# CHEMICAL AND PHYSICAL PROPERTIES OF TUMOR-AFFECTED SITKA SPRUCE[1]

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## ABSTRACT

The chemical composition, fiber properties, and pulpability of a Sitka spruce (*Picea sitchensis*) massive trunk and root tumor were compared with normal second-growth wood. In general appearance the tumored tissue looked like normal wood in that it had annual rings and definite sapwood and heartwood zones. However, the trunk tumor showed no visible evidence of compression wood, whereas the trunk of the affected tree above and below the tumor contained about 30% compression wood. The tumor tracheids were short, curved, and twisted; and numerous traumatic resin canals were present. The wood rays and bark showed no apparent abnormalities. Paper prepared from kraft pulp tumor wood was lower in burst, tear, tensile, and opacity, and higher in fold and shrinkage, density and air resistance compared to pulp from the second-growth control. Chemical analysis indicated that the tumor-affected tree had a higher hemicellulose content, primarily as galactan-containing polymers, than the second-growth control. The factor causing the tumor growth was not ascertained in this study.

*Additional keywords:* *Picea sitchensis*, tumors, chemical analysis, physical analysis, kraft pulping, paper properties, tracheids, roots.

## INTRODUCTION

Sitka spruce (*Picea sitchensis*) growing along the coasts of Washington and Vancouver Island is occasionally afflicted with large tumorlike growths on the trunks, branches, and roots. A review of the literature indicated isolated instances of similar growths on several other coniferous species, especially white spruce growing along the Atlantic Coast (DeTorok and White 1960; Peterson 1961; White 1962). Although physiological studies on white spruce tumors have been reported (DeTorok 1967; Tsoumis 1965; White et al. 1967), no information was available concerning the chemical composition of this type of tumor wood. (Beech and tomato wood tumors have been subjected to extensive chemical examination [Cernatescu-Asandei et al. 1968], but they appear to be of bacterial origin and have significant physiological differences from white spruce tumors.) White spruce tumor wood cells cultured *in vitro* have been successfully explanted into normal wood (DeTorok 1967). This suggests the potential for artificial growth stimulation in Sitka spruce, which would be of great interest to the pulp and paper industry, provided that the stimulated growth did not have significantly different chemical and fiber properties from normal Sitka spruce wood. Consequently, a study of chemical, physical, and pulping properties of Sitka spruce wood tumors was initiated.

A grove of tumor-afflicted trees occurs in the Olympic National Park near Kalaloch, Washington (Fig. 1). Permission to remove one of these trees for research purposes was granted by the National Park Service through the kind efforts of Bennett

FIG. 1. Tumor-affected Sitka spruce grove—Kalaloch, Washington.

T. Gale, Superintendent of the Olympic National Park. The authors also wish to acknowledge the help of Niel D. Smith, District Ranger, for his assistance in selecting and harvesting the tree used for this study.

### MATERIALS AND METHOD

A tumor-affected Sitka spruce growing about 150 yards from the Pacific Ocean beach near Kalaloch, Washington, in Olympic National Park, was felled on 20 December 1966. The tree was six inches in diameter (DBH) and contained 72 annual rings. A 4-foot section of the trunk containing a 17-inch diameter tumor and a tumorous root 1.5 inches in diameter containing 20 growth rings and two, 5-inch-diameter tumors, were used for this study.

For comparative purposes a normal second-growth Sitka spruce was harvested from the upper Wishkah River area of Grays Harbor County about 35 miles from the tumor-affected tree. The tree was 7.5 inches in diameter (DBH) and contained 45 annual rings. A 4-foot section of the trunk and a root section 1.5 inches in diameter with 8 growth rings were used.
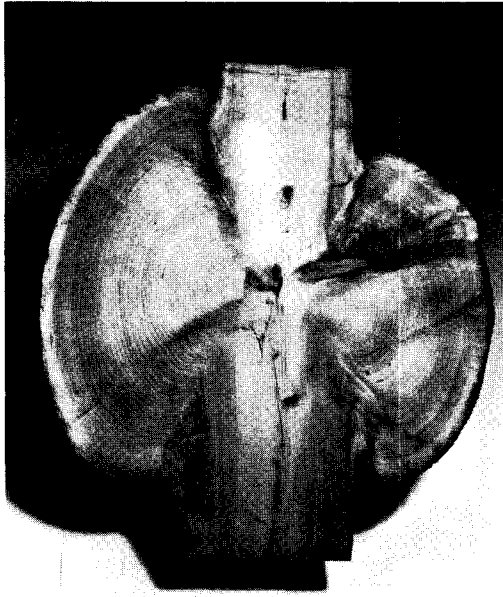
FIG. 2. Longitudinal section of trunk tumor.
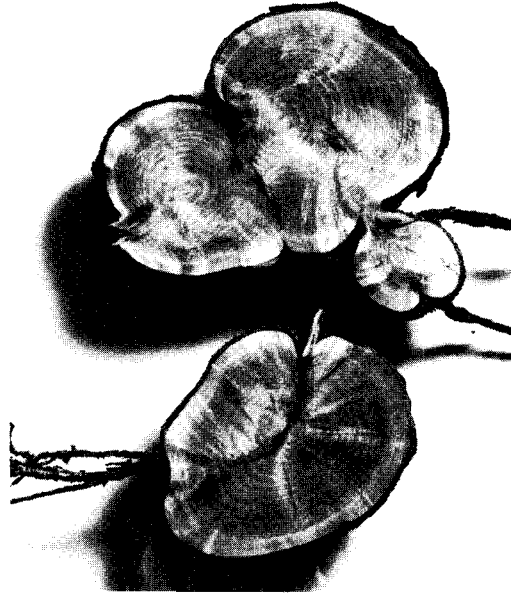


FIG. 4. Longitudinal section of root tumors.



FIG. 3. Root tumors.
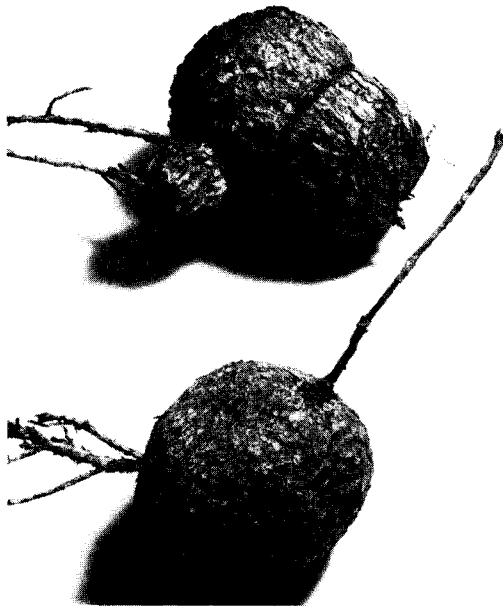


FIG. 5. Normal wood fibers ($\times 40$).

Fig. 6. Wood tumor fibers (×40).



Fig. 8. Normal root fibers (×40).



Fig. 7. Compression wood fibers—normal wood (×80).



Fig. 9. Root tumor fibers (×40).
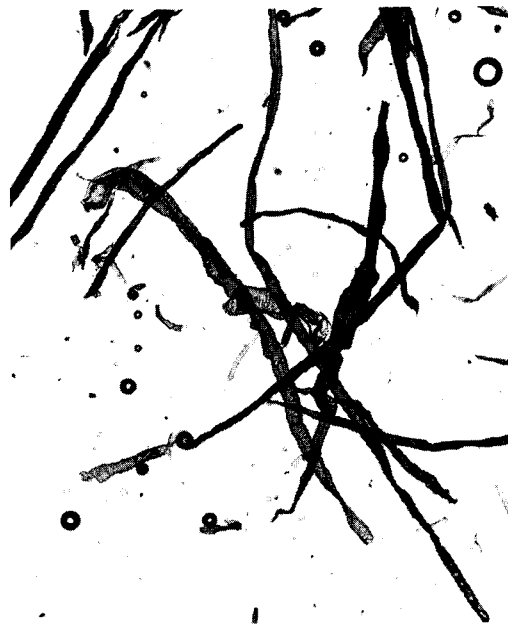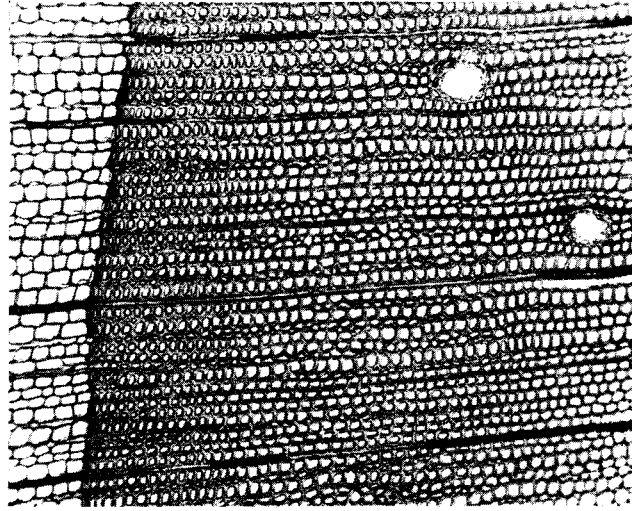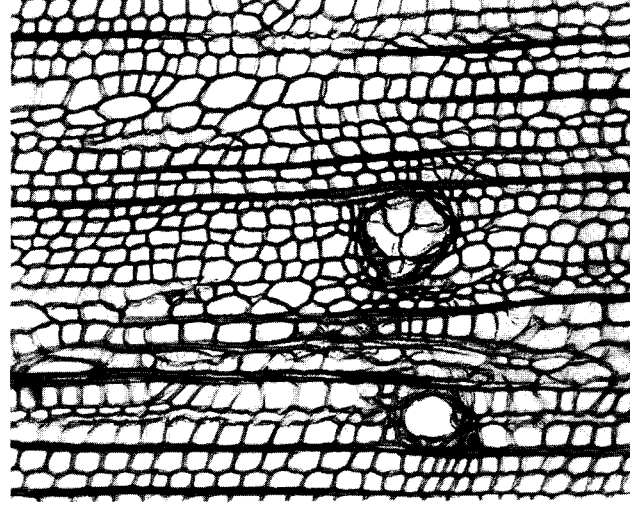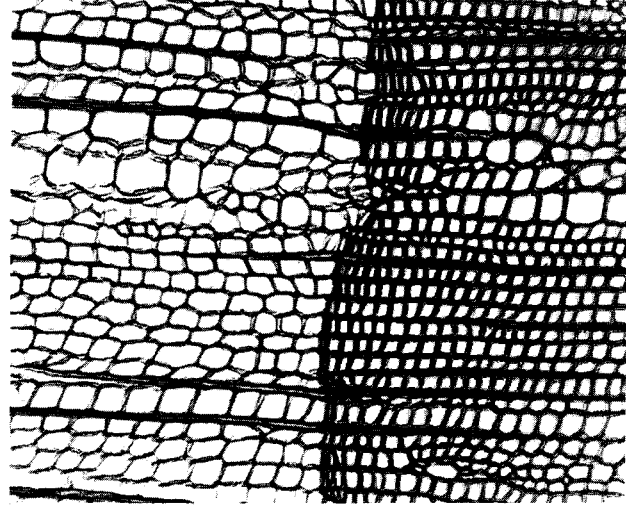
Fig. 12.   Wood tumor cross section (×80).



Fig. 13.   Normal wood radial section (×80).



Fig. 10.   Normal wood cross section (×80).



Fig. 11.   Wood tumor cross section (×80).
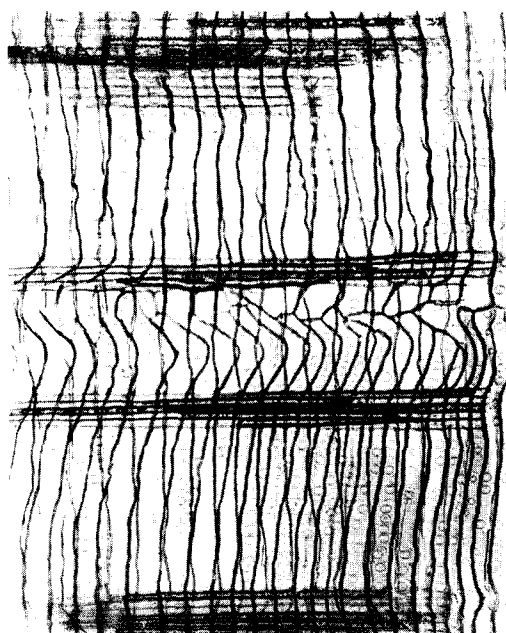
FIG. 14. Wood tumor radial section (×80).



FIG. 15. Root tumor radial section (×80).

Cross sections each ¾ inch thick were sawn from the trunk above and below the tumor, from the center portion of the tumor, and from the trunk of the control tree.

Similar cross sections were also cut from the root sections of the affected and control trees.

Whole cross sections, representing the

TABLE 1. *Chemical composition of tumorous and normal second-growth wood from Sitka spruce trees (percentages based on original oven-dry weight of wood)*

| | Wood Above Tumor | | Tumor | | Wood Below Tumor | | Calculated Comparative Analysis[c] | | Second Growth[a] Control | | Second Growth[b] Compression wood | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chemical Analyses[d] | | | | | | | | | | | | |
| Lignin | 29.1 | | 30.8 | | 30.2 | | 29.7 | | 27.3 | | 35.4 | |
| Cellulose | 39.3 | | 40.1 | | 39.8 | | 45.4 | | 48.0 | | 39.3 | |
| Hemicellulose | 31.5 | | 29.0 | | 30.0 | | 24.7 | | 24.6 | | 25.0 | |
| Acetylgalactoglucomannan | | 21.7 | | 20.6 | 21.3 | | 15.8 | | 17.6 | | 11.7 |
| Glucuronoarabinoxylan | | 6.3 | | 5.6 | 5.8 | | 6.1 | | 5.9 | | 6.6 |
| Arabinogalactan | | 2.1 | | 1.3 | 0.8 | | 2.2 | | 0.7 | | 5.6 |
| Pectin | | 1.4 | | 1.6 | 2.0 | | 0.6 | | 0.3 | | 1.2 |
| Ash | 0.1 | | 0.0 | | 0.1 | | 0.1 | | 0.1 | | 0.2 | |
| Sum | 100.0 | | 100.0 | | 100.0 | | 100.0 | | 100.0 | | 100.0 | |
| Extractives | 2.5 | | 4.3 | | 2.9 | | 2.0 | | 1.9 | | 3.1 | |
| Resin (Pet. Ether Sol.) | | 0.5 | | 0.6 | 0.5 | | 0.6 | | 0.3 | | 1.3 |
| Phenolics (Acetone Sol.) | | 0.7 | | 0.8 | 0.4 | | 0.6 | | 0.5 | | 0.6 |
| Carbohydrates ($H_2O$ Sol.) | | 1.3 | | 2.9 | 2.0 | | 1.2 | | 1.1 | | 1.2 |
| Avg. Density, g/cc | 0.55 | | 0.43 | | 0.61 | | 0.41 | | 0.46 | | 0.86 | |

[a]Sample free of compression wood.

[b]Compression wood obtained from second-growth control - 10% of wood weight.

[c]Wood calculated to contain 30% compression wood based on second-growth control analyses.

[d]Calculated on oven dry extractive-free basis.
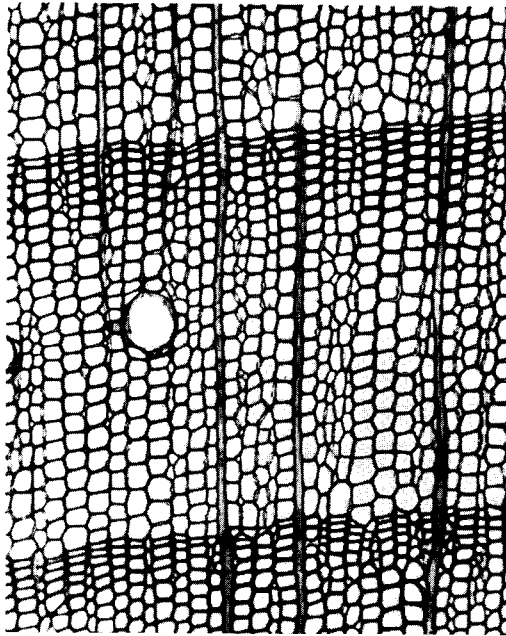
FIG. 16. Normal root cross section (×80).
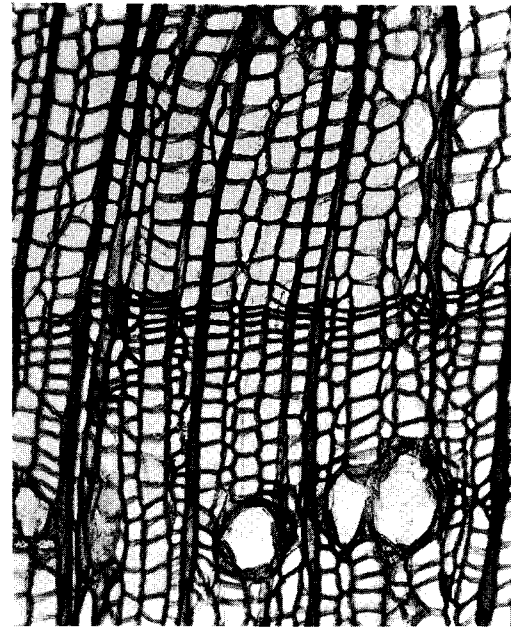


FIG. 17. Root tumor cross section (×80).

various samples described above, were cut into chips and ground to pass a 20-mesh screen in a Wiley mill. The air-dried wood meal was extracted in succession with petroleum ether (b.p. 30–60 C), acetone, and hot water in a Soxhlet extractor. Infra-red spectra were measured on the extracts, and the dried, extractive-free wood was

analyzed for lignin, ash, acetyl, uronic acid, and sugars (glucose, mannose, galactose, xylose, and arabinose) after hydrolysis (Beelik et al. 1967). The cellulose and hemicellulose content were obtained by computation. The data are shown in Tables 1 and 2.

Transverse, radial, and tangential micro-

TABLE 2. *Chemical composition of tumerous and normal second-growth wood from Sitka spruce tree roots (percentages based on original oven-dry weight of root)*

| | Root Tumor | | Root Adjacent To Tumor | | Second Growth Control Root | |
|---|---|---|---|---|---|---|
| Chemical Analyses[a] | | | | | | |
| Lignin | 26.1 | | 26.3 | | 28.5 | |
| Cellulose | 42.8 | | 34.3 | | 42.6 | |
| Hemicellulose | 30.8 | | 39.2 | | 28.7 | |
| Acetylgalactoglucomannan | | 20.1 | | 19.4 | | 20.3 |
| Glucuronoarabinoxylan | | 4.0 | | 4.1 | | 5.4 |
| Arabinogalactan | | 5.0 | | 13.9 | | 1.8 |
| Pectin | | 1.8 | | 1.8 | | 1.3 |
| Ash | 0.3 | | 0.2 | | 0.2 | |
| Sum | 100.0 | | 100.0 | | 100.0 | |
| Extractives | 9.6 | | 9.9 | | 5.0 | |
| Resin (Pet. Ether Sol.) | | 1.0 | | 0.6 | | 1.1 |
| Phenolic (Acetone Sol.) | | 1.7 | | 2.4 | | 1.5 |
| Carbohydrates (H$_2$O Sol.) | | 6.8 | | 6.9 | | 2.3 |
| Avg. Density, g/cc | 0.50 | | 0.58 | | 0.34 | |
| Apparent Heartwood, % | 70 | | 70 | | 1 | |

[a]Calculated on an oven- dry extractive-free basis.

Table 3. *Specific gravity distribution in normal second-growth and tumerous wood of Sitka spruce trees*

| Block No. | Below Tumor | | Above Tumor | | Tumor Wood | | Second Growth Control | |
|---|---|---|---|---|---|---|---|---|
| | Rings per inch | Sp.G. | Rings per inch | Sp.G. | Rings per inch | Sp.G. | Rings per inch | Sp.G. |
| 1 | 26 | 0.75[a] | 28 | 0.73[a] | 14 | 0.41 | 26 | 0.59 |
| 2 | 20 | 0.74[a] | 30 | 0.54[c] | 6 | 0.39 | 11 | 0.46 |
| 3 | 24 | 0.52[e] | 22 | 0.44 | 6 | 0.42 | 7 | 0.45 |
| 4 | 23 | 0.51 | 16 | 0.50 | 8 | 0.50 | 7 | 0.57[e] |
| 5 | 18 | 0.62[b] | 20 | 0.61[c] | 9 | 0.64[d] | 5 | 0.38 |
| 6 | 16 | 0.69[b] | 18 | 0.69[d] | 12 | 0.56 | 8 | 0.35 |
| 7 | 32 | 0.64[b] | 35 | 0.62[c] | 6 | 0.36 | 17 | 0.45 |
| 8 | 24 | 0.54[b] | 23 | 0.44 | 7 | 0.37 | 21 | 0.86[a] |
| 9 | 27 | 0.55[b] | 30 | 0.45 | 7 | 0.31 | | |
| 10 | 32 | 0.51 | 32 | 0.47 | 12 | 0.38 | | |
| Avg. | 24.2 | 0.61 | 25.4 | 0.55 | 8.7 | 0.43 | 12.8 | 0.51 |

[a] Thick zone of compression wood.

[b] Knotty zone.

[c] Medium amount of compression wood.

[d] Knot "shadow".

[e] Small amount of compression wood.

tome sections were prepared from the trunk tumor and root tumor and from the trunk and root of the second-growth control. The sections were stained with safranin and bismark brown and mounted on permanent slides (Figs. 10–17).

Inner bark samples were separated from the bark surrounding the trunk and root tumors and from the trunk and root bark of the control tree. Holocellulose was prepared from these samples by the standard acid-chlorite procedure (Beelik et al. 1967). The holocellulose fibers were stained with

methyl violet and the stained fibers were used to prepare microscope slides.

One-inch cross-sectional strips were sawn radially and cut into blocks to provide a density profile across the diameter of the section. The blocks were soaked in water for 24 h and blotted; density was determined by measuring the water displacement and oven-dry weight of each block. In the case of the tumor-affected tree, cross sections from above, below, and through the center of the tumor were cut so that the density strips were from the same relative location across each section. Each strip was cut into ten corresponding blocks. The density data are shown in Table 3, and comparative growth rates are presented in Table 4.

Conventional kraft cooks were made in a 2-liter experimental digester on handcut chips prepared from the following samples: (a) the trunk tumor, (b) wood from above the tumor, (c) wood from below the tumor, and (d) wood from the second-growth control. In addition, several chips (equivalent to about 5 g o.d. wood) from the root tumor and from the normal root were placed in small baskets and included in the cook made on the control wood. The unbleached pulps

Table 4. *Comparison of growth rate of normal second-growth and tumerous wood of Sitka spruce trees*

| Growth Ring Number | Sample Location in Stem | | | |
|---|---|---|---|---|
| | Right Side | | Left Side | |
| | 50 | 60 | 50 | 60 |
| Number of Tracheids | | | | |
| Above tumor | 35 | 18 | 69 | 55 |
| Below tumor | 40 | 9 | 85 | 38 |
| Within tumor | 110 | 34 | 78 | 35 |
| Est. Specific Gravity[a] | | | | |
| Above tumor | 0.54 | 0.55 | 0.58 | 0.74 |
| Below tumor | 0.62 | 0.60 | 0.69 | 0.75 |
| Within tumor | 0.33 | 0.37 | 0.40 | 0.42 |

[a] Estimated from interpolation from data in Table 3.

TABLE 5. *Pulping and paper test results for tumerous and normal second-growth Sitka spruce wood*

| | Trunk Tumor | Wood Below Tumor | Wood Above Tumor | Normal Tree |
|---|---|---|---|---|
| Growth Site | ----------------Kalaloch---------------- | | | Wishkah River |
| **Conventional Kraft Cook** | | | | |
| A.A. to Wood, (O.D. Wood) | ------------------------------25.5------------------------------ | | | |
| Sulfidity, | ------------------------------30------------------------------ | | | |
| Liquor to Wood Ratio | ------------------------------7.4 to 1------------------------------ | | | |
| Max. Temp., ° C | ------------------------------172------------------------------ | | | |
| Time to Temp., min. | ------------------------------90------------------------------ | | | |
| Time at Temp., min. | ------------------------------150------------------------------ | | | |
| Digester Yield, | 42.3 | 41.3 | 46.7 | 46.0 |
| Screen Rejects, | 0.2 | 0.3 | 0.1 | 0.6 |
| Screened Yield, | 42.1 | 41.0 | 46.6 | 45.4 |
| P Number[a] | 16.4 | 18.4 | 17.2 | 17.1 |
| Cuene I.V. | 8.96 | 8.46 | 9.00 | 8.65 |
| **Fiber Length, mm** | | | | |
| Number Average | 1.86 | 2.64 | 2.29 | 3.12 |
| Weighted Average | 2.35 | 3.01 | 2.63 | 3.53 |
| **Paper Test Data Abstracted from PFI Beater Tests at 400 Canadian Standard Freeness** | | | | |
| O.D., | 22.4 | 26.8 | 26.0 | 28.5 |
| PFI Revs. to 400 CSF | 5000 | 4000 | 4000 | 4500 |
| TAPPI Burst Factor | 83 | 99 | 109 | 106 |
| TAPPI Tear Factor | 146 | 159 | 183 | 172 |
| Double Folds, MIT | 3000 | 2080 | 2080 | 2080 |
| Breaking Length, meters | 10180 | 11370 | 12350 | 13200 |
| Shrinkage, | 14.2 | 8.6 | 7.9 | 7.6 |
| Opacity, | 77.1 | 85.5 | Dark | 86.7 |
| Density, g/cc | 0.79 | 0.74 | 0.73 | 0.63 |
| Air Resistance, sec/100 cc | 33 | 35 | 50 | 45 |
| Stretch, | 3.8 | 3.5 | 3.2 | 3.2 |

[a]TAPPI Standard T214 Su 71

were examined microscopically and evaluated for papermaking properties by PFI beater tests. The cooking data and beater tests are shown in Table 5.

### RESULTS AND DISCUSSION

The chemical analyses of the trunk sections of the tumor-affected and control trees are presented in Table 1. The chemical composition of the tumor was not appreciably different from adjacent nontumored wood in spite of the fact that the growth rate of the tumor was much greater and it contained no visible compression wood, whereas the adjacent wood above and below the tumor contained about 30% compression wood.

Because of the differences in compression wood content between the affected and control trees, the control wood was separated into compression-wood free and 100% compression wood fractions which were analyzed separately. These analyses were then used to compute a comparative control composite containing 30% compression wood. On the basis of this composite, it is evident that the affected tree contained less cellulose and more hemicellulose than the control, and the increased hemicellulose was present primarily as galactan containing polymers.

Comparison of the infrared spectra of extractives from tumor wood with those obtained from wood below and above the tumor and the control wood showed no more differences than are exhibited between the extractives in normal Sitka spruce woods of varying growth patterns. The somewhat higher content of extractives in the tumor wood is probably the result of the slightly higher volume of heartwood in the tumor. Hence, minor differences in infrared spectra can readily be accounted for by slight differences in the ratio of typical heartwood and sapwood constituents.

Except for a lower galactan content, the

chemical analysis of the root tumor (Figs. 3 and 4) were not appreciably different from that of the nontumored adjacent root tissue (Table 2). However, the root from the control second-growth tree was lower in hot water extractives (primarily low molecular weight arabinogalactans present in spruce heartwood) and much lower in cell-wall arabinogalactan and higher in lignin than the affected tree. The control root wood had nearly no heartwood and a much lower density and thinner cell walls. Consequently the difference in extractives might be expected, but the arabinogalactan content of the affected tree is higher than can be rationalized from differences in physical properties and heartwood content. The compositions of the extractives from the tumor-affected root and the control root were very closely similar, as indicated by infrared spectra.

The tumorous wood contained annual rings and well-differentiated sapwood and heartwood zones (Fig. 2). The average density of the tumors was lower than that of adjacent wood (Tables 1, 2, and 3), and compression wood was visible only in branch tumors. In the case of the trunk tumor, it appeared that growth factors operating above and below the tumor were also evident within the tumor. This is illustrated in Table 4, which shows the parallel differences in tracheid formation between the growth rings.

Microscopic examination of the wood and root tissues showed that the cellular structure of the tumor was highly disordered. The major deformities were confined largely to the tracheids and longitudinal resin canals. The ray cells, although generally larger than those of the second-growth control, were orderly in appearance and structure, and they did not appear distorted within the wood structure. The longitudinal tracheids were very irregular, showing variable width along the fiber axis, abnormally large lumina, and thin walls. They were short and generally curved or bent instead of straight, and they were often twisted within the wood structure so that bordered pits occurred in transverse as well as radial view. Observations made on pulp fibers prepared from tumor wood support the findings on the wood itself. The tumored wood also developed numerous traumatic resin canals that in normal trees are associated with wound areas. The epithelial cells surrounding the resin canals in the tumor wood were irregular in shape and often enlarged and irregularly spaced around the periphery of the resin canal. Photomicrographs of the pulped fibers are shown in Figs. 5–9.

The bark surrounding both the trunk and root tumors was normal in appearance and thickness and showed no external evidence of abnormal growth. Microscopic examination of the fibers from the inner bark showed no evidence of irregular cell formation or growth as did the fibers from the wood. These observations indicate that the factors that cause the tumor formation in the wood and its associated cellular irregularities do not affect the growth of the bark.

The data (Table 5) indicate that the pulping characteristics of tumor wood are not significantly different from normal wood. Microscopic examination of the pulp fibers showed that the fibers from tumors are short in length, misshapen and generally curved, thin-walled, and wider than normal fibers. The fibers from wood above and below the tumor were normal in appearance. Paper tests showed that tumor wood pulp was weak in all strength properties (mullen, tear, and tensile) except fold, which was exceptionally high. The pulp was further characterized by a high shrinkage and air resistance. Pulp from wood adjacent to the tumor had properties similar to those of control wood.

Examination of a number of tumors, from both root and trunk, indicated that the tumor originated at the center of the stem or root as a result of some change at the growing tip. This change caused the xylem cells to divide and enlarge more rapidly than normal wood, and thus a tumor ultimately appeared. The agent causing these changes was not ascertained in this study. It is possible that these changes could result from insect attack, a virus or an inorganic com-

pound from ocean salt spray. The last-mentioned possibility is an especially attractive hypothesis since Sitka spruce tumors seem to be limited to areas immediately adjacent to the ocean. However, if inorganic compounds from ocean spray were the only causative agent, one would expect tumorous trees to be more prevalent along the coast instead of occurring in extremely localized areas. This limited occurrence indicates that additional factors such as an inherent genetic abnormality or a micronutrient deficiency may have to be taken into consideration.

## CONCLUSIONS

Although this study was limited to the comparison of a single tumor-affected tree and a single control tree, the results indicate that tumor-affected Sitka spruce has a higher quantity of hemicellulose than normal trees, and the hemicellulose contains a high proportion of galactan-containing polymers. Furthermore, the results show that tumorous growth is confined to the woody xylem, and the effects are confined largely to abnormalities to the tracheid and resin canals with the rays showing no abnormalities in their cellular structure. Paper pulp made from tumors was deficient in most strength properties. This is a conse-quence of the disordered shape, short length, and thin walls of the tumor tracheids. Thus, a program to isolate and explant the spruce tumor growth factor does not appear attractive as a means of stimulating growth in trees destined for pulp manufacture.

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