem of this zone to produce the pattern of cork layers we observed.

Portions of outer bark were separated from inner bark along the last-formed cork layer, and black patches of fungal mycelium of *Bispora betulina* were present in pockets at this interface and in line with the radial checks and fissures (Fig. 4). These "fungal checks" were lined with thick-walled, ligni-

fied cells, and phenolic accumulations usually appeared in tissues adjacent to the checks. Starch, which is often prevalent in the rays and the concentric rows of axial parenchyma of the inner bark, was absent from such cells after the innermost cork layer was penetrated by the hyphae and a fungus had entered the inner bark. An apparent response to this penetration is expansion of parenchyma cells deeper within the inner bark, followed by formation of a new cork cambium, which produces cork cells to seal off further penetration of the fungus into the inner bark. The newly formed cork cambia appear to produce only one or two growth increments of cork cells, possibly until they are penetrated by the advancing hyphae.

Radial "fungal checks" in bark usually extend about 2–10 inches along the longitudinal axis of the tree stem (Fig. 4). Transverse surfaces of bark at the ends of logs show many checks that have remained closed and appear only as lines. These checks were numerous in all bark samples studied, and when considered collectively, they undoubtedly provide many radially oriented planes of weakness along the length of the stem. Because many bark furrows have distorted cork layers at their margins similar to those lining the radial checks, these major furrows probably resulted from growth stresses that caused the bark to break open along these "fungal checks," which serve as longitudinal lines of weakness.

Sclereids often were missing or decayed in the outer bark of many samples taken at breast height. Under polarized light, some decayed sclereids appeared to consist only of loosely oriented strands of white cellulose, which gave the sclereids a white or "bleached" appearance.

In some samples many intact white sclereids occurred throughout the bark, but in other samples the sclereids were completely removed. Fungal hyphae also were prevalent in parenchyma cells adjacent to bleached sclereids as well as within the sclereid walls. Upper logs generally showed little sclereid decay. When fractionation data for sclereid content of bark at breast height were analyzed, however, sclereid content was sometimes low for some trees. Microscopic examination usually showed large amounts of sclereid decay in these trees (Ross 1970).

A second "bleaching" effect possibly caused by fungi was observed in parenchyma cells in the outer bark of some trees from 50 to 100 years old. These parenchyma cells normally appear reddish-brown because of condensed tannins on their walls and in their lumina; however, parenchyma tissue was found that appeared white as though the condensed tannins had been removed. Fungal hyphae, which was present in this tissue, also penetrated through the walls of adjacent sclereids and appeared to remove the dark phenolic contents from these lumina (Ross 1970).

Further decay of bark was evident from an apparent brown-rot fungus that caused heavy damage to outer bark. High moisture, as determined by general observations of dampness of the bark, favored this fungal activity, which caused a flaky appearance of bark on old-growth trees. This flakiness occurred completely around butt logs or only in patches on the dampest sides of these trees.

Boring insects also caused heavy damage to outer bark in all parts of trees. Such insects were particularly damaging to cork layers near the base of trees, but insect galleries also were found in phloem tissue in the outer bark. Few insect galleries were found in the inner bark, but when they occurred, sclereids frequently formed in response to injury. Insect damage was lightest on dry sites. Many bark samples showed a darkening of outer phloem and cork tissue adjacent to insect galleries. This darkening was usually accompanied by fungal mycelium spreading out from the insect galleries where fungi had become established.

## SUMMARY AND CONCLUSIONS

Development of a system for classifying Douglas-fir bark into groups based on ex-

ternal appearance that would correlate with anatomical characteristics of bark, such as content of cork, sclereids and fines, and fiber dimensions, was not accomplished. Only in a few trees did a high content of sclereids appear to be responsible for a fibrous texture of the outer bark. Generally, cortical tissue masked patterns of cork and phloem configuration in young trees, but in older trees environmental effects, which included fungi and insects, affected external appearance of bark.

For our sample, appearance of external bark could not be related to tree-growth factors, such as site class, for equal-age trees. This study was not designed specifically to study this kind of relation, however, and sample size for these relations generally was not adequate.

In addition to general decay, fungi were found to attack bark in several rather specific ways. In one instance, fungal hyphae were present in tissue from which colored materials had been removed from the cell walls of sclereids in outer bark, leaving bleached or white sclereids. Another fungal attack appeared to remove only the colored deposits in the lumina of parenchyma cells and sclereids. Also, repeated penetration of a fungus through cork into the inner bark caused new and distorted layers of cork to be formed. These distorted layers of cork were along radial checks, many of which ultimately opened to become fissures observed on the external surface of the bark.

Research on utilization of Douglas-fir bark through product development needs to consider the effect of variation and modification of bark structure on properties of bark products. Although we were unable to use external appearance of bark to obtain information on anatomical characteristics of the bark or growth factors of the tree, there were some sources of bark variation that possibly could be used to place bark into quality classes. For example, cork and sclereid quality could be controlled considerably by sorting bark according to position in the tree and degree of decay. Perhaps the value of the information obtained in this study is that it describes several sources of bark variation that might affect quality of bark products.

## REFERENCES


BRAMBLE, W. C. 1936. Reaction of chestnut bark to invasion by *Endothia parasitica*. Am. J. Botany, **23**:89–94.

CHANG, Y. 1954. Bark structure on North American conifers. U.S. Dep. Agr. Tech. Bull. 1095, 86 p.

EAMES, A. J., AND L. H. MACDANIELS. 1925. An introduction to plant anatomy. McGraw-Hill, New York. 364 p.

GRILLOS, S. T. 1956. Structure and development of the bark of Douglas-fir, *Pseudotsuga menziesii*. (Mirb.) Franco. Ph.D. thesis, Oregon State Univ., Corvallis. 67 p.

GRILLOS, S. T., AND F. H. SMITH. 1959. The secondary phloem of Douglas-fir. Forest Sci., **5**:377–388.

GRONDAL, B. L. 1942. Douglas-fir cork. West Coast Lumb., **69**:20–24.

HOFMAN, J., AND B. HEGER. 1959. Vzrustavast hladkokorych a hrubokorych typu douglasky (Concerning the growth rate of smooth and rough bark of Douglas-fir). Preslia, **31**:287–303 (German summary).

JOHANSEN, D. A. 1940. Plant microtechnique. McGraw-Hill, Inc. 523 p.

KAUFERT, F. H. 1937. Factors influencing the formation of periderm in aspen. Am. J. Botany, **24**:24–30.

ROSS, W. D. 1970. Degradation of phenolic components of Douglas-fir bark by fungi. Ph.D. thesis, Oregon State Univ., Corvallis. 84 p.

STRUCKMEYER, B. E., AND A. J. RIKER. 1950. Wound-periderm formation in white pine trees resistant to blister rust. Phytopathology, **41**: 276–281.