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INTERNAL DISCOLORATION OF SWEETGUM¹

Terry C. Davis and Harold O. Beals²

INTRODUCTION

SWEETGUM is an important native hardwood on a wide variety of sites in the United States and offers considerable potential for tree improvement programs. It is usually an abundant and common component of forests on alluvial and moist upland soils in Alabama. Sweetgum exhibits adequate self-pruning when grown in tight stands and subsequently forms merchantable boles free from limbs; therefore, a high percentage of knot-free lumber is produced.

Three types of wood from sweetgum are recognized (2). The pale sapwood is called sapgum; uniformly reddish heartwood is called redgum; and variegated or streaked heartwood is called figured redgum. Various natural ranges and gradations of color among these wood types occur (3). Figured redgum and some other colorations not mentioned above result from microorganism or chemical action and are designated usually as stains, discolorations, or pathological heartwood (1, 5, 6, 15, 16, 18). There is sufficient evidence to suggest strongly that a considerable amount of these discolorations is a result of fungi that enter sweetgum trees through wounds.

A large number of hymenomycetes causes discolorations within living sweetgums (1, 6, 18). These discolorations are considered to be of less importance than discolorations initiated upon and within logs and lumber (6). Discolorations within living trees not caused by hymenomycetes have been ascribed to the ascomycete *Lasiochaeria pezizula* (a gray discoloration) and the yeast-like *Torula ligniperda* (a pink to red discoloration). Economically important blue discolorations causing degrade of sapwood in logs and lumber are caused mostly by several *Ceratocystis* species and to a lesser extent by three other genera of fungi (6). Occasional mineral stains occur in sweetgum wood, but specific examples are lacking (15).

Initiation and patterns of discoloration within sweetgum resemble what has been observed in northern hardwoods (16). Discoloration ap-

¹Research supported by McIntire-Stennis Research Funds as Project No. 916.

²Assistant Professor of Forestry and Forest Pathology and Associate Professor of Wood Technology, respectively.

parently is a result of wounding (either natural or artificial) at some stage of development. Small circular or irregular columns of discolored wood in sweetgum are associated with branch stubs and various types of injury ranging from beetle borings to fire scars; large, more regular columns of discoloration in trees found in North Carolina (and probably elsewhere) are associated with broken limbs or tops, mostly caused by ice damage (17). Such discoloration also may be initiated from wounds made by increment borings to investigate growth (19) or by cuttings to stimulate gum flow in storax production (4). Discolorations are sometimes associated with gum-infiltrated protection zones (7), sweetgum blight (9), or bleeding necroses (14).

Several studies of sweetgum in the southeast have been conducted to provide knowledge necessary for anticipated widespread planting of this species (10, 11, 12, 13). Preliminary tree improvement studies concerning various wood characteristics of sweetgum in Alabama have been completed. Colored heartwood is highly variable within sweetgum in Alabama; no color was detected in 10 percent of the trees from a genetic study involving trees 36 years of age or older (8). Trees with no colored wood are highly desirable as a seed or scion source if the condition is a trait that can be genetically perpetrated. Geneticists require evidence that such non-discoloration is genetically controlled and not merely a random escape from wounding. Since bark is the primary natural barrier to protect trees from wounding, and since wounding apparently initiates a considerable amount of discoloration, information concerning the relationship between bark thickness and internal discoloration could lead to selection of trees with thicker bark. Tree breeders also need information of correlations between amount of discolored wood and other morphological and growth characteristics. Among these, perhaps the most important are tree age and growth rate.

The specific objective of this study was to determine whether a relationship exists between internal discoloration of sweetgum and variations in tree age, growth rate, and bark thickness.

MATERIALS AND METHODS

Approximately 4,000 sweetgum trees and/or logs were examined at various mills (particularly at LaFayette, Goodwater, and Montgomery) and cutting sites in east central Alabama. Basal cross-sections (transverse sections from the flanged end of butt logs) were selected from 240 of these logs. These basal cross-sections were smoothed with a hand-held planer, designated by a letter/number procedure, and photographed. On cross-sections with little contrast for discoloration to show on photographs, areas of discoloration were outlined with a ball-

point pen. Percentage of discoloration was determined by the dot-grid method (16 dots/in.²). After the discoloration percentage was determined for each section, the largest radius was found by swinging a rule 360° around the center of the pith. The radius was then extended to the corresponding diameter, which was measured with a millimeter rule. Another diameter then was struck at right angles and measured. Thickness of inner and outer bark was measured at the four ends of these diameters. Growth rings were counted along the four radii; the average was taken as the approximate tree age at the height of the cross-section. In a few cases, there were necessary modifications in determining number of growth rings (knots, false rings, discoloration prohibitive, extreme figure, *etc.*) and bark thickness (missing or damaged bark, *etc.*). All modifications were made according to a pre-determined plan. On some sections, a 10 percent solution of ferric chloride was used to darken the rings and aid counting.

Approximately 250 logs were cross-cut into veneer bolts 4 feet in length. Blocks were rotary cut and the resulting veneer was clipped into widths prepared for wire-bound crates. Before peeling, percentages of cross-sectional discoloration areas were determined by the dot-grid method at one end of each veneer bolt from 20 logs. During peeling, clipped sections were gathered from the veneer chain to be examined for indications concerning origin of discoloration. Sections were gathered in sequence from the first section to exhibit discoloration until peeling ceased at a core diameter of 4-5 inches. Veneer cores then were cut into eight 6-inch sections to be split and examined for indications concerning origin of discoloration.

Sections of veneer and cores were examined carefully for evidence indicating origin of discoloration. Five general groups were recognized:

- (1) Limb stubs — indicated by discolored tight knots extending outward beyond the main, central stain column;
- (2) Birdpeck — indicated by small circular areas on veneer (cone-shaped when cut transversely or radially) often occurring in groups aligned circumferentially on the veneer bolt, where callus tissues had overgrown deeply-pecked cavities;
- (3) Fire wounds — indicated by tinted “catface” areas, some showing evidence of char and/or gum-filled protection zones;
- (4) Insect wounds — indicated by insect tunnels associated with small fusiform stain columns at various depths and heights; and
- (5) Other wounds — indicated by remains of overgrown canker faces and bands of discoloration.

Only 132 of the 240 cross-sections collected yielded complete and reliable data. Since statistical consultation suggested an analysis of cor-

relations of various measurements, the Barr-Goodnight (N. C. State) Statistical Analysis System was chosen for analysis. All raw data were transferred to computer punch cards for this analysis.

RESULTS AND DISCUSSION

A summary of averages and ranges of measurements and calculations from basal cross-sections from 132 sweetgums is presented in Table 1. Seven cross-sections selected to illustrate the extreme variation in internal discoloration of sweetgum are presented in figures 1 through 7.

A compilation of the statistical analysis is given in Table 2. The null hypotheses of correlations between percent internal discoloration of sweetgum and variations in tree age, growth rate, and average bark thickness appear to be most plausible. Table 2 also contains correlation notations among the above four factors and the following nine additional factors: (1) Average Outerbark Thickness; (2) Average Innerbark Thickness; (3) Wide Diameter; (4) Narrow Diameter; (5) Average Diameter; (6) Minimum Outerbark Thickness; (7) Maximum Outerbark Thickness; (8) Minimum Innerbark Thickness; and (9) Maximum Innerbark Thickness.

Quantity of discoloration within sweetgum apparently is extremely variable, although 59 percent of the 132 sections in this study exhibited less than 10 percent discoloration. Fifteen percent of the samples showed no discoloration, as shown in Figure 1. Slight discoloration is shown in figures 2, 3, and 4. The origin of discoloration in most logs that exhibited only minor central discoloration columns was attributed almost entirely to limb stubs (Figure 3); most partial-ring types could be attributed to birdpeck (Figure 2); and slight amounts originated from insect wounds (Figure 4). Only two sections exhibited discoloration that had entered through fire wounds. Discoloration in any section that exhibited considerable stain (figures 5 and 6) probably resulted from a progression of different causes.

Central stain columns occupied approximately the same percentages of cross-sectional areas at both ends of 16-foot logs, as well as at all interval sections. Only slight differences in the percentage of discoloration were detected when entire merchantable stems were cut and measured. Rapid longitudinal movement of stain fungi apparently helps maintain relative uniformity.

It appears that limb stubs are the most important source of initial entrance of stain organisms into living sweetgums in Alabama. All wood in existence at the time of limb death will become susceptible to invasion by these stain fungi over an extended growth period. However, there seems to be only slight outward movement except toward wounds

[7]

Table 1. A summary of ranges and averages of measurements and calculations concerning data from 132 cross-sections of sweetgum.

Measurements or calculations	Quantity of discoloration¹ (%)	Number of rings (approximate age)	Growth (mm/year)	Total bark thickness (mm)	Diameter I.B. (mm)	Outerbark thickness (mm)	Innerbark thickness (mm)
RANGE (Low to High)	0-57	30-93	3.0-13.7	2.1-17.9	171-617	0.8-12.0	0.1-7.2
AVERAGE	11	53	6.6	7.5	345	4.4	3.1

¹Determined by Dot-Grid Method.

Table 2, Statistical Analysis of Various Correlations Concerning Measurements from Transverse Sections of Sweetgum Logs Including Notations of Significance

	Maximum Innerbark	Minimum Innerbark	Maximum Outerbark	Minimum Outerbark	Average Diameter	Narrow Diameter	Wide Diameter	Average Innerbark	Average Outerbark	Average Bark Thickness	Growth Rate	Age in Years
PERCENT STAIN	.13 NS / .12	.08 NS / .39	.23 ** / .008	.15 NS / .07	.21 ** / .012	.20 ** / .018	.22 ** / .01	.12 NS / .17	.21 ** / .016	.21 ** / .01	.06 NS / .49	.13 NS / .12
Age in Years	.26 ** / .0029	.23 ** / .007	.08 NS / .39	.02 NS / .78	.44 ** / .0001	.44 ** / .0001	.43 ** / .0001	.31 ** / .0006	.05 NS / .56	.17 NS / .05	-.53 ** / .0001	
Growth Rate	.05 NS / .57	-.32 NS / .72	-.12 NS / .18	-.14 NS / .10	.49 ** / .0001	.47 ** / .0001	.49 ** / .0001	-.01 NS / .91	-.11 NS / .22	-.09 NS / .32		
Average Bark Thickness	.61 ** / .0001	.64 ** / .0001	.86 ** / .0001	.81 ** / .0001	.03 NS / .73	.04 NS / .65	.02 NS / .82	.68 ** / .0001	.92 ** / .0001			
Average Outerbark	.27 ** / .002	.37 ** / .0001	.92 ** / .0001	.88 ** / .0001	-.11 NS / .19	-.10 NS / .23	-.12 NS / .17	.34 ** / .0002				
Average Innerbark	.95 ** / .0001	.86 ** / .0001	.34 ** / .0002	.30 ** / .0009	.28 ** / .0015	.29 ** / .0012	.27 ** / .0024					
Wide Diameter	.27 ** / .002	.19 * / .03	-.11 NS / .18	-.15 NS / .09	.99 ** / .0001	.95 ** / .0001						
Narrow Diameter	.31 ** / .0007	.19 * / .027	-.09 NS / .30	-.15 NS / .08	.98 ** / .0001							
Average Diameter	.29 ** / .001	.19 * / .027	-.10 NS / .23	-.15 NS / .08								
Minimum Outerbark	.20 ** / .021	.39 ** / .0001	.69 ** / .0001									
Maximum Outerbark	.30 ** / .0008	.34 ** / .0002										
Minimum Innerbark	.70 ** / .0001											

* Significant at the 5% Level

** Significant at the 2% Level

NS Non-significant

/1 Linear Correlation Coefficient/Probability of a larger $|r|$ given $H_0: \rho = 0$

(When the probability is shown as .0001, it may be equal to or less than .0001)

that occur later. Stain organisms within the core of discoloration (when still viable) grow outward to occupy the rings that become physiologically inactive, and the core of discoloration maintains a margin associated with the outermost inactive growth rings of the tree for the entire circumference. Additional wounding by any source at any time could modify this pattern. Birdpeck wounds appear to be important in creating wounds of sweetgum in Alabama that lead to stain col-



Figure 1. Transverse section of sweetgum that exhibited no internal discoloration. Fifteen percent of 132 sections examined were similar to this.

umns which coalesce over a period of time with smaller central stain columns associated with limb stubs. This process leads to large, complex stain columns.

Any wounds outside a central stain column cause stains extending longitudinally to extensive distances both up and down the tree somewhat in proportion to the width of the wounds. The columns darken considerably over a period of several years. Depending upon the dominant organisms invading these wounds, two distinct situations may develop.

When the dominant invading organism is a stain-inducing fungus, the additional stain column that develops may expand inward and merge with the central core of discoloration (which probably was initi-

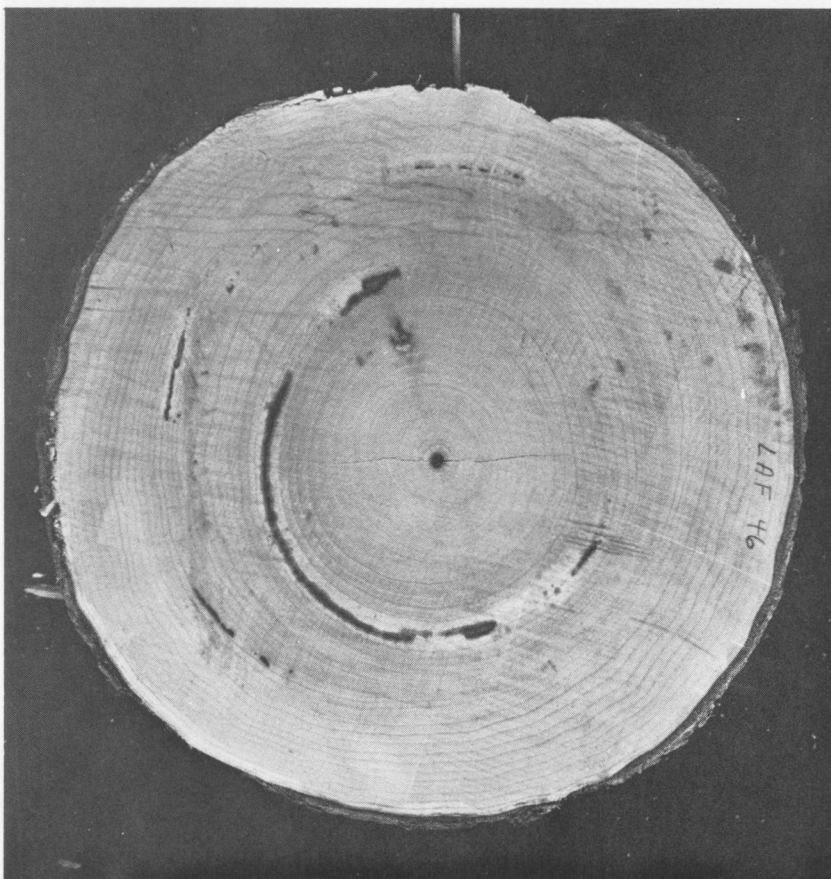


Figure 2. Transverse section of sweetgum that exhibited 1.6% discoloration, shown mostly in a narrow band conforming to a growth ring (a minute core of stain occurs at the pith). This band of discoloration (as well as the flecks and bars in outer rings) was initiated from birdpeck wounds.

ated at a limb stub). Tangential growth of such organisms is extremely slow. This phenomenon results in massive, aggregate stain columns with irregular margins extending in a radial fashion (figures 5, 6, and 7). Small bands of darker colors occur where these stains merge (Figure 7). When the wound is dominated by an organism that is not stain inducing, the wood behind this wound apparently is modified to induce



Figure 3. Transverse section of sweetgum that exhibited 6.2% discoloration. This small, central-column type discoloration is typical of stains initiated at limb stubs.

the fungus occupying the discolored core to grow outward radially to merge with the narrow stained column induced by the wound.

A third situation occurs when no central core of internal discoloration exists. Wound column discoloration may exist only as slight specks (single birdpeck), bars of different widths (wounds of any type), or partial rings (multiple birdpeck or large wounds). The nature of initial stain columns depends entirely upon the wound width. Stain columns induced from beetle tunnels may exhibit various inward depths and different configurations depending upon the depth and nature (mostly meandering aspects) of the tunnels (Figure 4).

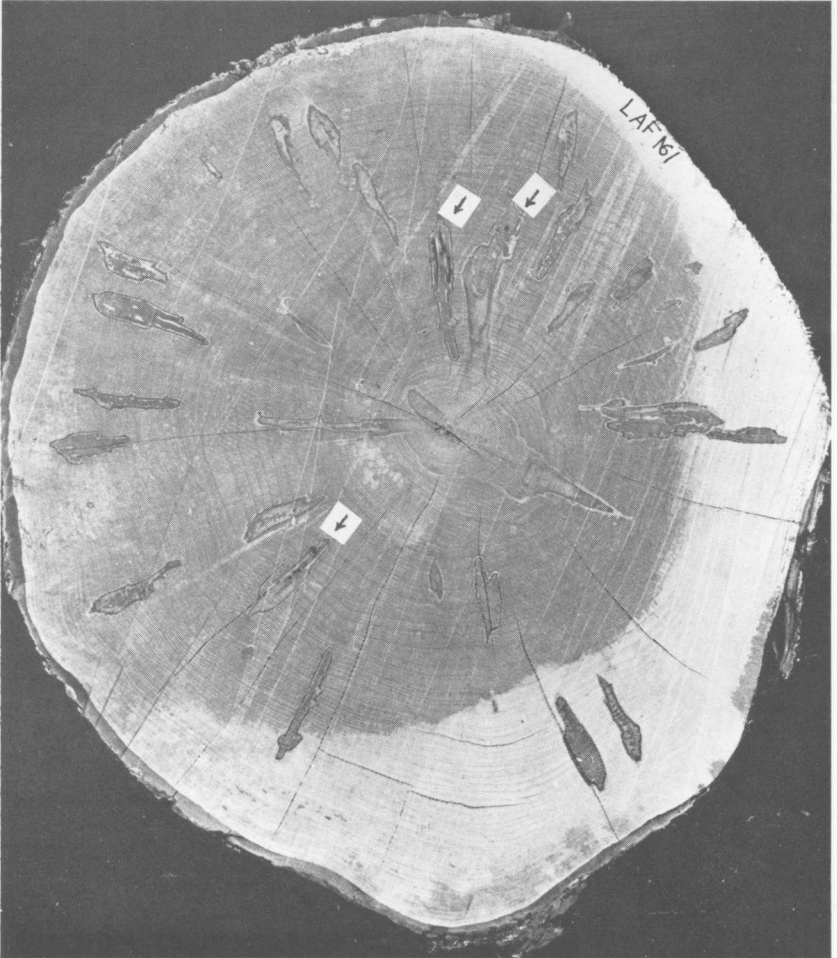


Figure 4. Transverse section of sweetgum that exhibited 8.7% discoloration. This type stain pattern is typical of discoloration induced by insects. Note that tunnels are visible in three areas ("arrows").

Measurements of stain columns originating from beetle bore holes in sweetgum indicate that expansion in a longitudinal direction was very rapid, radial expansion was slow, and tangential expansion was almost non-existent. A rough expansion ratio prepared from 20 stain columns associated with beetle tunnels in sweetgum was 300:12:1 for longitudinal, radial, and tangential growth, respectively. Such a ratio would vary depending upon nature of the tunnel, growth rate and tree age, season of the year, specific fungus or fungi involved, and probably many other factors.

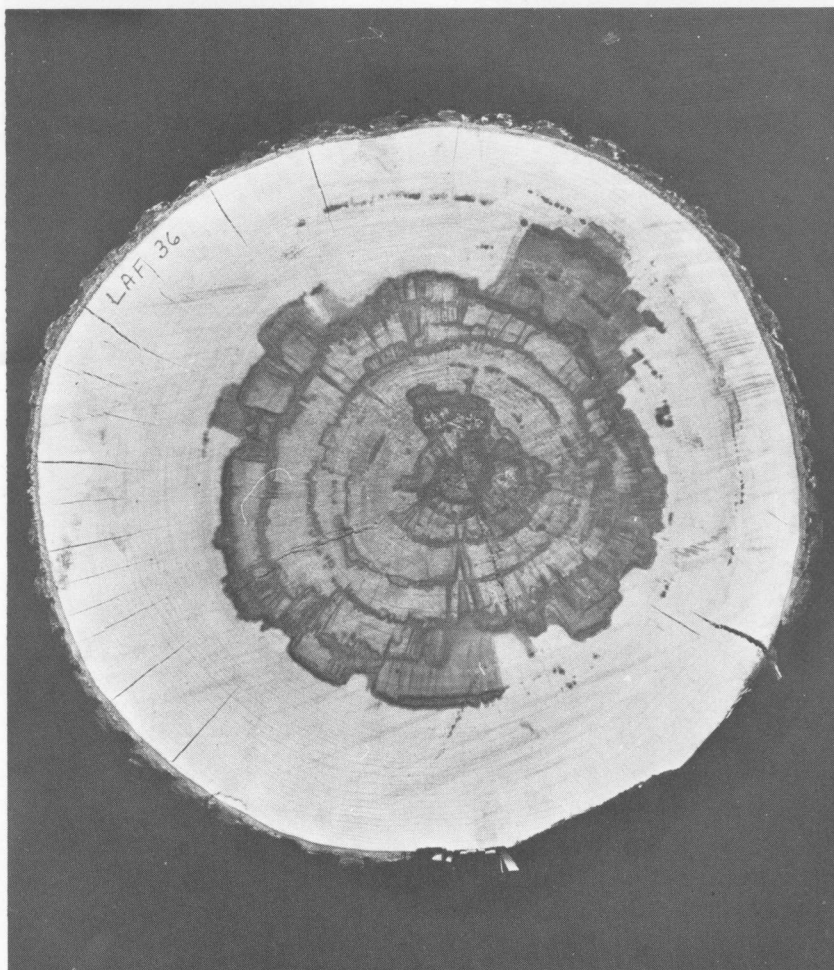


Figure 5. Transverse section of sweetgum that exhibited 38.7% discoloration. This is a complex type core of discoloration that probably originated at a limb stub but has expanded over a long period of time because of multiple wounding (mostly birdpeck).

Since the statistical analysis indicated no meaningful correlations between percent internal discoloration and variations in tree age, growth rate, and average bark thickness, the information gained in this study contains no definite guidelines for use by geneticists to select desirable sweetgums for breeding stock. However, there is sufficient evidence to suggest that trees should be bred for at least three charac-

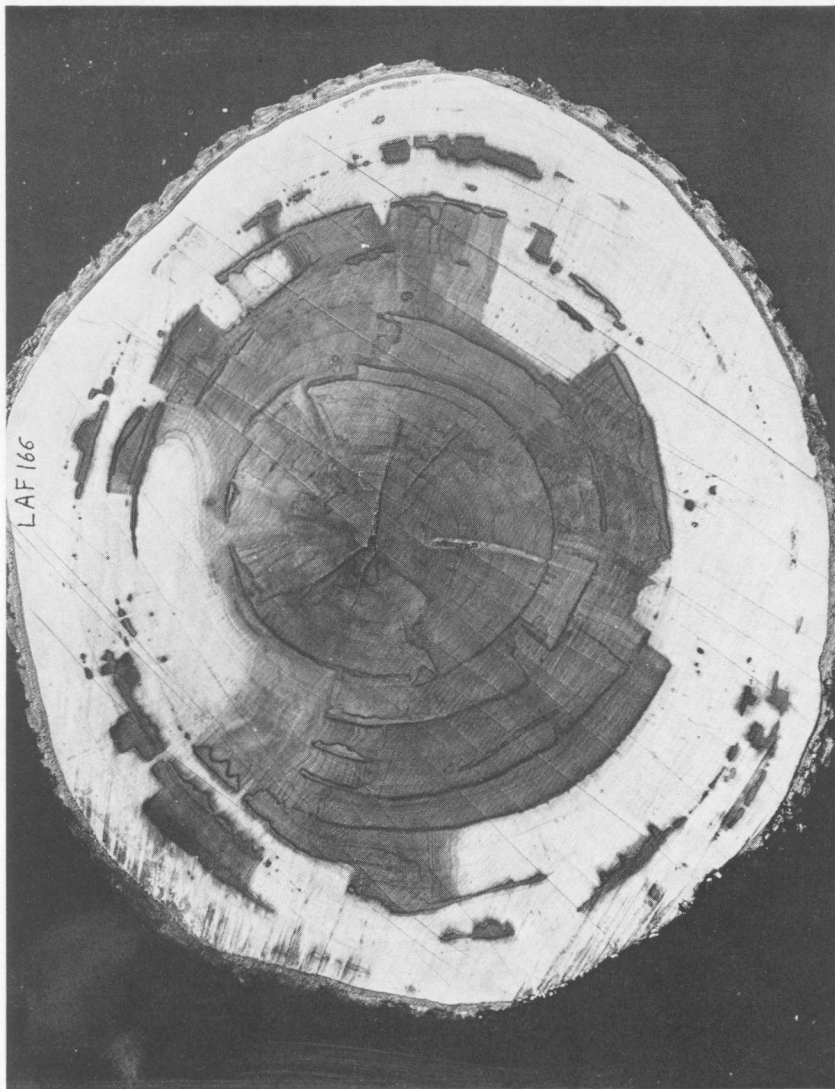


Figure 6. Transverse section of sweetgum that exhibited 45.3% discoloration. This also is a complex type core of discoloration that had multiple causes. Note the numerous lines and bands of darker discoloration.

teristics: (1) rapid height growth, (2) small limbs, and (3) early self-pruning of lower limbs. Although these three characteristics will not prevent internal discoloration, they should create conditions that tend to reduce it. There is nothing to indicate that rapid diameter growth will increase discoloration percentage. Protection of trees from wounding by any source whatever should minimize the amount of internal discoloration.

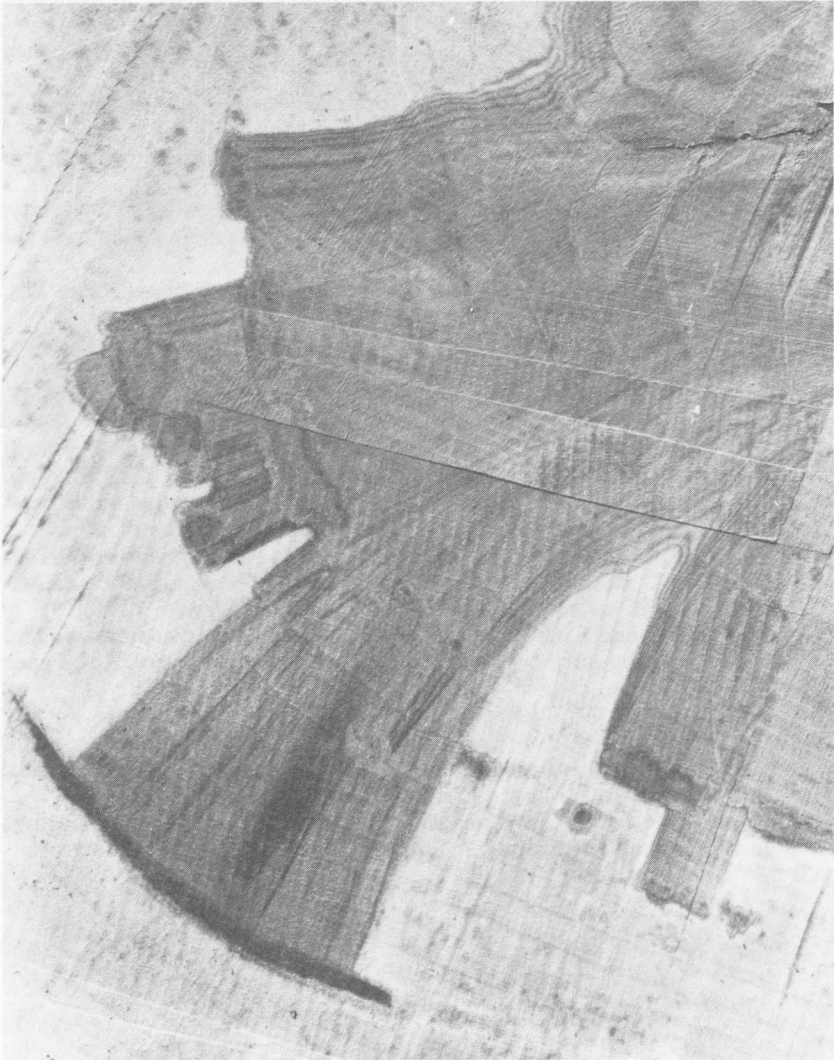


Figure 7. Transverse section of sweetgum showing part of an irregular margin of a stain column. Note different depths of initiation, radially oriented sides, and merging zone bands.

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