CURRENT WORK IN ONTARIO ON COMPRESSION WOOD IN BLACK SPRUCE IN RELATION TO PULP YIELD AND QUALITY

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In 1959 and 1960, during a series of symposia on wood quality organized jointly by the Ontario Department of Lands and Forests, the Faculty of Forestry of the University of Toronto, and the Ontario Research Foundation (ORF), it became clear that there was a serious lack of information regarding the structure and variability of the wood of the commercially important species of Ontario. Following these symposia a Wood Quality Unit was set up within the Department of Lands and Forests' Research Branch, and at about the same time the Department undertook to sponsor a wood quality research program to be carried out by the Department of Organic Chemistry of the ORF, which for many years had been doing contract research in the fields — among others — of lignin chemistry and the utilization of waste pulping liquor.

As the pulp and paper industry is basic to the economy of Ontario and as black spruce (*Picea mariana* (Mill.) B.S.P.) provides over 50 percent of the raw material used by that industry, it was decided to concentrate on this species. At present the major research effort is directed at attempting to relate specific paper properties to anatomical characters and these latter, in turn, to such factors as growth rate, age, and site. It is hoped that the results will be useful in the management of existing stands as well as furnish information that will assist in the selection of superior trees for breeding purposes.

A multi-unit micro pulp digester, based on a design found to be efficient by the Institute of Paper Chemistry, Appleton, Wis., has been built at the Foundation, while other facilities are currently being used to study problems ranging from the distribution of resins in black spruce in relation to deresination methods in pulp mills to the feasibility of exploiting the foliage of black spruce commercially.

Throughout this work the ORF has cooperated closely with the Wood Quality Unit of the Department of Lands and Forests' Research Branch. This unit has concerned itself with the investigation of field sampling problems and the difficulties of typifying whole tree characteristics from a limited number of increment cores. During these investigations it was observed that a large number of black spruce cores contained compression wood. Compression wood, found typically on the lower side of leaning trees and on the underside of branches, is composed of relatively weak, rounded, thick-walled cells rich in lignin. — all factors likely to detract from the quality of pulp and paper. Although much information is available on some aspects of compression wood such as its microstructure and the factors that appear to cause its formation, its distribution within trees and stands and its effect on pulp and paper quality have not been investigated with any thoroughness. The distribution of compression wood in the southern pines has been studied, for example, by Zobel and Haught (1962) and by Einspahr *et al.* (1962), and in *Juniperus procera,* an African species, by Phillips (1940). More recently Low (1964) studied the distribution of compression wood in Scots pine grown in the United Kingdom. The effect of compression wood on the pulp and papermaking properties of loblolly pine (*Pinus taeda* L.) has been investigated by Pillow and his coworkers (1935, 1941), while a study on *Pinus radiata* was reported by Watson and Dadswell (1957).

Moore and Yorston (1945), in an early review of the effect of wood properties on the quality of pulp and paper, give values showing that the inclusion of compression wood in balsam fir (*Abies balsamea* (L.) Mill.) sulfite pulp results in decreased yields and lower burst strength. There are other scattered references to the general effect of compression wood on pulp quality in the northern spruces, as, for example, by Green and Yorston (1939) in a discussion of "acid susceptible" wood. But as far as the writers are aware, compression wood in black spruce has been the subject of only one investigation — and that a minor one — dealing with mechanical pulp (Pillow *et al.* 1959). In view of the frequency, mentioned above, with which compression wood was observed in black spruce increment cores, a detailed study of the distribution of this abnormality in relation to pulp and paper quality appeared to be of basic importance to the research program.

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Amount and Distribution of Compression Wood

In a pilot study, estimates of compression wood were made on discs from the 10- and 75-percent height levels of 20 mature trees on a good site in Parnell Township, Ontario, using an adaptation of the point sampling technique employed, for example, by Ladell (1959), Myint Aung (1962), and Tsoumis (1964) for estimating the ratio of cell wall to lumen, or the frequency of different cell types on microscope sections. A transparent sheet of plastic with a known number of randomly placed dots was placed over discs, smoothed and wetted to accentuate the bands of compression wood, and counts were made of the number of points falling on them. With allowance made for points not falling on the disc (the count field was square), the amount of compression wood relative to the whole could be determined. Trials showed that six counts using approximately 100 points, repeated with the count field randomly placed each time, gave good reproducibility. Indirect evidence of the reliability of the method was subsequently obtained from pulping trials, as will be seen.

The results of this investigation showed that at the 10-percent height level, compression wood content in the 20 trees averaged 5.8 percent, with individual trees ranging from 3.1 to 11.3 percent. Corresponding values at the 75-percent height level were 0.0 to 5.1 percent, with a mean of 2.3 percent. No correlation was found between levels ($r = -0.075$ not significant).

The second and much more detailed investigation involved 11 mature trees from a good lowland site in Challies Township, Ontario. These trees were part of a sample collected earlier in connection with a study of specific gravity distribution. The sampling plan called for random selection with the rejection of trees with perceptible lean or crook, but in fact no such trees fell within the sample although the stand contained such trees. Each tree had been reduced in its entirety to f-inch discs up to the 90-percent height level. Estimates of compression wood were now made on every 15th disc, using the method described above with the refinement that a series of circular count fields of varying diameters was employed.

Estimates on all discs within each 10-percent height increment were averaged to give nine mean values for each tree centered on the 5-, 15-, 25-percent, etc., up to the 85-percent height level. Generally, five discs contributed to each value, the exact number depending on the height of the individual trees, which varied from 50 to 63 feet.

Table 1 lists the average compression wood contents for each tree. The values in the lefthand column are simple averages; those in the right were obtained by weighting the values for the different levels by wood volume. Simple tree averages ranged from 6.4 to 27.1 percent, with an overall mean of 14.7 percent. The weighted averages ranged from 5.3 to 26.1 percent, with an overall mean of 13.9 percent and a standard deviation of 1.83 percent. As leaning trees were not represented in the sample, the value of 13.9 percent can be considered as an underestimate of the average compression wood content of the stand.

Unweighted compression wood mean values from all trees by tree height tended generally to be high in the crown and at the base of trees (fig. 1). Patterns of variation in individual trees varied widely, however. In four trees — numbers 8, 11, 17, and 20 — the peaks at base and crown were very marked, whereas in another four trees — numbers 7, 14, 15, and 16 — compression wood content tended to increase more or less steadily with height within the tree. In trees numbered 13 and 21, compression wood tended to decrease with height. In spite of the diversity of trends with respect to height displayed by individual trees, compression wood content within trees was remarkably consistent. Except for the 85-percent level, the relationship between compression wood percent at each level and weighted tree means was very close, with correlation coefficients ranging from +0.788' to +0.961*** (fig. 2). For the 85-

Table 1. — Average compression wood content in 11 black spruce trees

Tree number	Simple average (percent)	Weighted average (percent)	Tree number	Simple average (percent)	Weighted average (percent)
7	6.4	5.3	16	14.6	12.0
8	10.3	10.8	17	17.3	17.3
11	17.5	16.9	18	13.4	11.2
13	8.3	9.3	20	19.3	18.4
14	27.1	26.1	21	18.2	18.6
15	9.6	7.4	Mean	14.7	13.9

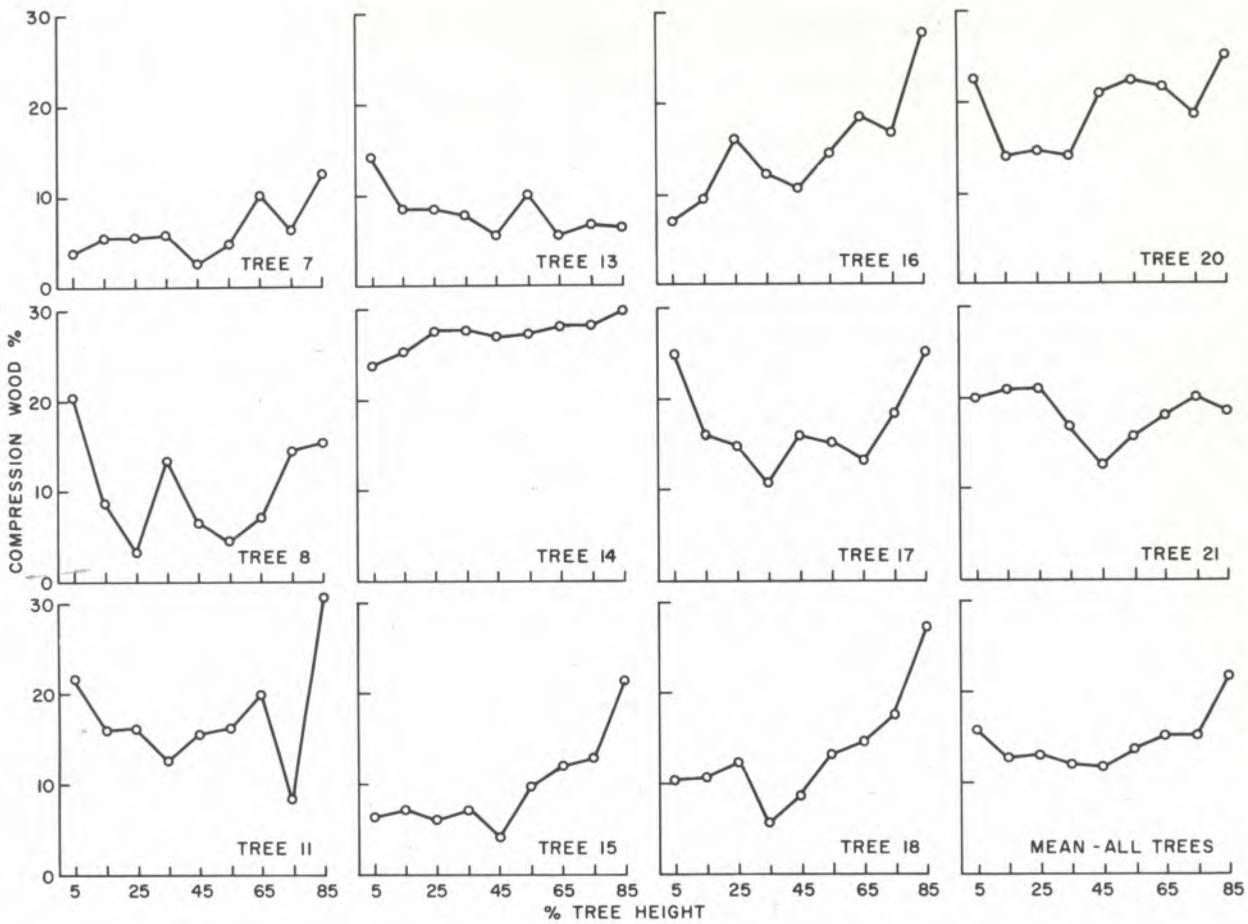

FIGURE 1. — Variation of compression wood content with height in each of 11 black spruce trees and in all trees combined.

percent level r was calculated at 0.597 (not sig.). If the results of the second, more intensive investigation can be confirmed it would appear that, to predict total compression wood from increment cores, the cores should be taken somewhat above breast height, perhaps at the 15-percent level where r was found to be +0.959. Studies of the predictive capability of increment core samples are at present underway, as are other confirmatory investigations.

Pulping Trials

The primary objective of the first pulping trial was to obtain indirect confirmation of the efficiency of the method used to estimate compression wood. As compression wood is abnormally high in lignin, and as high lignin content tends to reduce the yield of pulp, given equivalent pulping conditions, then a negative correlation between pulp yield and compression wood content might be expected — if the latter had been estimated correctly.

Accordingly, from the 11 trees mentioned above, 68 samples of known compression wood content were chipped and cooked for 3 hours using sodium bisulphite. Weight of chemical was 20 percent that of the wood. Liquor, to wood ratio was 5 to 1, so that actual concentration of chemical was 4 percent. Percent screened pulp yields were determined for each of the 68 pulps prepared; the relations between percent compression wood and pulp yield were then analyzed statistically, with Kappa number taken to be a covariable; [2] and the coefficient of correlation between yield and compression wood content was calculated. This was —0.745 and significant at over the 0.1-percent level.

[2] *Kappa number, as a measure of residual lignin, indicates the degree to which a pulp has been cooked and is commonly used as a basis for the comparison of pulps.*

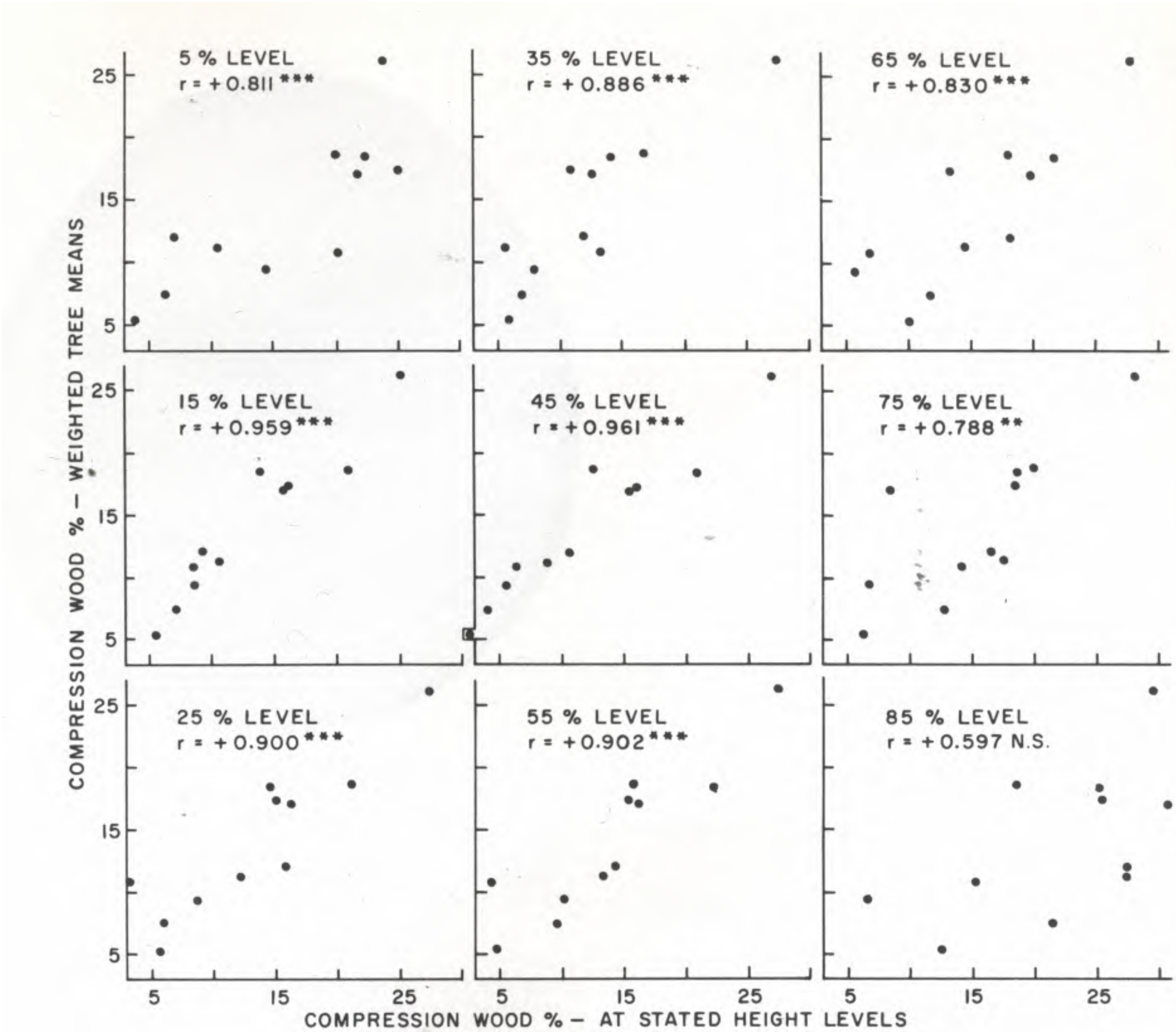

FIGURE 2. — Relation in 11 black spruce trees between the mean compression wood content of entire trees and the compression wood content at nine predetermined height levels.

The regression of yield on compression wood percent was calculated as $Y=53.05-0.2910X$, a linear relation being assumed. The regression was highly significant ($F=82.18$***), with compression wood accounting for 55.5 percent of the variation in yield. An estimate of the effect of compression wood on yield from pulps cooked to known lignin content was obtained by calculating a further regression, with the Kappa number of the pulps as a second independent variable. The regression was $Y=44.99-0.25X_1 + 0.14X_2$ ($F=91.17$***) where X_1 = percent compression wood and X_2 = Kappa number (fig. 3). Each variable was highly significant when the effect of the other was removed. F was 97.23' for compression wood and 45.16 * for Kappa number.

It was felt that these results amply proved the accuracy of the point sampling system of estimating compression wood. The results also suggest that compression wood content might prove to be a useful indicator of yield. This possibility is now being examined in the light of specific gravity differences in the same set of samples.

Characteristics of Black Spruce Compression Wood and Effects on Paper Strength

Three mature trees with pronounced lean were selected from a stand in Fournier Township, and a 4-foot bolt centered on the breast height level was removed from each and reduced to 3/4-inch discs. As was hoped, compression wood was present in large amounts and in well-defined areas. These areas were delineated, together with zones of opposite and side wood, using the procedure followed by Watson and Dadswell (1957) (fig. 4).

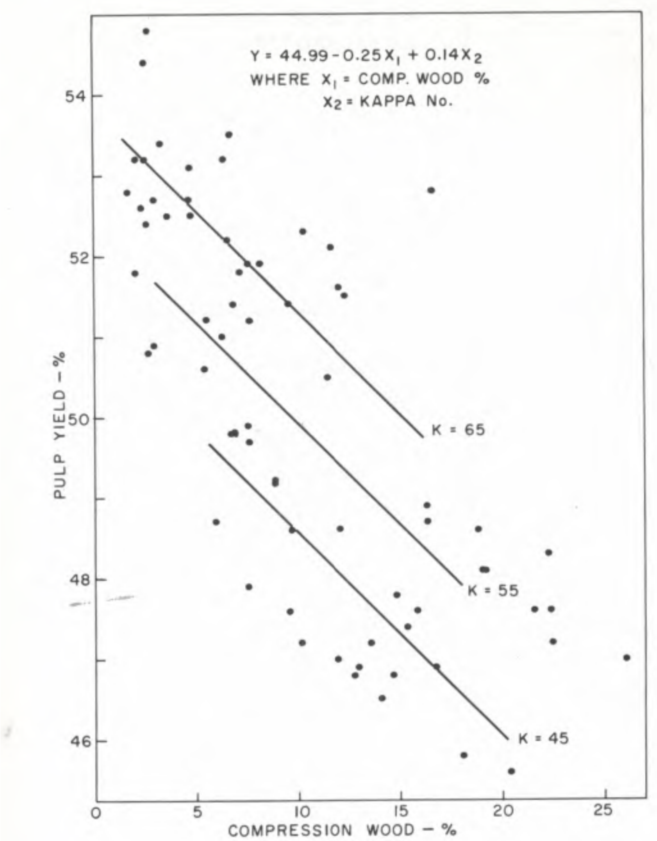

FIGURE 3. — Pulp yield and compression wood for pulps cooked to different lignin contents.

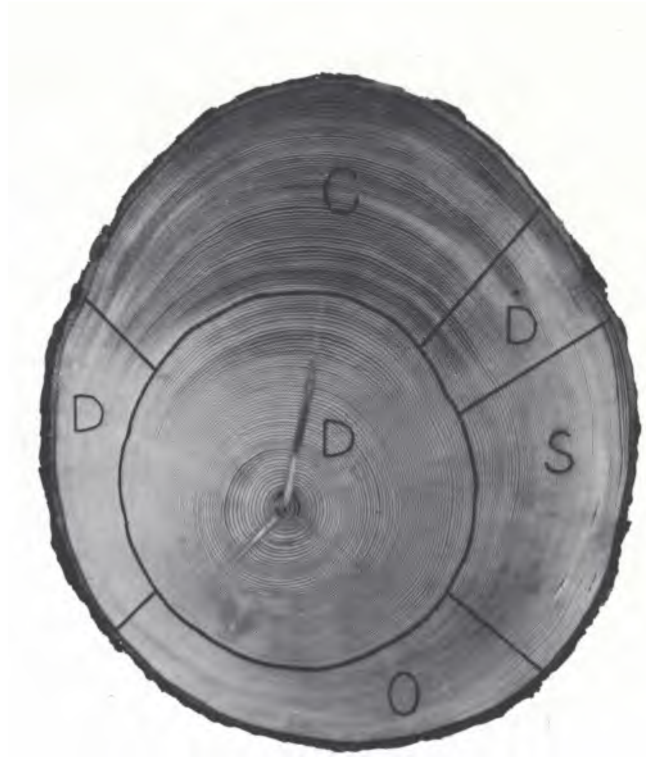

FIGURE 4. — Delineation of discs for pulp and papermaking tests. *C* is taken to be 100-percent compression wood. *S* (sidewood) and 0 (opposite wood) are taken as no compression wood; these were combined to give "normal" or control fraction. *D* is discarded as containing varying amounts of compression wood.

A comparison of chemical and morphological characteristics for the three zones and for control material obtained from the mature wood of a defect-free tree shows that the compression wood zone has a relatively high lignin content, is somewhat lower in pentosans, and displays a markedly higher specific gravity (table 2). These results generally agree with those obtained by other workers. Pillow *et* al. (1.935), for example, reported a lignin content of 35.2 percent for the compression wood of loblolly pine (*Pinus taeda* L.) compared to 28.3 percent for normal wood, with pentosans at 12.2 percent compared with 12.4 percent. That compression wood chips, after conditioning and before pulping, tend to equilibrate at a higher moisture content is of some general interest (table 2). The overall mean fiber lengths in the compression and side wood bands were statistically identical, and each was significantly less than the length in the opposite wood zone.

Pulp and papermaking trials were carried out first on pure samples from the three zones. Cooking procedure was essentially the same as that described above. When the trials showed that paper characteristics from the side and opposite wood zones were essentially the same, the chips from the two latter zones from all three trees were combined to form a fraction which was termed "normal" wood. Chips from the compression wood zones from all three trees were similarly pooled. Chips from normal and compression wood were then mixed to give a series of fractions containing different proportions of compression wood on a percentage ovendry weight basis. Percentage dry weight values were later converted to percentage dry volume values by assuming a specific gravity of 0.53 for compression wood and 0.40 for normal wood.

The fractions containing 0-, 5-, 10-, and 100-percent compression wood (by weight) were pulped over a range of, cooking times and Kappa numbers. Due to lack of material, only a single cook to give a Kappa number of 80 was made of the 20-, 30-, 40-, and 50-percent compression wood fractions. All pulps were beaten in a PFI mill over a series of predetermined number of revolutions; handsheets were prepared and strength tests carried out according to Tappi Standard T-220 m-60.

Figure 5 shows values for tear, burst, and tensile strength (breaking length) of handsheets from pulps beaten to 350 CSF plotted against percent compression wood by volume. Figure 6 shows strength values expressed as a percentage of those

Table 2.--Miscellaneous characteristics of fractions from black spruce trees with high compression wood content

Sample	Pento-sans	Lignins	Conditioned E.M.C.[1/]	Specific gravity	Tracheid length: Mean	Tracheid length: Standard deviation	Tracheid length: Coefficient of variation
	(Percent)		(Percent)		(mm.)	(mm.)	(Percent)
Opposite wood	7.6	25.2	8.8	0.408	3.47	0.29	8.3
Side wood	7.4	25.3	8.6		2.98	.78	26.1
Compression wood	7.2	31.1	9.2	.528	3.08	.13	4.1
Control	7.3	27.0	8.6	.396	3.40	.56	16.3

1/ Equilibrium moisture content: the moisture content attained by wood under given conditions of temperature and humidity.

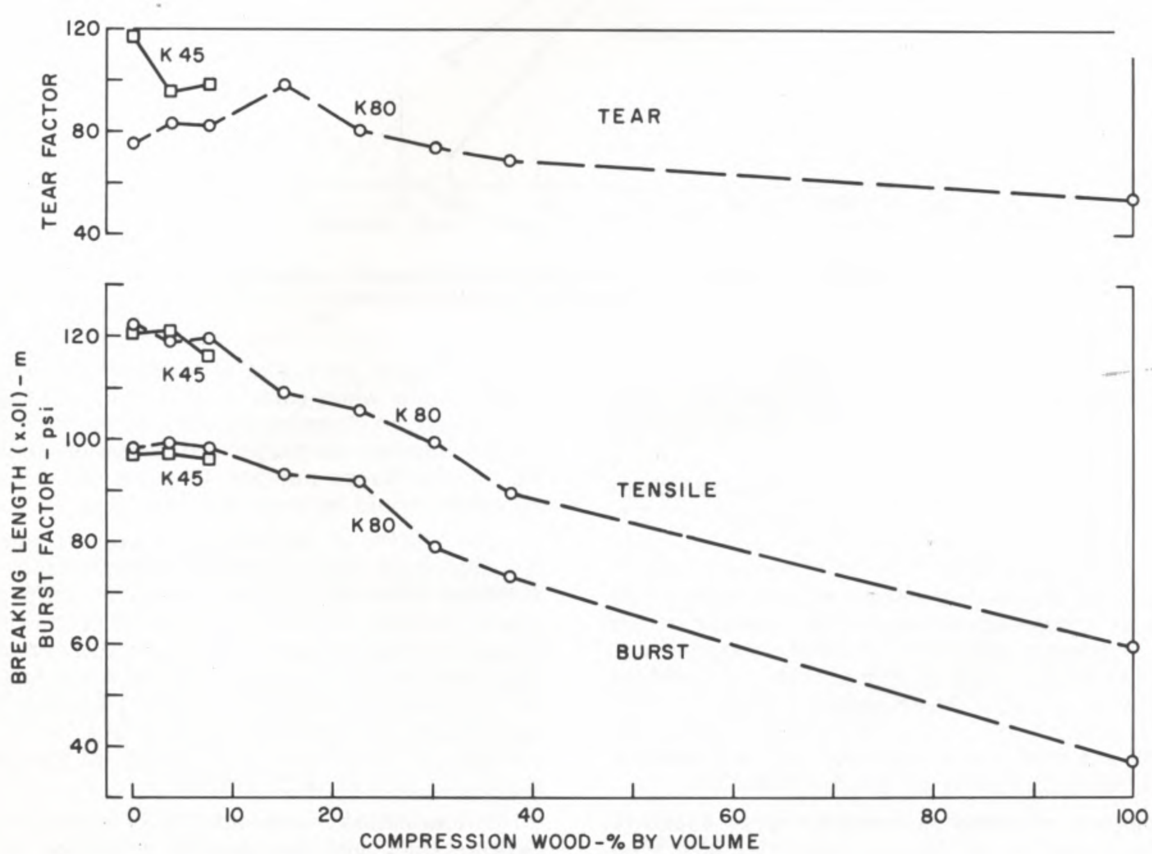

FIGURE 5. — Compression wood content and paper strength.

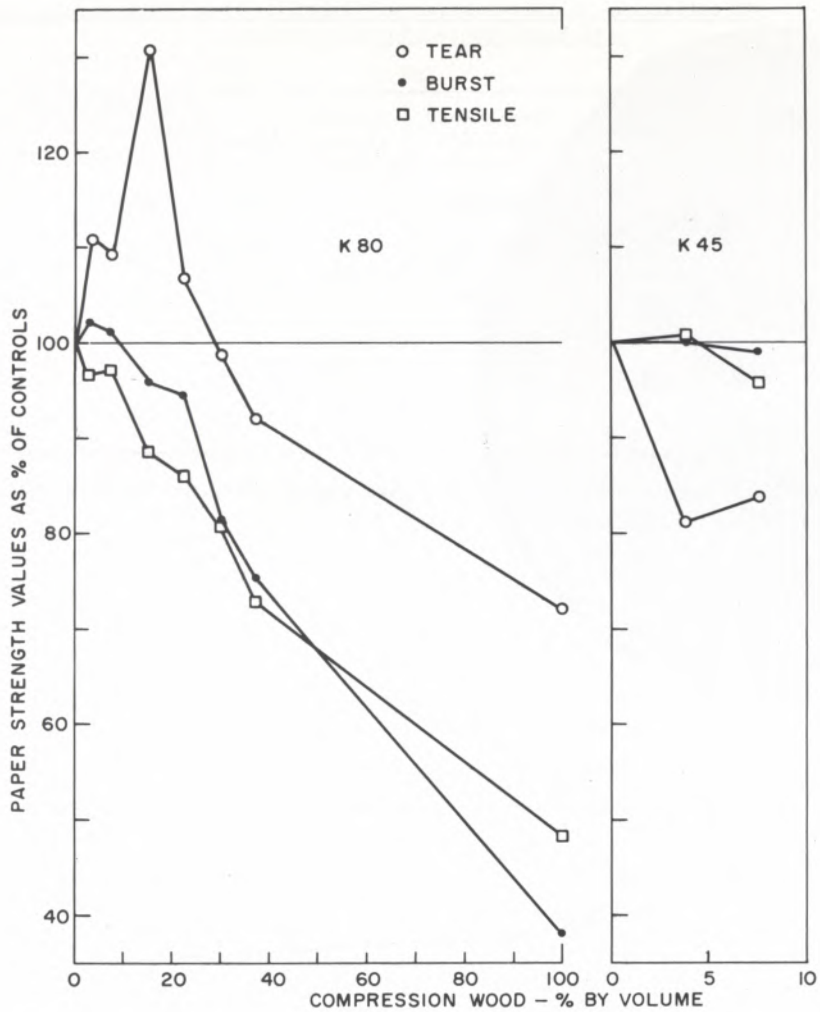

FIGURE 6. — Compression wood and paper strength values expressed as a percentage of the control values.

given by the normal wood fraction. All fractions were cooked to a Kappa number 80, but only three fractions were cooked to the lower Kappa number 45.

Tensile strength of paper made from the pulps cooked to a Kappa number 80 decreased steadily with increasing compression wood content, with pure compression wood having a tensile strength half that of the normal wood used as control. The effect of compression wood when present in the average amount indicated by the investigation discussed earlier — that is, approximately 15 percent by volume — would be to reduce tensile strength by 12 percent. With longer cooking times and Kappa numbers lower than 80, the reduction in tensile strength would be greater than this.

Compression wood in amounts up to about 10 percent appeared to have a beneficial effect on burst strength; the effect, however, disappeared with a longer cook and a lower Kappa number. Compression wood content of 15 percent resulted in a 4-percent decrease in burst strength with the Kappa number 80 pulps. Extrapolation indicated that in the Kappa number 45 pulps the detrimental effect would be even less than this.

The results of the tear tests present some anomalies, with the 15-percent compression wood fractions from the Kappa number 80 pulp giving a tear strength 30 percent greater than the control. It may be that at high Kappa numbers compression wood in small amounts enhances tear strength, but, on the other hand, the results from the Kappa number 45 pulp indicate a 20-percent loss in tear strength. It is felt that this aspect of the results should be treated with reserve.

In summation, these admittedly limited studies indicate that, with the possible exception of tear strength, the strength properties of paper will not

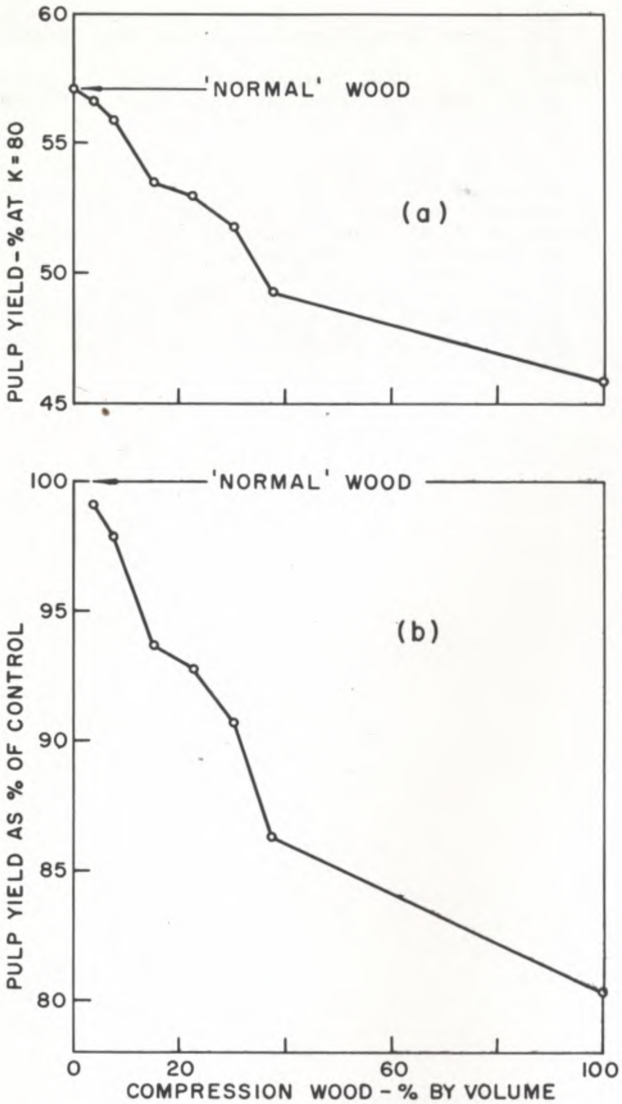

FIGURE 7. — (a) Compression wood content and screened pulp yield; (b) compression wood content and screened pulp yield expressed as a percentage of the yield from "normal" wood.

be affected adversely to an excessive degree by the presence of compression wood in the amounts normally encountered.

The effect on yield, however, could be significant. Screened pulp yields are plotted against compression wood percent in figure 7a, and yield expressed as a percentage of that obtained from the normal compression wood free fraction is plotted in figure 7b. Data presented earlier suggest that 15 percent is not an unrealistic value for the relative amount of compression wood in a stand. This would result in a loss in (chemical) pulp yield of over 6 percent. It would appear then that in a stand of 120-year-old black spruce on a medium site (Site Class 2, Plonski 1956) yielding 2,700 cubic feet or 34 tons of merchantable wood per acre, the loss resulting from the presence of compression wood might be as much as 1 ton per acre, or over 600 tons of usable pulp per square mile.

A more detailed account of this work will appear elsewhere in due course.

Summary

A point sampling system was used to measure the amount of compression wood in over 400 discs from 11 mature black spruce trees grown on a good lowland site in Challies Township, Ontario. Overall mean compression wood content in the 11 trees was found to be 13.9 percent by volume, with mean values in individual trees varying from 5.3 to 26.1 percent. Compression wood content tended to be higher at the base and in the upper crowns of trees. Correlation coefficients were calculated between mean compression wood content for trees and content at each of nine levels within trees. For all except the topmost level sampled, the coefficients were highly significant and ranged between +0.788 and +0.961, indicating strong uniformity of content within trees.

The accuracy of the point sampling method for the determination of compression wood content was confirmed by (sulfite) pulping trials on 68 samples, which showed that compression wood percent and pulp yield were closely correlated (r= – 0.745*"). Other trials indicated that while compression wood present in normal amounts does not result in a serious reduction in paper strength, pulp yields might be reduced by as much as 6 percent. Calculations based on known yields from black spruce stands of the commonest_ site class showed that reduction in pulp yields of this order would result in a loss of about 1 ton of usable fiber per acre.

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