A STUDY OF REACTION WOOD IN
PINUS CONTORTA.

by

JOHN HERBERT.

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CHAPTER 1

INTRODUCTION.

The term reaction wood includes the characteristically abnormal tissues known as tension wood in hardwoods, and compression wood in softwoods. The subject of this dissertation is a quantitative study of compression wood in *Pinus contorta*, (Loudon).

An awareness of the abnormal physical, chemical, and mechanical properties of compression wood, coupled with recent reports by Low (39) on the high incidence of compression wood in locally grown butt-swept Scots Pine, and observations by Mr. A. Moss (unpubl.) on the preponderance of butt-sweep in local stands of *Pinus contorta*, suggested that a study of compression wood in stands of *Pinus contorta*, and its possible implications in the future utilisation of these stands, would be of some value.

The choice of *Pinus contorta*, in preference to other species, was influenced by the following:

1) that the preponderance of butt-sweep in local stands of *Pinus contorta* was likely to be accompanied by considerable formation of compression wood.
ii) since large areas of *Pinus contorta* had been planted over the past 40 years, it was anticipated that a suitable sample area could be located within a reasonable distance of Edinburgh.

iii) that there was no available information whatsoever on compression wood in *Pinus contorta*.

iv) that planting of *Pinus contorta*, on poorer sites, is continuing at a high rate.

v) various statements appearing in Forestry Commission publications recommending the use of *Pinus contorta*, on poorer sites, on purely silvicultural criteria. (MacDonald 42, Wood 73).

Various approaches to the study were considered and it was finally decided to measure compression wood in trees drawn from both inland and coastal provenances.

Quantitative estimates of compression wood in individual stems, and classes of stems defined by the extent of stem deformation, would also be carried out.

Using information drawn from the literature pertaining to the influence of compression wood on pulp yields and quality, it was hoped to establish the value of these stands from a utilisation point of view.
The measurements required to obtain an overall impression of the distribution and amount of compression wood would provide information on the distribution of compression wood within and between individual trees, between classes of trees, and between the selected provenances. It was also hoped to demonstrate a relationship between the degree of stem deviation or butt-sweep, and the total amount of compression wood.

1.1 Objects: The study was designed with the following specific objects in mind:

i) to discover whether there was any difference in the amounts of compression wood formed in the selected inland and coastal provenances.

ii) to attempt to establish a relationship between stem deviation and the amount of compression wood in the tree.

iii) to produce an estimate of the total amount of compression wood in the stands.

iv) to study the distribution of compression wood in the stems.

v) to attempt to correlate the amounts of compression wood found at breast height, with the total amount of compression wood in the stems.

vi) to estimate the volume of reject timber, resulting from excess stem deformation, with the estimate based on Fort William Pulp Mill "round conifer pulpwood" specifications (Anon.1).
vii) to compare the degree of formation of compression wood in several classes of trees, with the classes to be defined by the degree of stem deviation from the vertical.

viii) to discuss the possible effects of the estimated amounts of compression wood on utilisation.

1.2 **Choice of Site:** Various constraints were imposed on any potential sample area in order that both individuals, and provenances, would be strictly comparable.

The area was required to provide reasonably homogeneous stands of inland and coastal provenances of *Pinus contorta* growing adjacent to each other on reasonably flat terrain; the trees to be of an acceptable size (about 6" breast height diameter, and 30' in height), and to have been subjected to similar silvicultural treatments. Further, to be representative in respect of form, provenance, growth rate, and site, of other areas of *Pinus contorta* in Scotland, and to be free of catastrophic effects including windthrow, severe insect attack, fire etc. A total of 40 stems, comprising 20 stems each of coastal and inland provenances, was required to be felled for analysis.
An abandoned provenance trial area in compartment 38, Teindland Forest, Morayshire, was selected for the study (O.S. grid reference NJ 288544 1in. 7th. series, Sheet number 29). The area was not ideal, being exposed, and subject to strong winds (although this is the case in many stands of upland *Pinus contorta*), and with a strictly limited number of stems in each provenance.

1.3 Choice of Provenance: 6 inland and 4 coastal provenances were represented in the experiment. These provenances were laid out according to a randomised block design system, with several replications of each provenance. Planting was from F.Y's 34 to 37 inclusive.

The inland East of Kamloops provenance (this will be referred to hereafter as the Inland or Kamloops provenance) was contained in two extensive (0.227 acre) plots. One of these plots is presently being used for basal area assessments, and was unavailable for the removal of trees. The second Kamloops plot was selected to provide the inland provenance sample for the following reasons:

i) practical considerations.

ii) it has been widely planted in Scotland.

iii) it was representative in form of the other inland provenances present, and other areas which I have seen.
iv) observations by Wood (72) that it appeared to be amongst the more useful of the inland provenances in Britain.

v) the single plot contained a reasonable number of stems (172), from which a sample could be drawn.

Coastal Provenances were represented in several intensive (0.013 acre) plots. Each provenance was represented by about 40 - 50 stems in total; this was not a sufficient number of stems from a statistical point of view, and so the morphologically similar Auchterawe (ex Ruttle-wood) and Coast U.S.A. provenances were combined to represent coastal origin (a total of 111 stems). (These will be referred to hereafter as the coastal provenances).

Further details of the selected provenances, and their distribution is contained on pages 70 and 145. For the origin of the selected provenances, and other detail, see page 147.

Lack of time precluded any pilot sampling to determine whether the amount and distribution of compression wood in these two coastal provenances was similar, but subsequent analysis has shown that in this respect they are virtually identical, and there is no valid reason for not regarding them as one population for the purposes of this investigation.
Introduction: Compression wood is a naturally and widely occurring defect in softwood species. It is formed in the lower sides of leaning trees, the underside of branches (Jacobs et al., 1956), and in the lower sides of any non-vertical components of the tree (Hale & Perem, 1922; Zobel & Haught, 1974). Compression wood is also formed in exposed trees on the lee side (Phillips, 1953; Spurr & Hyvarinen, 1966), the undersides of fallen stems, the lower sides of crooks and deformations, the upper boles of thinned stands, the outer sides of stems close to each other (Spurr & Hyvarinen, 1966), and commonly in hillside trees, widely spaced plantations, and second growth exposed to wind (Hale & Perem, 1922), and in stems bent by the weight of accumulated snow or ice (Anon., 192).

More vigorous stems tend to form more compression wood (Pillow & Luxford, 1958; Spurr & Hyvarinen, 1966).

Compression wood is usually associated with eccentricity of the stem cross section (Perem, 1951; Pillow & Luxford, 1958), and when eccentricity is present, the main areas of compression wood are located on the...
long radii of the cross-section (Jacobs 26, Peren 51).

Stem cross-sections show unusually large proportions of summerwood in the wide (compression wood) rings (Pillow & Bray 56); Kienholtz (34) studying compression wood in Mountain Hemlock quotes figures of 64.7% (increasing to 84.9% near the pith) summerwood on the lower side, and 34.5% summerwood on the upper (non-compression wood) side at 1½' above ground level.

In its well developed forms compression wood is readily recognisable by its darker colour than normal wood (Onaka 50, Watson & Dadswell 71) — usually reddish brown — its eccentricity, and by the greater width of apparent latewood (Watson & Dadswell 71). Obvious crescents of dark compression wood are formed if the lean is marked (Jacobs 26). In thin cross-section compression wood can be detected by its relative opacity to transmitted light according to the method developed by Pillow (55).

In tropical Juniperus procera, (Hochst) compression wood cannot be visually identified by any macroscopic features (Phillips 52).
Spiral formation of compression wood has been reported for coast redwood (Fritz 20), *Picea abies* (L.) Karst, and Alaskan Spruce (Douglass 15).

In logs compression wood is usually identified by eccentric annual rings (Pillow & Bray 56, Pillow & Luxford 58) and colour: in sawn timber it is usually distinguished from normal wood by its relatively wide annual rings, and its non-lustrous appearance which results from the lack of contrast between spring and summerwood (Anon. 2).

2.2 Anatomy of Compression Wood: Numerous descriptions of compression wood anatomy have been published, among the most detailed being Pillow & Luxford (58) and Dadewell et al. (14).

Compression wood tracheids appear rounded in cross-section, with numerous intercellular spaces (Dadswell 11, Dadswell & Wardrop 13). Jacobs (26) stated that tracheids are characterised by the appearance of having been developed under considerable turgor. This is in contrast to the more rectangular or hexagonal appearance of normal wood tracheids (Pillow & Bray 56, Watson & Dadswell 71).

In longitudinal section compression wood tracheids show numerous spiral checks in, or markings on, the
cell wall (Dadswell et al. 14, Watson & Dadswell 71). These striations are oriented at a large angle to the long axis of the cell (Dadswell et al. 14, Pillow & Bray 56).

They are particularly characteristic of compression wood tissues, and have been used by Phillips (52, 53), to identify compression wood in tropical Juniperus procera which exhibits no distinct macroscopic compression wood features.

The secondary cell wall is generally described as being thicker than the secondary cell wall of normal wood tracheids (Dadswell 11, Hale & Perem 22).

Most early reports observed that compression wood tracheids were shorter than normal wood tracheids but practical difficulties in obtaining matched specimens of compression wood and normal wood invalidated many results (Low 40). Recent improvements in technique have now shown beyond reasonable doubt that compression wood tracheids are shorter than corresponding normal wood tracheids. Thus Bisset and Dadswell (1950) are reported by Low (40) as showing that "compression wood development was accompanied by a sudden decrease in tracheid length in Pinus pinaster, Picea sitchensis and Pinus radiata". Through rings eleven to nineteen in Pinus radiata specimens, Watson & Dadswell (71) recorded tracheid
lengths ranging from 2.35 to 2.67 mm. in compression wood, with corresponding normal wood range from 3.17 to 3.71 mm. Dadewell et al. (14) measured the length of pulp fibres prepared from four zones of *Pinus radiata* cross-sections. The average fibre length for compression wood was 2.76 mm, for normal wood 3.85 mm, for opposite wood 3.51 mm, and side wood 3.55 mm. Similar results have been obtained by Dadewell (11) and Onaka (50).

The lack of a sharp distinction between spring and summerwood in the same annual ring of compression wood is attributed by Pillow & Bray (56) to a gradual change in the size and thickness of the cell walls of the tracheids, as compared with a more abrupt change in normal wood. This gradual transition from normal to compression wood has also been recorded by Core et al. (8) and Wardrop (69).

2.3 **Microstructure and Cell Wall Organisation of Compression Wood**: Anomalies in the physical behaviour of compression wood stimulated early research into the structure of compression wood cells. Detailed descriptions of the microstructure of compression wood cells is available in papers by Wardrop (69), Dadewell & Wardrop (13), Dadewell (11) and Onaka (50).

The secondary cell wall is a complex structure
usually consisting of an outer \( s_3 \) layer, a middle \( s_2 \) and an inner \( s_1 \) layer (Dadswell et al. 14). In compression wood cells the secondary cell wall consists of only 2 layers - the \( s_1 \) and \( s_2 \) - and the \( s_3 \) is absent or only very weakly developed (Dadswell et al. 14, Wardrop 69).

The outer \( s_1 \) layer is somewhat wider in compression wood than normal wood (Dadswell et al. 14, Watson & Dadswell 71), but the organisation of this layer appears to be the same in both tissues (Dadswell et al. 14). The \( s_2 \) layer is characterised by discontinuities in its structure, readily observed in longitudinal section. These discontinuities have variously been defined as oblique cracks (Phillips 52), radial cracks (Onaka 50), helical fissures (Wardrop 69), radial discontinuities (Dadswell 11, Watson & Dadswell 71), and appear to be highly characteristic of compression wood tissues in both the green and dried conditions. They have been used to define transitional (Wardrop 69) and macroscopically indistinct (Phillips 52, 53) forms of compression wood. Wardrop (69) notes the continuity of structure of compression wood and normal wood, and observes that even in partially differentiated compression wood these checks are very obvious near the middle of the cells although they may be absent near the tips.

The width of the checks varies greatly with species
eg. coarse in *Pinus* species, but extremely fine in *Araucaria* species (Dadswell et al. 14).

Watson & Dadswell (71) state that in cross-sections the checks are visible and..."can be imagined to consist of spirally arranged ribbons of cell wall material, the longer narrow edge of which is attached to the adjacent cell wall layer".

Amongst other techniques, growth of iodine crystals in secondary cell walls and swelling behaviour in strong acids and alkalis have shown that secondary cell wall microfibrils are helically arranged along the long axis of the cell (Wardrop 69). A high degree of microfibril (micellar) angle is characteristic of compression wood (Dadswell 11, Dadswell & Wardrop 13): Pillow et al. (57) report for *Pinus taeda*, compression wood microfibril angles of 30° to 45° and for comparable normal wood 5° to 10° (relative to the long axis of the cells). Pillow & Bray (56) measured microfibril angle in specimens of normal wood, mild compression wood and pronounced compression wood, for both spring and summerwood. Specimens were taken from the same *Pinus taeda* tree and microfibril angles were 22.8°, 30.9°, and 35.1° respectively for springwood, and for summerwood 4.8°, 23.1°, and 29.3° respectively. Harris & Meylan (24) report large microfibril angles for compression wood (up to
but found that in *Pinus radiata* the range of angles observed lay within the range observed for normal wood (normal wood including both juvenile and mature tissues).

The radial checks parallel the microfibril orientation of the $s_2$ layer (Dadswell 11, Wardrop 69), and the apertures of bordered pits extend along these checks indicating microfibrill angle (Onaka 50).

Although a large microfibril angle is characteristic of compression wood tracheids, Dadswell (11) and Harris & Meylan (24) have found that a comparably large micellar angle is frequently associated with shorter juvenile tracheids, and that there is a regular decrease in microfibril angle in the transition from juvenile to mature wood tissues. (Dadswell 11, Wardrop 69). In softwoods the change may be from $55^\circ$ to $20^\circ$ (Nicholls & Dadswell unpubl. data, quoted by Dadswell 11). Harris & Meylan (24), in studying *Pinus radiata*, report a range in microfibril angle of $15^\circ$ to $40^\circ$ for fifteen juvenile (7 year old) trees; two 36 year old trees showed a microfibrill angle range of $2^\circ$ to $35^\circ$, and core wood from a mature stem had microfibrill angles in the region of $35^\circ$ to $45^\circ$. 
Chemical Characteristics of Compression Wood: It has been widely and consistently reported that compression wood differs significantly in chemical composition from normal wood. In particular, it possesses a greater amount of lignin and a lesser amount of cellulose (both alpha and total cellulose) in its structure (Dadswell et al. 14, Pillow et al. 57). Zobel et al. (75) found a high negative correlation between cellulose yield and compression wood percentage for *Pinus taeda*. Working with *Sequoia* species, Pillow & Luxford (58) found the lignin content of compression wood to be 5% greater and the cellulose content 8% lower than normal wood. Chemical analysis of several Canadian conifers (Hale & Perem 22) showed that compression wood itself is variable, with the cellulose content increasing with age and decreasing with height. Variation in chemical components existed between degrees of compression wood formation. For compression wood, values of 27 to 39% cellulose and 33 to 40% lignin were obtained (compared to about 50% cellulose and 27% lignin in normal wood). In compression wood the lignin content sometimes exceeded the cellulose content. Pillow & Bray (56), comparing pronounced compression wood from a single *Pinus taeda* butt log with the average of results of normal wood from a number of *Pinus taeda* stems, quote the following figures (normal wood in brackets): total cellulose 46.1% (58.7%); alpha
cellulose 34.6% (45.7%); pentosan 12.2% (12.4%); lignin 35.2% (28.3%). Analysis of Pinus radiata for pulp studies (Watson & Dadswell 71), indicated 24.2% lignin in normal wood, and 32.8 to 34.4% lignin in compression wood. Pentosan yield was also lower for compression wood.

Chemical organisation in the primary wall of the tracheids, appears to be the same for compression wood and normal wood (Dadswell et al. 14). Onaka (50) found the secondary wall of compression wood tracheids to be relatively strongly lignified compared to normal wood. Further to this Lange (36), using microspectrographic techniques, found for Picea excelsa, Link. that the secondary walls in both compression wood and normal wood contained little lignin compared to the compound middle lamella. Excess lignin in compression wood was located in these lignin poor secondary walls. For Pinus radiata, there appears to be a considerable concentration of lignin between the s1 and s2 layers in the secondary walls of compression wood (Dadswell et al 14.).

2.5 Mechanical Properties of Compression Wood: Mechanical properties of compression wood have been variously recorded as comparing favourably or unfavourably with normal wood. Perem (51) and Onaka (50) have prepared comprehensive reviews on this aspect
of compression wood.

It is now widely accepted that compression wood is lower in tension parallel to grain, and lower in modulus of elasticity (Perem 51, Pillow and Luxford 58). Compression wood has a higher specific gravity than normal wood (Pillow & Luxford 58, A.J. du Toit 68); for 5 species of softwood Pillow & Luxford (58) reported compression wood as being from 15 to 40% heavier than comparable normal wood. This range is presumably accounted for by varying degrees of compression wood formation. A.J. du Toit (68) found for Pinus radiata that compression wood and opposite normal wood from the same height in the same tree had specific gravities of 0.470 and 0.451 respectively, whilst normal wood from a second tree had a specific gravity of 0.401.

Compression wood is higher in modulus of rupture, work to maximum load, total work, toughness, and crushing strength parallel to grain (Pillow and Luxford 58). Onaka (50) reports, however, that compression wood is usually less tough, but is greater in hardness in all directions.

Dadswell (11) records low impact strength for compression wood, and both Pillow & Luxford (58) and A.J. du Toit (68) state that when adjustments
are made for the greater density of compression wood it is weaker in all strength properties except hardness. There is some debate about this point for Perem (51), in a comprehensive study of the effect of compression wood on the mechanical properties of _Picea glauca_ (Moench) Voss. and _Pinus resinosa_ Sol., found that for compression parallel to grain, and static bending, that the relative weakness of the compression wood cell wall was more than fully compensated for by the greater amounts of cell wall substance per unit volume. He concedes, however, that generally, on a unit weight basis, structural organisation in compression wood is inferior to that of normal wood under the effect of mechanical stresses. Even slight forms (he defined 3 degrees of compression wood formation ranging from scarcely noticeable to that in which the apparent summerwood occupied more than 50% of the ring width) tended to lower specific strength, and specific strength decreased with increasing completeness of compression wood development.

It may be that in earlier measurements of the mechanical properties of compression wood, too little attention was paid to degrees of formation of compression wood.
2.6 Shrinkage Characteristics of Compression Wood:

Abnormal longitudinal shrinkage of compression wood is reported throughout the literature. For example, Pillow & Luxford (58) report longitudinal shrinkage for compression wood and normal wood as 0.3 - 2.5% and 0.1 to 0.2% respectively. For pronounced compression wood, longitudinal shrinkage was up to 5%.

Radial and tangential shrinkage were slightly lower for compression wood.

Onaka (50) found that the transverse shrinkage of compression wood was about half that of normal wood, whereas longitudinal shrinkage was greater. Core et al. (8) note abnormal longitudinal shrinkage of compression wood, and Dadswell (11) reports longitudinal shrinkage of up to 10% in drying compression wood from green to the oven dry condition.

A.J. du Toit (68) studied shrinkage in 100% compression wood, normal wood from the opposite side of the same tree, and normal wood from a tree with very little compression wood. Compression wood exhibited the highest longitudinal shrinkage, then opposite normal wood, then normal wood from the second tree. Transverse shrinkage was least in the compression wood samples.
Kelsey (32) found the longitudinal shrinkage/moisture content relationship for compression wood in *Pinus radiata* quite different from that of normal wood. For compression wood, shrinkage commenced at high moisture contents (about 30%) and increased linearly down to about 8% moisture content, when it became more rapid. For normal wood, shrinkage did not vary linearly over any of the moisture content range. Between green and 8% moisture content, a small contraction or expansion was recorded, but on further drying an appreciable contraction occurred. Maximum longitudinal shrinkage of compression wood to the oven dry state varied from 1.07 to 2.08%, for normal wood from 0.19 to 0.37%. Transverse shrinkage of compression wood varied from 3.96% to 6.44%, and was influenced by the drying method.

The abnormally high longitudinal shrinkage of compression wood has commonly been assigned to the large microfibril angle (longitudinal shrinkage decreases markedly with increasing steepness of the microfibril angle, Kelsey (31)) and the abnormal secondary wall structure of compression wood (Dadswell 11, Kelsey 31). However, on the basis of his measurements, Necszany (49), whilst conceding that shrinkage is influenced by chemical composition and microfibril orientation of the secondary cell wall, concludes... "that the middle lamella is the most important
morphological constituent of the wood affecting the extent of swelling and shrinkage", and that the cell wall plays a smaller part than has been assumed so far.

The abnormally high longitudinal shrinkage of compression compared to normal wood almost invariably causes distortion(warping, bowing, cupping etc) when found together in the same piece of timber. (Jacobs 26, A.J. du Toit 68).

2.7 Formation of Compression Wood in Relation to Stem Deviation and Tree Vigour: It has been reported in the literature that the degree of formation of compression wood is related to stem deviation (Pillow et al. 59, Zobel & Haught 74) and tree vigour (Curran 10, Spurr & Hyvarinen 66).

Although the evidence is often conflicting in relating the degree of deviation to the degree of compression wood formation, it is apparent that stem deviation is the main factor in initiating and maintaining compression wood formation. This statement is based on two widely accepted theories(a) that compression wood is of a functional nature in the correction of deviation from the vertical (Jacobs 26, Mergen 46) (b) that compression wood formation is in some way initiated by auxins, which themselves are considered
to be at least partly influenced by gravity, and would therefore tend to concentrate on the lower sides of leaning stems (Onaka 50, Spurr & Hyvarinen 66).

Fielding (18) remarks that leaning and butt-swept trees are subject to compression wood formation. Johnston (29) observed that Pinus patula growing on steep slopes tended to become bent, and because of this had formed compression wood. Pillow et al. (59) state that... "the percentage of trees forming compression wood increases as the vigour or the amount of inclination of individual trees increases" and... "trees which lean large amounts more frequently form compression wood than those that are only slightly inclined". In a Black Spruce stand where many trees had become inclined at an early age, about 55% of the stems had formed pronounced compression wood in the lower portion of the tree, and in a stand with more nearly vertical stems, only about 30% of the stems had formed pronounced compression wood. Pillow et al. (57) conclude that a stand in which many of the trees are inclined, irregularly spaced, or with crooked or bowed stems, is indicative of large amounts of compression wood in the stand. In a hurricane inclined Longleaf Pine stand, Pillow (54) found that compression wood was initiated in trees which had
previously been vertical and without compression wood, and compression wood was maintained or increased in amount in those stems which had previously formed compression wood.

Zobel & Haught (74) selected 15 Pinus taeda stems and divided them into 3 deviation classes - essentially straight, intermediate and crooked. The trees were felled, cut into 2' sections and discs were removed from the tops of the sections. There was an increase in compression wood formation from an average of 6% to 9% to 16% for the three classes respectively. An additional extremely crooked tree contained 67% compression wood. Deviation in these trees was in the form of inherent twist or corkscrew, rather than bend or sweep. Holmes (1944), reported by Low (40), found in 22 White Pine stems inclined by a hurricane 5 years previously, that in two broad classes of lean - slight (\(< 20^\circ\)) and pronounced (\(\geq 40^\circ\)) - that the main percentage of compression wood in the cross-section was significantly higher in the pronounced lean class at a height of 1, 4\(\frac{1}{2}\) or 8' up the stem. At higher levels there were no significant differences and this he attributed to rapid straightening in the upper parts of the trees of both groups.

McElwee & Zobel (45) divided 160 stems of Pinus serotina, Michaux, drawn from an extensive area into
3 deviation classes. In contrast to the above reports they could find no correlation between stem straightness and the amount of compression wood, but results were drawn from breast height increment cores only. Low (39) obtained data from twenty 33 year old Scots Pine stems, all showing "sickle shaped" curvature in the basal 10", and differing only in the degree of curvature. A series of deviation measurements failed to provide any close relationship between compression wood percentage and stem deviation. A subjective division into very slight, slight, moderate, and pronounced deviation classes showed differences between mean compression wood percentages for the former 3 classes to be negligible, and the difference for the pronounced class significant only at the 5% level.

Pillow & Luxford (58) studying Pinus ponderosa, Doug. found that trees with 3 - 5° of lean which had recently formed compression wood showed more than twice the rate of diameter growth than trees of similar inclination with no compression wood. Trees with lean greater than 5° showing no compression wood were non-vigorous. In a study of several hundred Pinus taeda and Pinus palustris, Mill. stems they found that compression wood formation increased as the rate of diameter growth increased, and for a given rate of diameter growth the
the proportion of trees forming compression wood increased with increasing stem deviation. In a mixed *Pinus palustris/Pinus taeda* stand increased growth rate, resulting from thinning 40 years previously, was paralleled by an increase in the proportion of trees forming compression wood (Pillow & Luxford 58). Johnston (29) comments that formation of compression wood in South African stands may be aggravated by the type of thinning currently prescribed.

Holmes (1944), reported by Low (40), grouped his sample trees into 2 vigour classes (those with \(<10\text{mm.}\) and those with \(>10\text{mm.}\) radial growth in the 5 year period before inclination). Radial growth on the lower side of the stem during the 5 year period of compression wood formation was found to be significantly higher for the more vigorous trees at all levels investigated (1' to 32'). Low (39) showed that in a total of 112 Scots Pine stems, the smaller stems tended to smaller average percentages of compression wood in comparison with the larger and more vigorous stems, but no definite trends were apparent.

Curran (10) notes that "compression wood occurs frequently in rapidly growing trees"... and that compression and associated abnormal fibres are found
in trees... "where the growth in early life has been extremely rapid".

2.8 Quantitative Estimates of Compression Wood in Stems and Stands: There is a paucity of information on the quantitative distribution of compression wood in individual stems, or stands. This is unfortunate in view of the potential effects of compression wood on sawn timber, pulp yields, and paper quality.

The position of compression wood formation varies with the orientation of the stem. Kienholtz (34) records the apparent summerwood percentage of the total annual ring width on the lower side of the stem as 67.4% (upper side 43.2%) at the 1½' level, but at the 6½' level over-correction had caused the proportions to be reversed, with the "upper" side showing 36.9%, and the original lower side 27.5% apparent summerwood. Low (39) found similar changes in the orientation of compression wood in Scots Pine.

Watson & Dadewell (71) examined cross-sections of *Pinus radiata* stems that had grown normally for a number of years, had then been blown over, and had continued to grow in a horizontal position. Compression wood formed in the lower side immediately the horizontal position was assumed.
Mergen (46), studying compression wood formation in the drooping terminal shoot of *Tsuga canadensis* (L) Carr. determined this compression wood to be of a corrective nature, and confined to the pith and first formed growth ring.

Zobel et al. (75) sampled dominants and co-dominants at the 4.5' level with an increment bore. For 14 plots of *Pinus taeda*, each containing 22 trees, results showed that between sample variation for compression wood was large, that the variation amongst plots was highly significant, and that the differences between trees were not significant. The cores indicated that the bulk of the compression wood was in those rings close to the pith. No actual compression wood values were reported.

Sectioning stems at 8' intervals up the stem, in three different aged *Pinus echinata*, Mill. stands, indicated, in each stand, a progressive decrease in the percentage of stems forming compression wood at successive heights above ground level, but for *Pinus clausa*, Vasey, the number of stems showing compression wood at successive heights was almost constant (Pillow & Luxford 58).

Low (40) points out that there is some conflict as to the relative proportions of compression wood in the butt and upper portions of the tree. He quotes Hale and Perem (22) and Paul and Smith (1950) as reporting
a concentration of compression wood in the butt. Kienholtz (34) obtained similar results for Mountain Hemlock. Pillow et al. (59) state... "compression wood is most commonly found in the lower portions of trees". In an examination of pulpwood prepared from two stands of black spruce, they found that about 80% and 60% respectively, had compression wood at stump height. At the 8' level, only 25% of trees from both stands had compression wood, and above this height the percentage decreased to 10% or less. Pillow (54) found that in a hurricane inclined Longleaf Pine stand, 33.9% of sections from the upper portion, and 6.9% of sections from the lower portions of the trees showed compression wood. On the other hand, Low (39) found, for 20 comprehensively analysed Scots Pine stems representing a full range of stem deviation, that the mean percentage of compression wood increased from the butt section (about 19%), to breast height (about 28%), and then remained relatively constant to timber height at 24%. Differences between the mean butt measurements, and breast height and 20' sections were significant at the 1% level of confidence. Pillow (54) states .... "other observations have shown that compression wood is usually more frequently found in the lower portions of the stem". It is true that the lower portion of a stem remains inclined longer than the upper portion, and hence there is an apparently greater opportunity for the formation of compression
wood in the butt (Pillow & Luxford 58). However, this ignores the fact that over-correction of the vigorous top portion (Jacobs 26, Low 40) can lead to the formation of compression wood in a zig-zag fashion up the stem (Kienholtz 34, Low 39).

Phillips (52) selected butt logs of Juniperus procera ranging in form from very fluted to non-deformed and, for analysis of compression wood, superimposed predetermined radii on the cross-sections. He found that in all the logs studied compression wood was present in a central 5 - 6" core. In a later study Phillips (53) compared the formation of compression wood in 2 exposed and 2 plantation grown stems of the same species. Discs were cut from the tops of bolts removed from butt, mid, and top portions of the merchantable bole. Two diameters were drawn on each disc, one corresponding to the prevailing wind direction, and the second at right angles to this. Under microscopical examination, and assuming "that this tissue extended as a quarter circular arch about any radius in which it was detected", he calculated the percentage of compression wood as 23% and 24% respectively for the two open grown stems, and 7% and 8% respectively for the plantation grown stems.

Low (39) selected 20 plantation grown Scots Pine stems so as to correspond with the mean breast height girth
of the stand. A series of deviation measurements were taken, but a significant correlation between stem deviation and the percentage of compression wood was found for only one measurement, relating to the basal 10' of the stem. Actual percentage of compression wood ranged from 7.9% to 45.5% in the whole stem, and from 6.9% to 50% in the basal 10'. The same stems were subjectively divided into very slight, slight, moderate, and pronounced deviation classes and the following mean compression wood percentages obtained (whole stem; basal 10' in brackets): 25.3 (24.0), 24.5 (22.3), 23.2 (22.7), 35.0 (39.3) % respectively. Differences between very slight, slight, and moderate were negligible, and differences between pronounced and other classes were significant at the 5% level only. Low also obtained compression wood data from 7 plots of 16 trees each, in Scots Pine stands. These comprised 24 to 40 year old trees, sampled to a top height of 3" diameter (u.b.). By measuring compression wood in cross-sections removed from the mid-point of every second internode, he found that compression wood formed from 5.4 to 57.1% of the total volume (u.b.), and from 21.2 to 41.5% of the total volume of the stand (u.b.).

McElwee & Zobel (45) drew samples from 6 areas in the Pinus serotina range, with each area represented by 3 plots of 10 trees each. The plot average for compression wood ranged from 10.9 to 44.8% and individuals
from 3 to 62%. These measurements were from breast height increment cores only, and further...."much of the core wood contained compression wood", and was neglected!

Holmes (1944) studying compression wood in White Pine inclined by a hurricane, is reported by Low (40) as sectioning...."22 trees at heights of 1, 4½, 8, 16 and 24' and found that the mean proportions of compression wood in cross-sections were 68.7, 68.5, 65.6 and 57.8% respectively, thus showing a tendency to decrease upwards in the tree.

Longleaf Pines, forced out of the vertical by a hurricane, were examined for compression wood by Pillow (54). A series of sections from ground level to 18' and the 18' immediately below 3" top-diameter were measured. Compression wood formation was initiated or increased following inclination: 33. 9% of the sections from the top 18' contained compression wood, and only 6.5% of the sections from the lower 18'.

Zobel & Haught (74) classified 15 Pinus taeda stems as essentially straight, intermediate, or crooked. Cross-sectional discs were removed at 2' intervals and measured for compression wood. Averages for the three classes were 6%, 9% and 16% respectively. One very crooked 51 year old stem contained 67% compression
wood in the merchantable bole.

In a study of the pulp quality of *Pinus elliotii* Engelm. Einspahr et al. (17) measured compression wood, in stem cross-sections removed at intervals of 7.5 feet up the stem, in 24 systematically chosen dominants and co-dominants in a 28 year old stand. The percentages of compression wood in the trees ranged from zero to 90%, with a mean of 35% and a standard deviation of 19.5%. No information was given on the distribution of compression wood up the stem.

2.9 Environmental Effects Associated with the Formation of Compression Wood: There have been a great many reasons advanced for the formation of compression wood but indications are that wind may be the principal causative agent by acting indirectly on the tree to produce lean, with its associated compression wood. Kienholtz (34) lists gravity, light, longitudinal tension and pressure, radial pressure exerted by the bark, and nutritional relationships as contributory causes. In addition Spurr & Hyvarinen (66) suggest moisture requirements, growth substances, galvanotropism, and growth rate, and conclude that compression wood formation is a response to a deforming force, and that this deforming force is most frequently gravity but may be of another character. Dadswell & Nicholls (12) concluded that compression wood was...
"largely an environmental factor", rather than structural.

Pillow & Luxford (58) observed that when young, the stem, or leader, is more susceptible to whip and wind effects, but becomes stiffer with age and there is less compression wood formation.

Examining cross-sections of two exposed and two sheltered (plantation grown) stems of Juniperus procera Phillips (53) found that compression wood tended to develop on the lee side of the stem, although not always diametrically opposite to the prevailing wind direction. Distribution of compression wood was similar in all stems but the amount was reduced in the plantation grown stems.

Watson & Dadswell (71) observed that compression wood formation is particularly noticeable in wood from an area of forest subjected to strong prevailing winds, or cyclonic disturbance. In a hurricane inclined *Pinus taeda* stand, Pillow (54) found that trees inclined by the hurricane had tended to immediate formation of compression wood. In measuring lean in a region of strong prevailing winds in South Australia, Fielding (18) recorded, for a 24 year old plantation grown *Pinus radiata* stand, that 97.2% of the stems had some degree of lean. With an increasing degree of lean, butt-
sweep, with it associated compression wood, tended to develop. Low (39) studying stem deviation in Scots Pine, grouped all the trees represented in 7 sample plots (121 - 138 trees per plot) into 12 30° directional classes. He concluded that stem deviation was not directionally random and that the majority of stems leant away from the prevailing wind direction.

Phillips (52) in studying Juniperus procera acknowledged that compression wood is usually associated with irregular growth, but in failing to find any relationship between stem fluting and compression wood formation concluded that it is associated with eccentric stem development rather than local wide ringed projections (flutes).

Compression wood formation associated with ridges developed over compression failures in Pinus strobus. L. is reported by Mergen & Winer (47).

Tsuga canadensis has a growth habit of drooping terminal shoots which turn upwards as the growing season progresses. Mergen (46) found zones of compression wood reflecting the orientation of the leader when the compression wood was laid down. If the leader was forcibly held upright throughout the growing season, no compression wood was formed. He concluded that in
this species there is the need to form tissue (compression wood) which is of a corrective nature.

In the case of Pinus strobus, Spurr & Friend (65) report formation of compression wood at the node where one of the laterals takes over the function of leader when the original leader has been killed by Pissodes strobi (Peck). Compression wood was confined to the lower side of the pith offset and outwards. McElwee et al. (45) indirectly attribute some compression wood formation in Pinus serotina to fire. Fire causes stem-buds to shoot and the shoots curve upwards with compression wood being formed in the lower side. He also records compression wood formation resulting from repeated, severe, tipmoth attacks.

Core et al. (8) note that compression wood "appears to develop as the result of some stimulus to the cambium when the tree is forced out of its normal growth pattern", whilst A.J. du Toit (68) considers the most likely theory of formation is by the interaction of the distribution of auxins, and gravitational forces. Onaka (50), on the basis of experiments with auxins, concluded that the direct cause of compression wood formation is the accumulation of auxin in excess of normal amounts on one side of the stem.

It appears that much formation of compression wood is
the result of stem deviation induced by wind effects, followed by gravitational effects producing a greater concentration of auxin in the lower side of the stem. The latter appears to directly stimulate formation of compression wood.

2.10 **Effects of Compression Wood in Structural Timbers:**

In estimating the potential effect of any abnormal tissue in timber, the end use of that particular timber must be defined. As a general purpose, easy working softwood, normal wood of *Pinus contorta* is eminently suitable.... "it is soft, straight-grained and of fine uniform texture", is non-resinous, seasons evenly and uniformly, and finishes well (McElhanney 44). In association with compression wood, however, serious degrade is found owing to peculiarities in the technical structure of compression wood (Onaka 50) as compared to normal wood.

Tieman (67) comments that owing to the different shrinkage properties of compression wood and normal wood, irregular distribution of compression wood in a board causes tremendous internal stresses to be set up. He notes that much warping and twist in timber is due to compression wood, and that stresses may even exceed the tensile strength of the timber, causing it to fracture.

A.J. du Toit (68) records that the degree of development
of compression wood, and its relative volume, have a
definite effect on the amount of warp and twist in a
piece of timber. He further notes that warp and twist
are to be expected even in full sized clear grades con-
taining compression wood.

Warp, bow, cup, twist, brittleness, check etc., is
variously reported for timber containing compression
wood eg. Pillow & Luxford (58) and A.J. du Toit (68).
Phillips (52) reports that warp in sawn timber of the
tropical Juniperus procera is due largely to compression
wood.

Compression wood tends to cause "bind" in felling and
milling (Pillow & Luxford 58), and is objectionable in
sawing and utilisation generally (Mergen & Winer 47).

The re-sawing of large boards containing compression
wood results in serious distortion of the resultant
small dimension stock owing to the release of stresses
set up by the differential shrinkage of compression and
normal wood tissues in the original board (Anon. 2).
This author further notes that timber containing comp-
pression wood shows excessive "working" in structural
uses due to the high shrinkage of compression wood being
balanced by a correspondingly large swelling when moisture
is resorbed during humid changes.
Timber containing compression wood is denser and more difficult to nail and work than normal wood (Anon.2), and Core et al. (8) conclude, that compression wood should be excluded from any use where its abnormal properties could contribute to eventual failure of the product.

2.11 Pulping Properties of Compression Wood: The literature on pulping properties of compression wood is not extensive, and the following information is drawn mainly from papers by Green & Yorston (21), Curran (10), Watson & Dadswell (71) and Dadswell et al. (14).

It is of interest to record that Pinus contorta is normally favourably regarded as a pulping timber. Pinus contorta kraft pulp has a particularly high bursting strength and is very desirable for blending with and improving the properties of low bursting strength Douglas Fir kraft pulp (Anon.3). McElhanney (44) indicates the suitability of Pinus contorta for pulp, and Edwards (16) states that...."more recently it has come into prominence again for wood pulp" (1955).

In the sulphite process, not only does compression wood cause degrade in pulp strength, quality and yield, but Green & Yorston (21) first reported an...."acid susceptible wood" and that this tissue...."is very frequently associated with compression wood".
Pulps prepared from it had low strength characteristics. Curran (10) reported that wood associated with compression wood is frequently abnormal (in physical rather than chemical properties), and Watson & Dadswell (71) and Dadswell et al. (14) found, in *Pinus radiata*, that pulp prepared from heartwood and opposite (to compression wood) zones had low strength properties. Examination of the pulp showed many broken fibres from fracture at the many slip planes and compression failures in tissue from these zones. These tissues are analogous to the "acid susceptible wood" of Green & Yorston (21), with acid cooking conditions causing fragmentation at these cell wall deformations. Acid susceptible wood includes any tissues in which cell wall deformations are common: frequently opposite wood and wood on the pith side of compression wood zones, is acid susceptible (Dadswell et al. (14), Watson & Dadswell 71). Green & Yorston (21) carried out tests on pulp prepared from about 50% acid susceptible wood. They found it less bulky, and with lower bursting and tearing strengths than normal wood pulp. Results indicated..., "that a small percentage of undesirable compression wood may be associated with a much larger quantity of wood which is apparently normal, but which gives a weak sulphite pulp".

Dadswell & Nicholls (12) comment that thick walled compression wood fibres are less desirable for many
pulp strength properties rather than finer walled early wood fibres. The coarse compression wood fibres tend to form coarse textured paper (Curran 10).

There is little doubt that the spiral checks or discontinuities in the secondary cell wall of compression wood fibres are responsible for low strength properties. Fragmentation readily occurs along these lines of weakness (Pillow et al. 57, Watson & Dadswell 71) and this particularly affects yield, and tearing and bursting strength.

Sulphate pulps are least affected by compression wood in the raw material. Pillow & Bray (56) used pulp prepared from 100% compression wood of Pinus taeda and compared it to pulp prepared from normal slab wood. Lower yields (compression wood 42.4%, normal wood 48.5%) and decreases in strength properties and chemical purity were observed. Tearing strength, freeness, and folding endurance were lower; total and alpha cellulose contents about 3% lower and lignin content considerably higher. Increased fibrillation was observed in compression wood fibres. Screen analysis showed 74.8% normal wood and 31.0% compression wood was retained on a 24 mesh screen; 6.0% normal wood and 41.5% compression wood passed through a 150 mesh screen.
Weak, extremely shivy compression wood pulps are reported by Curran (10), and Pillow et al. (57) report lower yields and lower bursting and tearing strength in pulps prepared from compression wood.

Sulphate processed compression wood pulps have markedly higher bleach requirements. (Curran 10, Dadswell et al. 14) and consumption of chemicals is higher (Curran 10) in pulp preparation.

For Pinus radiata, Watson & Dadswell (71) prepared pulp from 100% compression wood, normal wood, side wood, opposite wood, and heartwood. Under the same cooking conditions well cooked shive-free pulps were obtained from all zones. Compression wood yields were 5 - 10% lower than yields from other zones, with a lower cellulose content and up to 10% higher lignin content. Compression wood pulps were lower in burst, tear and folding endurance. Less fibrillation was observed for compression wood fibres. Tests showed that the high lignin content did not account for the poor strength properties of compression wood pulps. Dadswell et al. (14) report very similar results, again for Pinus radiata. Compression wood pulp yields were about 9% lower than normal wood yields.

Sulphite pulps are markedly affected by compression wood in the raw material. Watson & Dadswell (71)
report for 100% compression wood from *Pinus radiata*, a 14% lower pulp yield, high lignin and low cellulose contents, low burst and tear strength, and low folding endurance (in comparison with pulps prepared from normal wood). Excessive numbers of broken fibres were observed after beating. Dadswell et al. (14) obtained similar results from *Pinus radiata* and note that the pulp is difficult to bleach. Curran (10) working with *Pinus taeda* compared pulps prepared from compression wood and normal wood. Raw material from the same log, and prepared under the same regime, gave a 10% reduction in yield, and a much darker unbleached pulp with a much higher bleach requirement. Although normal wood pulps... "required only 15% of bleach, the pulp from compression wood was practically unbleachable". He found that compression wood pulps showed a reduction of approximately 50% in strength properties, and with only 20% furnish of compression wood sulphite pulp in a newsprint run, differences in pulp properties were evident to an appreciable degree in the newsprint produced.

Groundwood pulps are again adversely affected by appreciable amounts of compression wood. Pillow et al. (59) working with Black Spruce, compared pulps made from green timber virtually free of compression wood, green timber with much compression wood, and dry timber with pronounced compression wood, to normal commercially
produced pulp. The pulp prepared from all samples containing compression wood had larger proportions of fine fibre fragments, freeness values were much lower, and compression wood pulps were lower in strength properties. The tearing action of the grinding stone caused compression wood fibres to break across the secondary cell wall discontinuities. Thus in groundwood pulps, the shorter compression wood tracheids, with their spiral checks, tend to disintegrate more readily, and consequently pulp strength is reduced (Anon., 2).

Using a Baur defibrator, Watson & Dadswell (71) attempted to compare pulps prepared from compression wood, normal wood, opposite wood, side wood, and heartwood zones. However, the compression wood fibres invariably fragmented and, unlike pulp from the other zones, could not be formed into sheets.

The deleterious effects of compression wood are most serious under acid or mechanical pulping processes (Dadswell et al. 14). Sulphate processing, even with 50% compression wood, resulted in pulps acceptable for most purposes (Watson & Dadswell 71). However, sulphite processing of compression wood resulted in considerably decreased yields and weaker pulps. Further... "the presence on the pith side of the compression wood bands or zones, and in some cases on the opposite side of the stem, of "acid susceptible
wood”, ...."results in a very weak pulp on acid cooking" (Watson & Dadswell, 71).

Even with relatively small proportions of recognisable compression wood it appears that considerable reductions in both pulp yield and paper quality are to be expected under acid cooking conditions.
CHAPTER 3.

METHODS

3.1 Preliminary Measurements: In order to develop workable and reasonable parameters for the characterisation of stems, it was necessary to make some preliminary field measurements. Further, it was necessary to test the sample area for "edge-effects".

3.1.1 Bias due to "Edge-Effects": The two selected coastal provenances were represented by 9 plots with 7-11 stems per plot and an additional single plot with 30 stems (page 147). With such a large "edge" the possibility of "edge-effects" was obvious. However, the stems in the plot centres were found to be as equally deformed as the edge trees and so any great variance due to "edge-effects" seemed unlikely. The problem was less acute in the single Kamloops plot and a series of systematic trial measurements showed, in fact, that there was no measurable difference in the degree of butt-sweep between edge and more centrally situated trees.

3.1.2 Type of Butt-Sweep: For the purposes of this study no attempt was made to differentiate between types
of butt-sweep. Two main forms of sweep, however, were easily recognised. The coarser coastal stems tended to be J-shaped with the curvature extending to a height of about 10 to 15'; the Kamloops stems also tended to be J-shaped but curvature was frequently restricted to the basal 5 - 6'. Occasional Kamloops stems were sickle shaped, with curvature past the vertical contained within the basal 6' (Diag. 1).

On the basis of these observations a simple method of division into stem deviation classes was developed.

3.1.3 Stem Deviation Classes: An important part of the study was to determine whether there was any measurable difference in the degree, or distribution, of compression wood with different degrees of butt-sweep. It was therefore necessary to form classes based on the amount of butt-sweep, or stem deviation, from the vertical.

In many of the stems some degree of verticality was restored at or about 10' above ground level. Stems were initially characterised in the following manner:

1) All stems under consideration were permanently numbered; 1 to 111 for the combined coastal provenances and 1 to 174 for the Kamloops provenance. Plastic tags or paint were used for numbering.

ii) visiting each tree in turn, a 10' pole was held
A. Sickle-shaped.
B. Straight but Leaning
C. J-shaped.

Diag. 1. Main Types of Stem Deviation Recognised in This Study. (not to scale).
vertically against the original underside of the stem. The foot of the pole was held at the same level as the base of the tree, from which a measurement was to be taken. Thus the stem formed the hypotenuse of a right angled triangle, with the pole forming a second vertical side, and a horizontal line drawn from the lower side of the base of the stem (with allowance made for excessive butt swell) to the foot of the pole forming the third side (Diag. 2). This third side was measured to the nearest inch, and this measurement (Z") recorded in a field note book. A spirit-level was taped to the pole to ensure that it was held vertically.

iii) to facilitate the division into deviation classes, and to indicate the distribution of stem deviation measured in this manner, a frequency graph was drawn up for the combined coastal provenances (Diag. 4). Each stem was then placed into one of four deviation classes based on measurement Z (Table 1). For the inland Kamloops provenance, the range of deviation was too small to justify the formation of more than two classes. Each stem was placed into one of these two classes (Table 1). See also Diag. 5.
Diag. 2. Measurement of Stems for Classification into Stem Deviation Classes.
It is to be noted that because of their sickle-shaped rather than J shaped stem form, a total of 9 inland stems were unmeasurable by this method. They were obviously more deformed than the average class 1 stem and therefore placed in class 2. This unusual stem form appeared only when seedlings had been planted on a loose mound of earth, and the mound had collapsed sideways. These stems, which were then displaced from the vertical, had curved sharply upwards to become vertical directly above the displaced base of the stem.

3.2 Sampling: Because of the time consuming nature of compression wood studies, it was essential to restrict the number of stems to be analysed. Consequently, it was necessary to adopt some sampling procedure whereby the maximum of information could be obtained.
from a reasonable number of representative stems.

3.2.1 Sampling Method: A stratified random sampling technique appeared to be the most acceptable sampling method, particularly in that it allowed all classes to be equally represented in the sample. However, since each class was not equally numerically represented in the stands, any comparison of the formation of compression wood between the provenances would have to be weighted in respect of their representation in the stand.

Owing to physical homogeneity within the stands, the fact that all plots had been subject to the same silvicultural treatment, and the fact that bias due to "edge-effects" seemed unlikely, no special precautions or modifications to the basic sampling technique were considered necessary.

3.2.2 Size of Sample: A sequential sampling technique with pre-determined confidence limits was obviously the best method to determine sample size. However lack of time precluded this treatment. It was decided to limit the total sample size to 40 stems; 20 drawn from each provenance. Thus each of the 4 coastal classes would be represented by 5 trees, and each of the 2 inland classes by 10 trees.
3.2.3 Procedure: The sampling procedure was as follows:

i) as before, all stems under consideration had been permanently numbered.

ii) both sample populations were stratified by placing each stem into the appropriate deviation class according to its' measured deviation from the vertical. (page 46).

iii) each tree was represented by a paper slip carrying its' number.

iv) treating each provenance separately, the paper slips were drawn from a box until all classes were represented by the requisite number of stems.

v) the numbers of the selected stems were recorded in a field note book; and the stems permanently marked with paint.

3.3 Stem Analysis: It was necessary to adopt a method whereby the amount of compression wood in each stem could be reliably estimated with reasonable ease. Past studies of this kind have frequently used cross-section discs removed from fixed positions in the stem, to represent each stem. Analysis of the discs for compression wood has frequently been by the method developed by Pillow (1) (page 60).

It was decided to adopt the above method for the estimation of compression wood. However, the
problem remained as to how many discs were necessary to give a reliable estimate of the amount of compression wood. On the advice of Dr. A.J. Low (Silviculturist, Forestry Commission Research Branch), who has carried out a study of compression wood in Scots Pine, it was decided that a single disc removed from every second internode would be sufficient. Subsequent analysis showed that there was little difference in the amount of compression wood in consecutive discs, and although more exhaustive measurement of any stems to determine the accuracy of the method was not feasible (due to complications in travelling), it appears that the results are wholly acceptable.

In practice it was not possible to define reliably internodes below breast-height in stems of the Kamloops provenance. Consequently, for all stems, four discs, labelled A to D, were removed from the ground level to breast height (51") section. Section D thus represented compression wood at breast height and sections C, B and A represented compression wood at 17" intervals down to ground level.

Further discs were removed from the mid-points of the second internode above breast height, and thereafter from the mid-point of every second
internode up to the first sectionable internode above 4" top diameter (o.b.). These were labelled 2, 4, 6 etc., up the stem (Diag. 3). Stems were represented by an average of 10 discs.

3.4 Further Characterisation of Stems: One of the objects of the study was to attempt to correlate compression wood formation with the degree of stem deviation (or butt-sweep). Thus far the stems had been characterised by a single measurement only (page 46) and it was decided to introduce a further simple, but if possible, meaningful parameter. A review of the relevant literature (page 21) indicated conflicting results as to this relationship.

As compression wood is found in large amounts at all heights in the stem (Low (41), et al., it was considered that a measurement describing the whole stem, rather than part of it, would be more likely to bear a constant relationship to the amount of compression wood.

Observation showed that few, if any, stems were truly vertical below about 25' (3-4" diameter) and further, that lean always tended to be in the same direction as the initial butt-sweep. Accordingly the following measurement was designed (Diag. 3).
i) A painted line (about 5" long) was drawn up the centre of the original underside of the stem i.e. up the side of maximum curvature.

ii) from the centre of the mid-point of the highest sectionable internode a string suspended plumb-bob was lowered to a point exactly opposite the base of the painted line (and the base of the tree).

iii) the distance from the centre of the base of the tree to the point of the plumb-bob was measured to the nearest inch, and this measurement recorded on a field sheet.

iv) when the tree was felled and marked for sectioning, the paint spot and the painted line were used for orientation purposes so that exactly the same triangle could be formed by the stem, string, and the base measurement.

v) the string was held taut and the shortest distance from the string to the stem centre of every sectionable position in the stem (page 51) was measured to the nearest inch. Each measurement (labelled A, a, b, c, etc., in Diag. 3) was recorded on a field sheet next to its respective cross-section. It proved impossible to take these measurements while the tree was standing.

For Explanation See Text.
vi) on the field sheet provision was made for the case where a stem "overcorrected" i.e. curved back past the vertical, but in practice this column was not required.

Using this method of measurement, two identities were obtained: the base distance A, and the sum of all the deviation measurements \( A + a + b + c + \ldots + x \), the latter of which it was hoped would describe more completely the degree of stem deviation.

3.5 **Other Field Operations:**

3.5.1 Direction of Butt-Sweep: It has been widely reported in the literature e.g. Fielding (18), Low (39), that butt-sweep in a stand tends to be in one direction, and that this direction is frequently that of the prevailing wind. With this in mind, the compass direction of the initial sweep of all numbered trees was measured and recorded on a field sheet before felling.

3.5.2 Felling: When all the necessary measurements had been made on the standing stems, those stems which had been selected for compression wood analysis were felled as required. The Forestry Commission kindly volunteered the services of a chain-saw, and operator, and a few trees were felled in this manner.
However, felling was of such a sporadic nature that it was found to be more convenient to fell the trees by hand. A Swedish type bow-saw was found to be satisfactory for this purpose. Trees were cut as close as possible to ground level, and following felling, the top was removed at the point from which the uppermost section was to be taken.

3.5.3 Stem Volume Measurements and Calculations: Under-bark diameters were measured to the nearest one tenth inch at the stem base, and at the point of removal of the uppermost cross-section, and were calculated as the mean of two measurements taken at right angles to each other.

The distance between these two points was measured along the centre curve of the stem, to the nearest inch. Results were recorded on a field sheet.

Underbark volume, in cubic feet, was calculated according to Smalian's Formula (Jerram 28) where

\[
\text{Volume} = \frac{\pi s_1^2 + \pi s_2^2}{2} \times \frac{1}{2} \times 1
\]

\[1 = \text{length}\]
\[s = \text{sectional area}\]

\[
\text{Volume (feet}^3\text{)} = \frac{2 \pi r_1 \pi r_2}{144}
\]

\[1 = \text{length}\]
sectional areas were derived from Appendix III
P 114 Jerram (28).

3.5.4 **Reject Timber**: (Fort William Paper Mill Specifications).

The probable end use of many locally grown *Pinus contorta* stands is as pulp wood. Stands grown under similar conditions are unlikely to reach millable size under economically justifiable rotations. It was therefore of interest to determine the volume of reject timber caused by excessive stem curvature. For convenience Fort William "round conifer pulpwood" specifications were used. A copy of the pertinent specification is contained on (page 143).

For measurement purposes the most stringent specification was adopted, and no allowance was made for chamfering. The procedure was as follows:

i) A 10' pole was laid along the zone of maximum curvature, with each end of the pole resting on the mid point of top and bottom diameters.

ii) if curvature was excessive i.e. the line of the pole was at any point more than 1½" outside the curve of the log, the pole was moved up the stem until a point was reached at which curvature was within the acceptable limits.

iii) the height at which this point was reached
was marked on the log, measured to the nearest inch, and recorded on the field sheet as "reject height".

iv) the underbark diameter at this point (being the mean of two measurements taken at right angles to each other) was measured to the nearest inch, and recorded on the field sheet.

v) the volume of reject timber was calculated according to Smalian's Formula (page 55) and recorded on the field sheet.

3.5.5 Marking for Sectioning: In all operations pertaining to the removal of sections for analysis, great care was taken to preserve the orientation of the sections, in respect of original upper and lower sides of the stem. Immediately a tree was felled, and using the orientation line defined on (page 53) to indicate the original underside of the stem, all sectionable internodes in the stem were marked on the underside with a short paint line running directly up the stem. This side was already indicated by the original line for sections below breast height. The exact position from which each cross-section was to be removed was measured out (page 54), and this position marked with a further paint line at right angles to, and cutting across each orientation line. Thus the point from which each section was to be cut was marked by a cross, the position of which corresponded to the original underside of the stem.
Sectioning: For the identification of compression wood the method developed by Pillow was to be adopted (page 60). This required that stem cross-sections cut for examination be no greater than \( \frac{1}{8} \) to \( \frac{3}{16} \) in thickness. It was intended to remove 4" to 6" long blocks from each sectionable position in the stem, and to machine cut from these blocks the required cross-sections. The bulkiness of the blocks, however, presented transport problems and this method was rejected.

It was found that completely acceptable sections could be cut in the field using a Swedish type bow-saw fitted with a coarse-toothed blade. A single tree could be sectioned in about one hour.

As each section was cut from the stem it was lettered or numbered according to its position in the stem, the tree number was recorded on one side, and on both sides arrows were drawn parallel to, and with their points coinciding with the centre of the original underside of the stem. The points of these arrows thus coincided with the centres of the crosses which had previously been marked on the outside of the stem.

For marking, "Pentel" Pens, with waterproof ink, were used, and to avoid any possible confusion all sections cut from coastal stems were marked with
black ink, inlaid with red ink.

Cut sections were placed in plastic bags, transported to Edinburgh University, sprinkled with a few mls. of fungicide, and stored at +20°C until required for examination.

3.5.7 Shrinkage Test Blocks: At the outset of the study it was intended to compare the shrinkage properties of compression wood and normal wood. Accordingly, from the first and fifth internodes above breast height in all coastal stems, 6-8" long stem sections were cut. From these stem sections it was proposed to cut blocks for the measurement of shrinkage during drying.

Unfortunately lack of time, and technical difficulties, prevented this part of the study from being carried out.

3.5.8 Sequence of Field Operations: These may be summarised as follows:

1) numbering of all stems under consideration for the study.

ii) measurement of edge effect.

iii) stem deviation measurements for the formation of classes.

iv) record compass direction of butt-sweep.
v) sampling, and marking of selected stems.
vii) characterisation of stems using the plumb-bob method.

vii) felling and trimming.
viii) marking for sectioning.
ix) stem volume measurements.
x) measurement of whole stem deviation (vi continued).

xi) measurement of reject height where necessary.

xii) sectioning and removal of shrinkage blocks.

In practice, all field operations were completed in about 4 hours per sample tree.

3.6 Identification of Compression Wood:

Compression wood was identified by its relative opacity to transmitted light according to the method developed for non-tropical timbers by Pillow (55). The compression wood contained in stem cross-sections 1/8" to 3/16" in thickness appeared opaque, and was readily distinguished from the translucent normal wood when viewed through the transmitted light of a standard light-table. According to Pillow (55) even mild forms of compression wood are visible by this method.

Although the springwood of both compression wood and normal wood is translucent, compression wood is confined largely to the summerwood zone, and therefore
remains identifiable (Pillow 55). Where heavier forms of compression wood were found i.e. compression wood was not confined to the expected summerwood zone, an opaque, apparent summerwood zone was visible, which sometimes occupied 80%, or even more, of the total annual ring width.

The greater opacity of "summerwood" compression wood is apparently due to the discontinuous structure in the secondary cell wall of the compression wood lacheids, this structure tending to dissipate the light (Pillow 55).

Very smooth sections were not necessary, and untouched sections cut in the field were satisfactory.

Low (39) used a light-green filter to increase the contrast between normal wood and compression wood, but such techniques were not used.

When sections became dry the contrast between compression wood and normal wood was reduced, but storing in plastic bags in a cool room prevented excessive moisture loss, re-wetting was not required.

3.6.1 Validity of the Method: The validity of this method for the identification of compression wood in Pinus contorta was confirmed by preparing a series of
slides taken from zones of compression wood and examining them under a microscope. Compression wood was identified by its characteristic structure and appearance in longitudinal, and cross-section (page 9).

3.6.2 Limitations of the Method: Using such a method of visual identification of compression wood, it seems unlikely that the finest distinction between compression wood and normal wood is possible. Harris & Meylān (24), Wardrop (69) and Pillow and Bray (56) all comment on the continuity of structural organisation which exists in transition zones from normal to compression wood. Harris & Meylān (24) remark... "that positive identification must give way in practice to some form of subjective judgement". Core et al (8) note that very mild types of compression wood can be identified only through a careful study of minute anatomy. However, the purpose of the study was not to precisely define tissue boundaries but rather to measure the more obvious compression wood zones. The method has been used exclusively for such studies.

3.7 Definition of Zones of Compression Wood: In order to obtain a more complete understanding of the distribution and degree of formation of compression wood, particularly in relation to stem deviation
class, and provenance, it was necessary to define degrees of formation of compression wood. Low (41) assessed compression wood formation as slight, moderate, or pronounced according to the degree of opacity and the proportion of ring width occupied by compression wood. Perem (51) defined compression wood zones as slight, intermediate, and pronounced, the latter with the apparent summerwood occupying more than 50% of the annual ring width. In the present study zones of compression wood were subjectively assessed as slight to moderate, or moderate to pronounced, and defined as follows:

i) slight to moderate zone: any cross-sectional area where compression wood was present (apparent summerwood) and occupied less than 50% of the total annual ring width.

ii) moderate to pronounced zone: any cross-sectional area where compression wood (apparent summerwood) was present, and occupied 50%, or more, of the total annual ring width.

Where there was any doubt as to a zones' classification, measurements were taken across the annual ring with a millimetre scale, and its classification confirmed.

3.8 Measurement of Compression Wood: There were several alternatives as to the method of measurement of compression wood. Low (41) outlined zones of comp-
compression wood with pencil, and measured the area of these zones with a dot grid containing about 40 dots per square inch. At Forest Research Institute (New Zealand) zones of compression wood, and total sectional area, have been traced onto tracing paper, and area (or volume) relationships obtained by cutting round these zones and weighing the contents (C.J. Mountfort pers. comm.). The former method was tested in a pilot run, but found to be excessively laborious. The following method for the estimation of compression wood was therefore developed.

3.6.1 Tracing of Sections onto Plastic:

i) Passing through the pith, and at right angles to the orientation arrows (recorded on both sides of every cross-section) a straight line was drawn completely across one side of the section with indelible marking pencil. The section was therefore divided into two portions, representing original upper and lower sides. The original lower side was almost invariably greatest in area owing to stem eccentricity on that side, which often continued right up the stem.

ii) Sections were then placed on the light-table.

iii) On the same side of each section slight to moderate and moderate to pronounced zones of compression wood were outlined in indelible pencil.
Different coloured pencils were used for the two classes of compression wood.

iv) A piece of clear, moderately stiff plastic measuring about 12" x 12", was placed on top of the section and the underbark perimeter of the section traced onto the plastic with a wax pencil. The line dividing upper and lower sides was drawn in, and all outlined zones of compression wood traced onto the plastic using a different coloured wax pencil for the two classes of compression wood. The original upper and lower sides were again indicated.

v) Each section, and the compression wood it contained, was now represented in outline on a sheet of plastic. Tree number and position in stem for each section was indicated on each sheet.

vi) When all the sections from one tree had been traced onto plastic sheets in this manner, the required measurements were made.

3.8.2 Measurement of Area: It was now necessary to measure total sectional area, areas of slight to moderate and moderate to pronounced compression wood on the original upper side, and areas of slight to moderate and moderate to pronounced compression wood on the original lower side. All measurements of area were made with a planimeter in the following manner:
i) each sheet of plastic, with its sectional and compression wood outlines, was clamped onto a mapping table covered with a sheet of white paper.

ii) total sectional area was measured.

iii) the areas of all outlined zones of compression wood were measured separately, and summed where necessary, to give the required total measurements.

iv) all results were recorded on a laboratory sheet, and at the same time all data from the field sheets transferred onto the laboratory sheet.

v) all planimeter readings were taken to the nearest third figure, as it was considered that further accuracy would be spurious.

vi) planimeter measurements, randomly checked, were found to be 100% reproducible.

vii) total sectional areas for each tree were summed to give a unit measurement representing the total sampled volume of the tree.

viii) in a like manner areas of compression wood were summed to give unit measurements representing total volumes in the sampled portion of the stem. The following identities were obtained:

a). total volume of slight to moderate compression wood in the original lower side.
b) total volume of slight to moderate compression wood in the original upper side.

c) total volume of slight to moderate compression wood in the sampled portion of the stem.

d) total volume of moderate to pronounced compression wood in the original lower side.

e) total volume of moderate to pronounced compression wood in the original upper side.

f) total volume of moderate to pronounced compression wood in the sampled portion of the stem.

g) total volume of combined compression wood in the sampled portion of the stem.

viii) these results were recorded on the laboratory sheets and further analysed.

A summary of all results, including field measurements, is to be found on pages 150 to 161.

3.8.3 Correction Factors: So as to enable an estimate to be made of the total amount of actual compression wood, rather than zones of compression wood, the following technique was adopted:

i) two representative cross-sections per tree were selected.
ii) through zones of both slight to moderate, and moderate to pronounced compression wood, radii were drawn in on the sections (with their origin at the pith) so that each zone of compression wood was divided approximately into thirds i.e. two radii passed through each zone under consideration.

iii) for both classes of compression wood, the amount of compression wood, and the total annual ring width, in which the compression was contained, were measured with a transparent scale graduated in millimetres.

iv) measurements were taken along the radii, within the outlined zones of compression wood.

v) from the two sections taken from each tree, at least 60 pairs of measurements for each of the two classes of compression wood were obtained.

vi) the ratio of recognisable compression wood to total annual ring width was calculated for each of the two classes of compression wood, and for every tree, and the results recorded.

vii) results are recorded on pages 158 and 161.

3.9 Estimation of Total Stand Volume and Area: The 40 sample stems were measured, and their volumes
calculated according to Smalian's Formula. The stems within each class were selected randomly, and the proportional representation of each class within the stands was recorded.

The volume (u.b.) was calculated separately for each class, and multiplied by a factor derived from the numerical representation of each class in populations.

This, in fact, gave an overall sampling intensity of approximately 18% in the coastal stands and 12% in the more homogeneous Kamloops stand.

The intensity of sampling was concentrated in those classes forming a smaller proportion of the stand, but only in Kamloops class 1 did the sampling intensity fall below 10%.

Results, to a mean top diameter of 3.3" (u.b.), and including the estimated reject volume are contained in Table 2.
<table>
<thead>
<tr>
<th>Provenance and Class</th>
<th>Sample Vol. (to mean 3.8&quot; diam. u.b. ft.3)</th>
<th>Total Estimated Stand Volume (to mean 3.8&quot; diam.u.b.ft.3)</th>
<th>Reject Volume (ft.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
<td>31.45</td>
<td>28.16</td>
<td></td>
</tr>
<tr>
<td>&quot; 2</td>
<td>27.09</td>
<td>63.88</td>
<td></td>
</tr>
<tr>
<td>&quot; 3</td>
<td>24.57</td>
<td>319.66</td>
<td>4.39</td>
</tr>
<tr>
<td>&quot; 4</td>
<td>26.08</td>
<td>207.57</td>
<td>5.87</td>
</tr>
<tr>
<td>TOTALS:</td>
<td>109.19</td>
<td>619.27</td>
<td>10.26</td>
</tr>
<tr>
<td>Kamloops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
<td>25.97</td>
<td>328.13</td>
<td></td>
</tr>
<tr>
<td>&quot; 2</td>
<td>31.25</td>
<td>173.80</td>
<td></td>
</tr>
<tr>
<td>TOTALS:</td>
<td>57.22</td>
<td>501.93</td>
<td></td>
</tr>
<tr>
<td>GRAND TOTALS:</td>
<td>166.41</td>
<td>1121.20</td>
<td>10.26</td>
</tr>
</tbody>
</table>

Sample trees of the coastal provenances were removed from 10 plots, 9 measuring 0.013 acres in area, and the tenth, 0.026 acres. Total area was 0.143 acres. Sample trees of the Kamloops provenance were removed from a single plot 0.227 acres in area. The total
sample area was therefore 0.370 acres.

3.10 **Statistics:** Basic statistical techniques, such as those found in Bailey (5) or Snedecor and Cochran (64), were employed in the analysis of results.

In comparing the amounts of compression wood formed by the two provenances, the sampling method was such that weighting of the results was necessary. Thus, because each class was not equally numerically represented in the respective stands (Table 1), results were weighted in respect of their distribution in the stands. The method used (page 141) was suggested by Mr. D.C. Williams (Statistician, Department of Statistics, University of Edinburgh).

If, in comparing the means of any two samples, it was suspected that their respective variances were not equal, equality was tested for by the variance-ratio or F-test. It was found that tabulated values were exceeded only once in the data, and therefore variance was assumed to be equal in all but one case.

Unless otherwise stated, calculations are based on the measurements of zones of compression wood, and not on the estimated actual amount of compression wood following adjustment made by correction factors.
3.10.1 **Statistical Methods**: The following statistical methods were employed in the analysis of results:

i) 'Students' t-test for the comparison of two small sample means.

ii) 'Students' t-test, with a pooled estimate of variance, for the comparison of several small sample means.

iii) Analysis of variance.

iv) Correlation coefficients.

v) Linear regression analysis.

vi) Comparison of stratified sample means (page 141).
CHAPTER 4.

RESULTS.

4.1 Total Compression Wood in The Stands: Table 3 (q.v.) shows the volumes and percentages of compression wood in the 6 deviation classes, and the totals for the Kamloops and coastal stands separately. Whole stand volumes for total wood and compression wood were calculated in the manner described on page 68.

Estimated volumes of actual compression wood (obtained by multiplying the volumes of slight to moderate and moderate to pronounced compression wood in each tree by its respective correction factors) are included for academic interest. They have little practical value from the utilisation point of view owing to the association of acid susceptible wood and non-recognis-able compression wood with bands of recognisable compression wood (pages 39 and 124).
<table>
<thead>
<tr>
<th>Provenance and Class</th>
<th>Class Volumes (u.b.) ft.³ (ac.)</th>
<th>% Compression Wood</th>
<th>% Actual Compression Wood</th>
<th>% Compression Wood in Stand</th>
<th>% Actual Compression Wood in Stand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compression Wood</td>
<td>Total Wood</td>
<td>Actual Compression Wood</td>
<td>Compression Wood</td>
<td>Total Wood</td>
</tr>
<tr>
<td>Coastal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
<td>61.69</td>
<td>207.57</td>
<td>24.24</td>
<td>29.72</td>
<td>11.68</td>
</tr>
<tr>
<td>&quot; 2</td>
<td>107.98</td>
<td>319.66</td>
<td>42.64</td>
<td>32.86</td>
<td>13.34</td>
</tr>
<tr>
<td>&quot; 3</td>
<td>26.63</td>
<td>63.88</td>
<td>12.38</td>
<td>41.68</td>
<td>19.38</td>
</tr>
<tr>
<td>&quot; 4</td>
<td>11.75</td>
<td>28.16</td>
<td>6.17</td>
<td>41.74</td>
<td>21.92</td>
</tr>
<tr>
<td>TOTALS</td>
<td>208.05</td>
<td>619.27</td>
<td>85.43</td>
<td>33.60</td>
<td>13.79</td>
</tr>
<tr>
<td>Inland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
<td>49.85</td>
<td>173.80</td>
<td>16.7</td>
<td>28.68</td>
<td>9.63</td>
</tr>
<tr>
<td>&quot; 2</td>
<td>96.96</td>
<td>328.13</td>
<td>38.24</td>
<td>29.55</td>
<td>11.69</td>
</tr>
<tr>
<td>TOTALS</td>
<td>146.81</td>
<td>501.93</td>
<td>54.97</td>
<td>29.25</td>
<td>10.95</td>
</tr>
</tbody>
</table>
Thus, for the coastal provenances, a total of 208.05 ft.\(^3\), or 33.60% of the total standing volume to a mean top diameter of 3.8" (u.b.) was estimated to be compression wood. The comparable figures for the inland provenance were 141.86 ft.\(^3\), or 29.25% of the total standing volume, and there is little apparent difference in the formation of compression wood between the two provenances (see following section).

Over 400 cross-sections, representing 40 trees, were analysed for compression wood. In only two sections was there no identifiable compression wood, and in the remaining sections measurements of compression wood ranged from 1.5% to 77.5% of the total cross-sectional area. The lowest recorded volume of compression wood for any single tree was 10.8% compression wood in a class one coastal stem, and the highest, 50.6% compression wood in a class 3 coastal stem. It was not possible, either in the case of the coastal or inland provenances, to remove a utilisable length of timber from any tree without it containing compression wood.

It therefore appears that compression wood is likely to be present in almost all trees, at any given height, in such stands of *Pinus contorta*.

The measured volumes of compression wood, by percentage, for compression wood and compression wood adjusted with
correction factors (actual compression wood), for all
trees, are contained in a summary of results (page 48).

4.2 A Comparison of the Amounts of Compression Wood Formed
in the Coastal and Inland Provenances: One of the
initial objects of this study was to determine whether
there was any difference in the amounts of compression
wood formed between the inland and coastal provenances.
If a large and significant difference did exist, then
it could be said that the provenance containing the
lesser amount of compression wood would be likely to
show less degrade, due to compression wood, when it was
utilised either as saw-timber or as pulp-wood.

Accordingly, the two provenances were analysed for
differences in amount of compression wood following the
method indicated on page 41. This, in effect, is a
comparison of stratified sample means, and was necessary
because each class was not equally numerically represented
in the stands. Nine stems in the Kamloops stand, pre-
viously classed as unmeasurable (page 48), were not
included in the calculations.

The significance of the difference between means of comp-
ression wood was calculated as 1.567. The t distribution
with 34 degrees of freedom at a confidence level of 5%
was 2.032, and it was perhaps surprising to find that
there was no difference in the amount of formation of
compression wood between the two provenances.
When the individual class means for the percentage of compression wood are compared, there is obviously little difference in the percentages of compression wood formed in Kamloops classes 1 and 2, and coastal classes 1 and 2 (page 84). The mean percentages of compression wood for each class were 28.68%, 29.55%, 29.72% and 32.86% respectively. In addition, the range of mean stem deviation for each class, defined by all three parameters (Z, A, and the sum of the deviation measurements), although proportionately higher than the range for percentages of compression wood, was not excessive. For example, the mean parameter A was 10.8", 16.9", 28.6" and 36.2" for the same 4 classes respectively (Diags 2 and 3).

Coastal classes 3 and 4 contained considerably higher percentages of compression wood (means of 41.68% and 41.74% respectively), and had considerably higher stem deviation measurements with mean parameter A measurements of 53.2" and 63.8" respectively. However, these 2 classes made up only 11.71% and 5.41% respectively, of the coastal population. Hence, although a large volume of any stem in these two classes may be compression wood, their actual contribution to the compression wood in the stand is greatly diminished, in respect of their individually large percentages of compression wood, when their volumetric representation in the stand is considered.

To summarise, the inland Kamloops provenance, although
Diag 4. Frequency Distribution of Stem Deviation: Coastal Provenances.
Diag. 5. Frequency Distribution of Stems. Inland (Kamloops) Provenance.
subjectively and quantitatively assessed as of consider-
ably better stem form than the coastal provenances, tends
to form comparable amounts of compression wood. This
is partly due to the fact that the severely deformed
coastal stem containing large amounts of compression
wood constitute a relatively small volume of the coastal
population.

Past thinning has undoubtedly removed higher proportions
of severely deformed stems, and in an unthinned popul-
ation their relative proportions would be in excess of
the above results.

4.3 Distribution of Stem Deviation in the Stands: Stem
deviation from the vertical, was measured according to
the method outlined on page 46, and the recorded parameter
2 used to form the x ordinate in Diags. 4 and 5 (q.v.).

The stems of the two coastal provenances form an approx-
imately normal distribution, with a peak in the 8" to
15" range. This range contains the majority of the
coastal class 2 stems (10 to 19" deviation), with this
class containing 53.15% of the population. Coastal
class one contains 29.73% of the population, and coastal
classes 3 and 4 contain 11.72% and 5.41% respectively.
The range of stem deviation for the coastal population
measured by this method was from 3" to 41", with a mean
of 14.12".
The distribution of stem deviation in the Kamloops provenance forms a peak in the 0" to 5" range, with this range containing all the class 1 stems, and many of the class 2 stems. Kamloops class 1 (0 to 4" deviation) contains 61.12% of the population, and Kamloops class 2 (5" + deviation), 38.88% of the population. The range of measurements for the inland population was from 0" to 15" with a mean of 3.75".

Although the recorded range of stem deviation for the coastal provenances greatly exceeded the range recorded for the inland Kamloops provenance, only 17.13% of the coastal stems had a stem deviation measurement in excess of 19", and the difference between the means was not great.

A subjective assessment of stem deviation in the coastal and inland provenances must, however, result in the conclusion that the coastal provenances tend to coarseness and a considerably greater degree of stem deformation.

4.4 Comparison of the Amounts of Compression Wood in the Stem Deviation Classes:

4.4.1 Kamloops Provenance: This stand was relatively homogeneous in respect of stem form and the range of stem deviation from the vertical so limited that only two classes were formed (page 47; Table 1).
Analysis of stems for compression wood showed a range of 19.1% to 38.7% compression wood in class 1, with a mean of 28.68% compression wood. Class 2 had a range of 15.5% to 47.8% compression wood and considerably more variation in the percentages of compression wood than class 1 stems (page 161). The mean for class 2 was 29.55% compression wood. As was expected with such uniformity of stem form, and variation in the amounts of compression wood, the calculated t value (0.220) did not exceed the tabulated t values at any level, and the difference between the mean percentages of compression wood was not significant.

Thus, no real difference existed between the amounts of compression wood formed in the two Kamloops classes.

4.4.2 Coastal Provenances: These stands showed a far greater range of stem deviation when measured for division into classes. Percentages of compression wood formed in individual stems of any one class showed a wide range as did mean values between the most widely separated classes (Table 4). For classes 1, 2, 3, and 4, ranges in the percentage of compression wood for individual stems were: 10.8% to 39.0%, 26.5% to 40.2%, 32.3% to 50.6%, and 35.5% to 44.8% respectively. The corresponding mean percentages of compression wood for classes 1 to 4 were 29.72%, 32.86%, 41.68%, and 41.74% respectively.
A $t$-test, with a pooled estimate of variance, was used to estimate the significance of the differences between means. Results are contained in Table 4.

**TABLE 4**: Mean Percentages of Compression Wood in the Four Coastal Classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean %</td>
<td>29.72</td>
<td>32.86</td>
<td>41.68</td>
<td>41.74</td>
</tr>
</tbody>
</table>

Values for significance of difference between any two means are: at 1% level, 14.27; at 5% level, 10.36.

The differences between means for classes 1 and 2 are negligible, as are differences between classes 3 and 4. Means for trees with pronounced stem deviation are by far the highest but variation within the classes is such that significance is reached only at the 5% level, and only for the difference between means of class 1 (effectively straight stems) and classes 3 and 4.

On the basis of these results, it appears that a tree which is subjectively or quantitatively assessed as showing pronounced stem deviation from the vertical will, in fact, tend to contain larger amounts of compression wood than its less deformed neighbours. It seems unlikely, however, that the amount of compression wood in a stem may be accurately predicted using a simple
method of measurement of stem deviation alone. This is further discussed on pages 98 and 118.

4.4.3 Actual Compression Wood in the Stem Deviation Classes:
As will be demonstrated (page 105), the formation of slight to moderate and moderate to pronounced compression wood varies between the classes. The stems showing less deviation from the vertical tend to form greater proportions of mild compression wood and therefore, when the correction factors are applied and the percentage of actual compression wood calculated, the differences, especially between widely separated classes, are exaggerated. t-tests, with a pooled estimate of variance in the case of the four coastal classes, were employed to determine the significance of differences between mean percentages of actual compression wood. Results are contained in Table 5.

TABLE 5: Mean Percentages of Actual Compression Wood for All Classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>Kamloops 1</th>
<th>Kamloops 2</th>
<th>Coastal 1</th>
<th>Coastal 2</th>
<th>Coastal 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean %</td>
<td>9.63</td>
<td>11.69</td>
<td>11.68</td>
<td>13.34</td>
<td>19.38</td>
</tr>
</tbody>
</table>

Values for significance of difference between Kamloops means are: at 5% level, 3.96; for coastal means; at 0.1% level, 9.94; at 1% level, 7.23; at 5% level, 5.25.
Differences between Kamloops class means are negligible, as are differences between coastal class 1 and 2 means. A highly significant difference exists between coastal class 1 and coastal class 3 and 4 means, and between coastal class 2 and 4 means. A very highly significant difference exists between coastal class 1 and 4 means.

These results should be compared with those in the foregoing section, where differences between means were not significant beyond the 5% level, and then only for differences between coastal class 1 and 3 and class 1 and 4 means.

The significance values for the difference between Kamloops and coastal class means were not calculated as contamination of class differences was not desired. However, it is clearly seen that in comparison with results obtained in the foregoing section, the differences between these class means are exaggerated.

The results emphasise the variation in formation of degrees of compression wood in the different classes, and these differences are further discussed on pages 105 and 108.
4.4.4 Combined Provenances: There is considerable homogeneity between the provenances in respect of the amount of compression wood formed, stem form, distribution of compression wood up the stem, and distribution of zones of compression wood. This applies particularly to Kamloops classes 1 and 2 and coastal classes 1 and 2, whilst coastal classes 3 and 4 although themselves not identical in all respects (pages 90 and 93), are together, different from all other classes.

A t-test with a pooled estimate of variance was carried out on the combined classes to illustrate the comparability of their mean percentages of compression wood.

Results are contained in Table 6.

**Table 6**: Mean Percentages of Compression Wood for All Classes in Combined Provenances.

<table>
<thead>
<tr>
<th>Class</th>
<th>Kamloops 1</th>
<th>Kamloops 2</th>
<th>Coastal 1</th>
<th>Coastal 2</th>
<th>Coastal 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean %</td>
<td>28.68</td>
<td>29.55</td>
<td>29.72</td>
<td>32.86</td>
<td>41.68</td>
</tr>
<tr>
<td>Coastal 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41.74</td>
</tr>
</tbody>
</table>

Values for the significance of differences between means are: Kamloops means 3.728 at 5% level; Kamloops and Coastal means 12.488 at 1% level; 16.440 at 0.1% level; Coastal means 12.553 at 5% level.
Differences between Kamloops class 1 and 2 means are negligible, as are differences between coastal class 1 and 2 means, and coastal classes 1 and 2 and Kamloops class 1 and 2 means. Coastal class 3 and 4 means, although considerably greater, are not significantly different to other coastal class means, or to the Kamloops class 2 mean. A significant difference (at the 1% level) exists only between Kamloops class 1 and coastal classes 3 and 4, i.e. between stems which were effectively straight and stems which were excessively deformed.

Although the sample stems were drawn from morphologically distinct populations of the same species, it was considered that because of this comparability of compression wood anatomy in the majority of the stems, there would be little value in treating them as distinct entities for a number of the following calculations. This argument is enlarged in those sections where calculations are based on the 40 sample trees as a whole.

4.4.5 Comparisons Between Classes with Slight or Moderate Stem Deviation, and Pronounced Stem Deviation: Although the differences between the mean percentages of compression wood in the coastal classes themselves did not reach a high level of significance (page 81), it was felt that the populations did fall into two distinct classes, viz. those stems with slight to moderate stem deviation, and those stems with pronounced stem deviation. Accordingly.
four equal sized classes were constructed and differences between mean percentages of compression wood were tested for Kamloops classes 1 and 2, combined coastal classes 1 and 2 (all with subjectively and quantitatively assessed slight to moderate stem deviation), and combined coastal classes 3 and 4 (with pronounced stem deviation).

A t test with a pooled estimate of variance was used for the comparison. Results are contained in Table 7.

**TABLE 7**: Mean Percentages of Compression Wood in Combined Classes and Provenances.

<table>
<thead>
<tr>
<th>Class</th>
<th>Kamloops 1</th>
<th>Kamloops 2</th>
<th>Combined Coastal 1 and 2</th>
<th>Combined Coastal 3 and 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean %</td>
<td>28.68</td>
<td>29.55</td>
<td>31.29</td>
<td>41.71</td>
</tr>
</tbody>
</table>

Values for significance of difference between any two means are: at 1% level, 10.06; at 0.1% level, 13.27.

Differences between means for those three classes showing slight to moderate stem deviation are negligible, but highly significant differences (at \( p = 0.01 \)) are found between combined coastal classes 3 and 4, and all other classes. Thus, there is a tendency for those stems showing a stem deviation measurement of \( Z = 19" \) or less, to form smaller percentages of compression wood.

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than those classes (coastal 3 and 4) showing stem deviation measurements of up to \( Z = 41'' \), which was the highest recorded deviation for the latter two classes.

4.4.6 Range of Values of Compression Wood and Stem Deviation within Classes: It is of interest to note the wide range in the estimated percentages of compression wood, and the associated stem deviation measurements, for each of the classes. In Table 8 (q.v.), highest and lowest sample tree compression wood percentages are recorded along with highest and lowest stem deviation measurements in that class, for all three deviation measurements. Highest and lowest values for the percentage of compression wood are not often associated with the highest and lowest stem deviation measurements respectively, but where this is so, it is indicated.
TABLE 8: Extreme Compression Wood and Stem Deviation Values Obtained for Each Deviation Class.

<table>
<thead>
<tr>
<th>Provenance and Class</th>
<th>%Compression Wood</th>
<th>Measurement Z&quot;</th>
<th>Measurement A&quot;</th>
<th>Sum of Deviation³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lowest</td>
<td>Highest</td>
<td>Lowest</td>
<td>Highest</td>
</tr>
<tr>
<td>Coastal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
<td>10.3</td>
<td>39.0</td>
<td>4+</td>
<td>9</td>
</tr>
<tr>
<td>Class 2</td>
<td>26.5</td>
<td>40.2</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Class 3</td>
<td>32.3</td>
<td>50.6</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Class 4</td>
<td>35.5</td>
<td>44.8</td>
<td>30</td>
<td>41</td>
</tr>
<tr>
<td>Kamloops</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
<td>19.1</td>
<td>38.7</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Class 2</td>
<td>15.5</td>
<td>47.8</td>
<td>5+</td>
<td>8</td>
</tr>
</tbody>
</table>

Where the lowest deviation measurement in each class is associated with the lowest percentage of compression wood in that class it is signified +, where the highest deviation measurement is associated with the highest percentage of compression wood it is signified √.
The range and variation in the classes is greatest in those stems showing smaller deviation measurements i.e. Kamloops classes 1 and 2 and coastal 1 and 2. The severely butt-swept coastal class 3 and 4 stems all tend to form large amounts of compression wood, whilst the more mildly butt-swept stems may contain relatively little to a great deal of compression wood.

The results indicate that any individual stem from either provenance which is effectively vertical, straight and leaning, or mildly butt-swept, will contain anything from approximately 10% to 40% compression wood, with a mean percentage of about 30% compression wood for large numbers of stems. Trees that are severely butt-swept, or otherwise badly deformed, will contain from about 30% to 50% compression wood, with a mean of about 40% compression wood for large numbers of stems.

4.5 Variation in Stem Form*: In the measurement of stem deviation, it became clear that differences existed not only in the degree of stem deviation between classes and provenances, but also in the form of stem deviation.

* Stem form to be read as synonymous with "stem deviation" and "stem deviation from the vertical".
The differences in stem form were not apparent between all classes. Kamloops classes 1 and 2, and coastal classes 1 and 2 were similar in stem form (with the two coastal classes tending to a greater degree of stem deviation) but differences were apparent between coastal class 3 and coastal class 4, and also between these two classes and all other classes.

In Diag. 6 (q.v.) mean deviation measurements for each class (obtained from characterisation of the whole stem page 52) were plotted against height in the stems. A distance of approximately 3' existed between consecutive sections above breast height, and the mean height for all stems at the 12th. internode was 20.98'.

On the basis of field measurements of stem form Kamloops class 2 was selected as typifying stem form in Kamloops classes 1 and 2, and coastal classes 1 and 2. Coastal classes 3 and 4 are plotted separately (only 2 measurements were available for each of the latter two classes at the 12th. internode).

The Kamloops class 2 stems show a gradual and constant
decrease in deviation from the vertical up the stem. Coastal class 3 stems also tend to a gradual, but variable, decrease in stem deviation from the vertical with height, but here the stems are more sharply butt-swept to a height of approximately 4'. Coastal class 4 stems are even more sharply butt-swept, again to a height of approximately 4', but thereafter there is a more rapid straightening effect. Thus, the latter class, although showing a greater degree of deviation in the basal portion of the stem, fails to maintain its degree of deviation with increase in height.

The sum of deviation measurements for coastal classes 3 and 4 have means of 244.2 and 245.8 respectively, and are strictly comparable in total effective deviation from the vertical, but not in the distribution of this deviation.

Assuming that the degree and distribution of compression wood is in part related to stem form, it might be expected to find differences in these three classes. Comparison of Diags. 6 and 7 does show variation in the amount and distribution of compression wood with height, and this apparently reflects stem form (see following section).

4.6 The Relationship Between the Amount and Distribution of Compression Wood, and Stem Form:
Diag 6. Mean Stem Deviation, with Height in Stem.
Diag. 7  Mean Percentages of Compression Wood, with Height in Stem.
4.6.1 Distribution of Compression Wood: Diag. 7 (q.v.) shows the mean percentage of compression wood, in each of three classes, for all sections between ground-level and the 12th internode above breast height. On the basis of results of measurement of compression wood, Kamloops class 2 was selected as typifying the distribution of compression wood in Kamloops classes 1 and 2, and coastal classes 1 and 2 (pages 156 to 161). Coastal classes 3 and 4 are plotted separately. Only two measurements were available for each of the latter two classes at the 12th internode. Diag. 7 should be compared with Diag. 6, which illustrates the stem form for the same three classes.

Kamloops class 2, with a relatively straight stem form, maintains an almost constant percentage of compression wood from ground-level to approximately 21'. The actual range is from 22.7% compression wood (at section 12) to 32.9% compression wood at section C (34''), with a mean of 29.11% compression wood to section 12.

Coastal class 3 stems which are sharply butt-swept in the bottom 4' of the stem, and maintain a relatively high degree of stem deviation above this height, contain a preponderance of compression wood in the 17'' (section C) to 7' (section 2) region of the stem i.e. in the zone of extensive butt-sweep. Above this height there is a gradual decrease in the amount of
compression wood formed, which parallels the gradual decrease in stem deviation from the vertical. In this class of stem, compression wood reached a maximum (in 4 out of the 5 stems), at 51".

The range is from 17.6% compression wood at section 12 (mean of two observations) to 51.4% compression wood at 4.25' (section D). The mean is 39.2% compression wood to section 12.

In coastal class 4, where the stems are even more sharply butt-swept, the greatest amounts of compression wood are confined to the basal 17" to 4.25' region of the stem, after which there is a more rapid decrease in the amount of compression wood, again paralleling the considerably more rapid decrease in stem deviation above this height. In this class of stem, compression wood reached a maximum (in 4 of the 5 stems) at 34". The recorded range for this class is from 29.5% compression wood at section 10 (approximately 18') to 57.2% compression wood at section 0 (34''). The mean is 38.4% compression wood to section 12.
In order to test whether the observed mean percentages of compression wood were significantly different at varying heights in the stem within a given class, t-tests (with pooled estimates of variance) were carried out for Kamloops class 2, and coastal classes 3 and 4. Mean percentages of compression wood in sections removed at ground-level, 34", 51", 6th. section (about 10'), and 10th. section (about 18'). were compared. This series of heights embraced the full range of mean values for each of the three classes. Results are contained in Table 9.

As implied in Diag. 7 (q.v.) there is no difference between the amounts of compression wood formed at different heights in the Kamloops class 2 stems. In coastal class 3 stems, the mean percentages of compression wood in sections removed from ground-level, and the 10th. internode above breast-height, are significantly lower (at $p = .05$) than the percentage of compression wood at 51" (breast-height). At the same level of confidence, the mean percentage of compression wood in sections removed from a height of 34" is significantly higher than that in sections from the 10th. internode.

Only in coastal class 4 is a very highly significant difference found between the percentage of compression wood at various heights in the stem. At the 0.1% level of confidence, the mean percentage of comp-
## TABLE 9: Mean Percentages of Compression Wood at Different Heights in the Tree for Three Stem Forms.

<table>
<thead>
<tr>
<th>Class</th>
<th>Kamloops 2</th>
<th>Coastal 3</th>
<th>Coastal 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height</strong></td>
<td><strong>Ground Level</strong></td>
<td><strong>34&quot;</strong></td>
<td><strong>51&quot;</strong></td>
</tr>
<tr>
<td><strong>Mean % Compression Wood</strong></td>
<td>25.10</td>
<td>32.98</td>
<td>30.62</td>
</tr>
</tbody>
</table>

Values for significance between any two means are: at 5% level, 11.45

<table>
<thead>
<tr>
<th>Class</th>
<th>Coastal 3</th>
<th>Coastal 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height</strong></td>
<td><strong>Ground Level</strong></td>
<td><strong>34&quot;</strong></td>
</tr>
<tr>
<td><strong>Mean % Compression Wood</strong></td>
<td>42.64</td>
<td>57.22</td>
</tr>
</tbody>
</table>

Values for significance between any two means are: at 0.1% level, 25.80; at 1% level, 19.06
ression wood at 34" is significantly higher than at the 10th. internode above breast-height, and at the 1% level of confidence differences exist between the percentage of compression wood at 34", and the percentage of compression wood at the 6th. and 10th. internodes respectively.

Thus it is clear that the amount and distribution of compression wood formed by a tree, is strongly influenced by the form of that tree. If the stem form is reasonably straight, as in Kamloops class 2 (and the other classes it represents), the percentage of compression wood formed at consecutive heights up the stem tends to remain constant. If, as in the coastal class 3 stems, the basal portion of the stem is sharply butt-swept, and above this zone of butt-sweep tends to remain displaced from the vertical, it may be expected that the greatest percentages of compression wood will occur in the butt-swept zone, and smaller, but not highly significantly smaller, percentages of compression wood above this region. If, as in coastal class 4 stems, the basal region is very sharply butt-swept, but above this zone tends more rapidly to verticality, it may be expected that high percentages of compression wood will be found in the butt-swept zone, and that some highly significant differences will exist with the smaller percentages of compression wood above this zone.
4.6.2 The Relationships between the Percentage of Compression Wood in the Tree, and Stem Deviation from the Vertical: As is implied in the results of the foregoing section, a mathematical relationship between stem form and the percentage of compression wood formed in the tree, is to be expected.

The similarity in the distribution and amount of compression wood in Kamloops classes 1 and 2 and coastal classes 1 and 2 indicate that the same relationship would be valid for both provenances. When the percentage of compression wood in each stem is plotted against stem deviation, all sample stems tend to be on the same line for all deviation parameters. Consequently, calculations are based on the combined results of the coastal and inland provenances.

Diag. 8 shows the percentage of compression wood in each stem plotted against stem deviation (Z). The associated regression line is also indicated.

Correlation coefficients and linear regressions were calculated for the percentage of compression wood against the three parameters describing stem deviation.

The three parameters comprise the measurement Z, which is the distance in inches from the foot of a 10' pole held vertically against the lower side of the stem, to the lower side of the stem at ground level. (Diag 2)
Diag. 8. Relationship of Stem Deviation to Percent Compression Wood.
the measurement A, which is the distance in inches from a plumb-bob suspended from the uppermost sectionable internode to the centre of the stem at ground level (Diag 3); and the sum of the deviation measurements.

Results are contained in Table 10.

**Table 10:** Relationship Between Percentage of Compression Wood and Stem Deviation Parameters.

<table>
<thead>
<tr>
<th>Percentage Compression Wood compared with:</th>
<th>Correlation Coefficient</th>
<th>Regression $y = C.W. %; ; ; x =$ parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter Z</td>
<td>0.477 **</td>
<td>$y = 26.50 + 0.502x$</td>
</tr>
<tr>
<td>Sum of Deviations</td>
<td>0.424 **</td>
<td>$y = 25.59 + 0.054x$</td>
</tr>
<tr>
<td>Parameter A</td>
<td>0.382 *</td>
<td>$y = 26.92 + 0.196x$</td>
</tr>
</tbody>
</table>

Values of correlation coefficients reached significance at the 1% level of confidence for both Z and the sum of deviations. However, the associated regressions accounted for only 24.41% and 22.09% respectively, of the variation in $y$. This further indicates that it is not possible to accurately predict the amount of compression wood contained in a tree, with such stem deviation factors, although more meaningful results were obtained in comparing percentages of
actual compression wood with the same three deviation parameters (see following section).

4.6.3 The Relationship Between the Estimated Percentage of Actual Compression Wood in the Tree, and Stem Deviation from the Vertical: The actual percentages of compression wood were estimated as indicated on page 67. Zones of slight to moderate compression wood were predominant in those stems showing relatively little stem deviation, and moderate to pronounced compression wood predominant in those stems showing greater stem deviation (page 105). Because of this, the percentages of zonal compression wood were reduced by correspondingly greater proportions in Kamloops classes 1 and 2 and coastal classes 1 and 2. Thus the linear relationship of the above section became curvilinear, in the form of an asymptote (Diag. 9).

To restore the linear relationship, it was necessary to square the actual percentages of compression wood. In Diag. 10 (q.v.) the y ordinate represents the squares of the actual percentages of compression wood, and the x ordinate, the parameter Z. As in the above section, these two variables showed the highest correlation coefficient.

Correlation coefficients and linear regressions where calculated for the squares of the percentages of actual compression wood, against the three stem deviation parameters. Results are shown in Table 11.
Diag. 9. Scattergram of Actual Compression Wood Against Stem Deviation, Showing Curvilinear Relationship.
Diag 10. Relationship of Estimated Percent Actual Compression Wood to Stem Deviation.
TABLE 11: Relationship Between Estimated Actual Percentage of Compression Wood and Stem deviation Parameters.

<table>
<thead>
<tr>
<th>Actual Percentage of Compression Wood compared with:</th>
<th>Correlation Coefficient</th>
<th>Regression Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter Z</td>
<td>0.741 ***</td>
<td>$y^2 = 83.10 + 11.556x$</td>
</tr>
<tr>
<td>Parameter A</td>
<td>0.664 ***</td>
<td>$y^2 = 46.48 + 5.799x$</td>
</tr>
<tr>
<td>Sum of Deviations</td>
<td>0.537 ***</td>
<td>$y^2 = 78.21 + 1.045x$</td>
</tr>
</tbody>
</table>

Although correlation coefficients reached a high level of significance in all cases, the associated regressions for Z and A accounted for only 42.59% and 40.39% respectively of the variation in $y$. As implied in Diag. 10 these results were not entirely unexpected in spite of the significant correlations obtained. It is apparent that either such methods of measuring stem deviation are not satisfactory, or that factors other than stem deviation contribute substantially to the formation of compression wood. These are possibly physiological elements acting, at least in part, independently of stem inclination.

4.7 A Comparison of Breast-Height Compression Wood and Total Tree Compression Wood: As in so many aspects of tree anatomy, the results of this study indicated that some linear relationship might be expected between breast-height and total tree values. Accord-
ingly, the data was analysed to determine if a correlation existed between the percentage of the breast-height section occupied by compression wood, and the percentage of compression wood in the whole tree.

When the relationship was expressed graphically, all sample trees tended to lie on the same straight line (Diag. 11) and so calculations were based on the combined populations.

The mean percentage for compression wood at breast-height was 36.89%, and the mean percentage of compression wood for whole stems, 32.30%. A very highly significant correlation coefficient of 0.836 was obtained, and the associated linear regression of $y/x$ (where $y$ = whole tree compression wood and $x$ = breast-height compression wood) was calculated to be $y = 8.08 + 0.647x$ (Diag. 11). This regression accounted for 60.06% of the variation in $y$, the remaining 39.94% being independent of $x$.

The correlation coefficient, and tolerance limits of the regression, are considerably superior to those obtained from stem deviation measurements (pages 98 and 100) and may provide a more acceptable method for estimating whole tree compression wood.

It is of interest to record that Low (39) studying compression wood in Scots Pine, obtained a compar-
Diag. II. Relationship of Whole Tree Compression Wood to Breast-Height Compression Wood.

$Y = 8.08 + 0.647X$

$\times$ Coastal Sample Trees.

$\circ$ Kamloops Sample Trees.
ably high correlation coefficient (0.776) for the same relationship.

4.8 Occurrence of Compression Wood at Different Heights in the Stem: It has been established that the distribution of compression wood at different heights in the stem varied between those classes showing markedly different stem form (page 92).

It was desired to obtain an overall impression of the distribution of compression wood in the sample tree stems. A comparison was made between the mean percentage of compression wood in the stems for all heights between ground level and the 12th internode above breast-height. Some condensation of the data was necessary, and accordingly the percentages of compression wood for each section, at a given height for all sample trees within a class, were summed and the means calculated. This produced a "mean tree" for each class and an analysis of variance was carried out on these results. Mean percentages of compression wood for the 40 trees at given positions in the stem are contained in Table 12.

The variance ratio was calculated to be 3.55, which is in excess of the tabulated value at $p = .001$ and therefore highly significant differences were indicated between mean values of compression wood at various heights in the stem.
The mean height to the 12th internode above breast-height i.e. section 12, was 20.98', and the distance between consecutive sections, about 3'.

<table>
<thead>
<tr>
<th>Section</th>
<th>A (17&quot;)</th>
<th>B (34&quot;)</th>
<th>C (51&quot;)</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12 (mean 20.98')</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean %</td>
<td>26.95</td>
<td>36.02</td>
<td>40.40</td>
<td>36.73</td>
<td>36.08</td>
<td>08.08</td>
<td>70.77</td>
<td>32.97</td>
<td>26.53</td>
</tr>
</tbody>
</table>

Values for significance of difference between any two means are: at 1% level, 8.74; at 0.1% level, 11.41.

Differences between mean percentages of compression wood above about 7' are negligible. At the 0.1% level of confidence, significant differences exist between mean percentages of compression wood in Section A (ground level) and 34", and between mean percentages of compression wood at 34" and section 12 (20.98'). At the 1% level, differences exist between mean percentages of compression wood at ground level and all heights up to, and including, breast-height, between 17" and 20.98', between 34" and sections 6, 10 and 12, between 51" and sections 10 and 12, and between about 7' (section 2) and 20.98' (section 12). This indicates that compression wood is concentrated in the zone of maximum butt-sweep i.e. about 17" to 7', and that the amount of compression wood formed
by the tree tends to decrease with increasing height.

The mean percentage of compression wood at ground level (section A) is considerably less than in the zone 17" to 7' above ground level, and this value is comparable with the relatively small percentages of compression wood higher up the stem.

This concentration of compression wood in the basally swept portion of the stems possibly indicates that compression wood is of a functional nature in causing the stem to become erect. The consistently low values obtained for the percentage of compression wood at ground level may perhaps be explained in that a butt-swept stem, tends to straighten out not from the base of a tree, but from a point several feet above the base. Thus, if compression wood is of a functional nature in causing the stem to become erect, it might be expected that compression wood would be concentrated not at the base of the stem, but some distance above this point.

It is of interest to note that Low (39) found similarly low values for compression wood in sections removed from the base of Scots Pine stems, and a remarkably similar distribution of compression wood with height.
4.9 Distribution of Zones of Compression Wood: Distinct differences were apparent between some classes of stems and their distribution of zones of compression wood. Differences also existed between provenances.

4.9.1 Slight to Moderate Zones: Those classes of stems showing relatively little deviation from the vertical tended to form considerably greater proportions of slight to moderate compression wood. Kamloops class 1 stems contained a mean of 97.74% of slight to moderate compression wood and thereafter, as stems became more deformed, the amount of this kind of compression wood decreased, and the proportion of moderate to pronounced compression wood increased. Coastal class 3 stems, with approximately equal amounts of slight to moderate, and moderate to pronounced compression wood, represented a "transitional" stage to coastal class 4 stems with a mean of 39.88% slight to moderate compression wood.

Zones of slight to moderate, and moderate to pronounced compression wood usually comprised 25% to 30%, and 60% to 70% recognisable compression wood respectively.

Thus, although Kamloops classes 1 and 2 and coastal classes 1 and 2 were especially comparable in their overall amounts of compression wood (page 84), the percentage of actual compression wood increased with increasing stem deviation from the vertical (page 82)
The coastal stems, although rarely forming significantly greater volumes of compression wood, tended to produce pronounced rather than mild forms of compression wood, and when the percentage of actual compression wood was graphed against stem deviation, an asymptotic curve was formed (Diag. 9), in contrast to the linear relationship obtained when zonal compression wood was graphed against stem deviation (Diag. 8).

A t-test with a pooled estimate of variance was used to estimate the significance of the differences between mean percentages of slight to moderate compression wood in the six classes. Results are contained in Table 13.

<table>
<thead>
<tr>
<th>TABLE 13: Mean Percentages of Slight to Moderate and Moderate to Pronounced Compression Wood for All Classes.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zones of Compression Wood</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Slight to Moderate</td>
</tr>
<tr>
<td>Moderate to Pronounced</td>
</tr>
</tbody>
</table>

Values for significance of difference between means are: Kamloops means at 1% level, 12.58; Kamloops & coastal means at 0.1% level and 1% level, 20.35 and
and 15.41 respectively, coastal means at 0.1% and 1% level, 23.50 and 17.79 respectively.

Differences between the means of any two consecutive classes are not significant, but differences between classes further removed all reach significance, and the level of significance increases with increasing distance between classes.

In the coastal class 3 and 4 stems, zones of slight to moderate compression wood frequently comprised those areas along the lateral edges of zones of moderate to pronounced compression wood, since recognisable compression wood in the latter zones tended to decrease towards the lateral edges. In coastal classes 1 and 2 whole zones of compression wood were often slight to moderate in nature, and frequently, but by no means invariably, found towards the periphery of the cross-section.

Zones of slight to moderate compression wood predominated in all the Kamloops stems. These zones of compression wood were commonly dispersed about the stem cross-section and, compared to the more discrete bodies of compression wood in the coastal stems, appeared diffuse in nature. This was one of the few differences between the provenances, and is recorded in Plate 2.
4.9.2 Moderate to Pronounced Zones: The percentages of moderate to pronounced compression wood in the stem deviation classes are recorded in Table 13. Since the relative amounts of slight to moderate and moderate to pronounced compression wood are expressed as percentages of the total volume of compression wood, an inverse relationship exists between the two, and the same values of significance are applicable.

Zones of moderate to pronounced compression wood were often triangular in outline, with the apex of the triangle lying in the first formed annual rings (Plate 1). Zones frequently extended from near the pith to the periphery of the cross-section, with up to 80% of the zone comprising actual compression wood.

In consecutive cross-sections up many of the coastal stems, these zones of pronounced compression wood were remarkably constant in position and outline. They could occasionally be identified throughout the whole length of the stem, as in Plate 3.

In the more severely deformed coastal stems in particular, discreet zones of moderate to heavy compression wood occupied up to 77.5% of the total area of the stem cross-section. These large areas of pronounced compression wood were confined mainly to the basal 8' of the stem (Plate 1).
4.10 Orientation of Compression Wood.

4.10.1 Comparisons Between Classes: In the measurement of compression wood, the amount of compression wood occurring in the original upper and lower sides of the stems was recorded for each section (page 65). The percentage contribution to the total compression wood for each side of the whole tree was calculated and the results analysed for the significance of differences between class means. t-tests (with a pooled estimate of variance in the case of the four coastal classes) were used. It must be emphasised that when sections were divided into upper and lower sides, the lower side was almost invariably greater in area owing to increased radial growth on that side.

Means for compression wood on the original upper side of the stem for Kamloops classes 1 and 2 were 23.91% and 14.78% respectively. For significance at the 5% level of confidence, the difference between means must exceed 13.16, and therefore the differences are not significant.

Results for coastal classes 1 and 2 are contained in Table 14.
TABLE 14: Mean Percentages of Compression Wood in Original Upper and Lower Sides of Four Coastal Classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>Compression Wood Upper Side</th>
<th>Compression Wood Lower Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal 1</td>
<td>16.62</td>
<td>83.38</td>
</tr>
<tr>
<td>Coastal 2</td>
<td>8.24</td>
<td>91.76</td>
</tr>
<tr>
<td>Coastal 3</td>
<td>10.76</td>
<td>89.24</td>
</tr>
<tr>
<td>Coastal 4</td>
<td>3.82</td>
<td>96.18</td>
</tr>
</tbody>
</table>

Values for significance of difference between means are: at 5% level, 9.82; at 1% level, 13.53.

Significance is reached for the difference between class 1 and class 4 means, but only at the 5% level.

Owing to excessive variance between classes, values for the significance of differences between Kamloops and coastal class means were not calculated.

It is seen that in those stems showing less deviation from the vertical, and especially in the Kamloops stems, there is a tendency for compression wood to be found in all areas of the stem cross-section, whilst in the most deformed stems, compression wood is almost entirely confined to the original lower side of the stem.
Comparisons Between Original Upper and Lower Sides of the Stems: Compression wood obviously predominated in the original lower side of the stem, at all heights in the stem.

Low (39) and Kienholz (34) indicate, for Scots Pine and Mountain Hemlock respectively, that compression wood tends to form in opposite sides of the stem as the vigorous top portion of the stem overcorrects, but this was not confirmed for Pinus contorta. In this species compression wood formed primarily in the original lower side of the stem, although zones of compression wood tended to be of a more dispersed nature in the Kamloops stems (page 107). A considerable range of variation was found in the orientation of compression wood in the latter, with a maximum of 51.3% compression wood in the upper side of the stem for one tree, and a minimum of 0.6% in another. For all Kamloops stems, the mean percentages of compression wood, expressed as a proportion of the total tree compression wood, were 19.35% and 80.65% for the original upper and lower sides respectively.

For all coastal stems, a range of 1.8% to 28.4% compression wood was recorded for the upper side, with mean percentages of compression wood for upper and lower sides (expressed as proportions of total
tree compression wood) of 9.86 and 90.14% respectively.

Compression wood tended to form initially on the original lower side of the stem, and, to a great extent, maintained this orientation throughout the length of the stem. There were no major differences in the orientation of compression wood between provenances. The dispersed nature of zones of compression wood in the Kamloops stems gave a greater range of variation, and a higher mean value (19.35% for Kamloops stems compared to 9.86% for coastal stems) for compression wood in the original upper side of the stem.

4.11 Reject Timber: The volume of reject timber, due to excess stem deformation, was estimated according to the method outlined on page 56. The most stringent pulpwood specification of the Fort William Pulp and Paper Mill was employed as the basis of the measurements (page 143).

Although subjective assessments of stem deformation in the coastal provenances would invariably result in high estimates of stem deformation, a surprisingly small volume of timber would be rejected under this specification.
All coastal class 4 trees contained reject timber in the basal, butt-swept portion of the stem, and a single class 3 stem contained reject timber in the same region. There was no reject timber in the Kamloops stems (Table 2).

Reject timber totalled $5.87 \text{ ft.}^3 (20.85\%)$ in coastal class 4 stems, $4.39 \text{ ft.}^3 (6.87\%)$ in coastal class 3 stems, and $10.26 \text{ ft.}^3 (1.66\%)$ of the total measured volume of the coastal provenances, after allowance had been made for the volumetric proportions of classes 3 and 4 in the coastal stands.

It is apparent that, for pulping purposes, there is little loss of timber in the coastal stands as a whole, and none in the Kamloops stand. The loss, due to excessive stem deformation, would be very much higher if the stands were being considered for saw-timber.

4.12 The Effect of Wind on Lean and Butt-Sweep in the Stands: The compass direction of the initial lean or butt-sweep was recorded for all trees in all sample stands in order to determine whether butt-sweep or lean was randomly distributed. The direction of lean or sweep for each tree was assigned to one of sixteen, $22.5^\circ$ compass sectors. Measurements were obtained for a total of 283 stems, and the percentage of the total number of stems showing lean or sweep
in any given direction is shown in Diag. 12 (q.v.).

It is to be noted that butt-sweep was much more common than lean, the former occurring in about 95% of the cases. It appeared that when a straight stem was forced out of the vertical, the more rapidly growing upper portion of the tree tended to regain verticality directly above the point to which it had been displaced. The lower portion of the tree tended to remain in the same position, and thus, over a period of years, lean in a straight stem was apparently converted to butt-sweep.

A total of 24 Kamloops stems (13.95% of all Kamloops stems) were assessed as effectively vertical. All other Kamloops stems, and all coastal stems showed measurable butt-sweep, or lean.

As indicated in Diag. 12, deformation was not randomly distributed, and it must be concluded that some systematic influence - probably wind - was effective in inducing this stem deformation.

With prevailing south to south westerly winds, the majority of lean and butt-sweep was not confined to those sectors diametrically opposite to the direction of the prevailing winds, but was displaced in an easterly direction. Thus, 83.0% of the stems leaned, or were butt-swept, in the NE to E directions.
Diagram 12  Directions of Initial Stem Deviation

(Percentage of Total Number of Trees)
Adjacent mature stands presumably have had some funnelling effect on the wind, tending to displace its main force towards the east.

It is of interest to record that naturally regenerated coastal *Pinus contorta* growing under natural conditions, does not have this tendency to butt-sweep (Mr. A. Moss, pers. comm), and it appears that environmental conditions, particularly in the young stages, are of paramount importance in the formation of butt-sweep.
5.1 Validity of Results: It must be emphasised that the results have been drawn from limited populations growing in a particular environment. It is believed that the sampling method, and the sample itself (which comprised 40 stems in a total population of 283 stems) are satisfactory.

Unfortunately time did not allow for testing the applicability of results to different populations of the same provenances growing under similar environmental conditions. However, further stands of *Pinus contorta* have been visited in the Black Isle, at Milbuie, and at Inchnacardoch, and in these three areas the stem form of *Pinus contorta* of Auchterawe ex Butterwood, Coast U.S.A., and East of Eskloops origins has been similar, and generally comparable to the stem form in the sample area.

Actual and zonal areas of compression wood have been calculated and recorded. Many results are based only on the measurement of zones of compression wood, as this measurement is of wider applicability to the
study for the reasons outlined in the following section.

In making comparisons between classes the numerical, or where necessary, the volumetric proportions of each class in the stands have been taken into account when applicable.

The remainder of this section will be divided into two parts, the first comprising a discussion of results, and the second, a consideration of the possible effects of compression wood on the utilisation of these stands.

5.2 General: The division of sample stems into deviation classes was not justified in the case of the Kamloops provenance. There were no real differences between total compression wood, actual compression wood or distribution of compression wood in the two classes formed (pages 79, 82, 92). The results indicated that an effectively straight, and vertical stem of this provenance, would contain comparable amounts of compression wood to a stem with a measured deviation lying at the upper limit of the range of deviation for this provenance. Kamloops class 2 stems showed a greater range than class 1 stems in the percentage of compression wood formed in a stem (Table 8), but differences between any mean values did not reach significance.
In the case of the coastal provenances the stems were divided into four artificial deviation classes, but on the basis of their compression wood anatomy fell naturally into two distinct groups viz. those with a stem deviation measurement $Z$ of less than 19" (classes 1 and 2) and those with a stem deviation measurement $Z$ of 20"+ (classes 3 and 4). Even here, differences between mean percentages of compression wood reached high levels of significance only between widely separated classes (pages 81 and 82).

When comparisons were made between the mean class percentages of compression wood in both the inland and coastal provenances (page 84), the stems again fell naturally into two well defined groups comprising Kamloops classes 1 and 2 and coastal classes 1 and 2 in one group, and coastal classes 3 and 4 in the other (page 86). It was therefore concluded that differences in the percentage of compression wood formed in the six classes varied only between those stems showing slight to moderate and pronounced stem deviation respectively, and not between stems from different provenances showing comparable stem deviation.

The lack of sharp distinction between stem deviation classes was not altogether unexpected. Low (39) obtained very similar results for four stem deviation
classes of Scots Pine, and Zobel & Haught (74) and Holmes (1944) also indicated similar relationships. With these results in mind it was not surprising to find relatively little correlation between stem deviation measurements and the percentage of compression wood in the stems, although more meaningful results were obtained in relating actual compression wood to stem deviation measurements (pages 98 and 100). Zobel & Haught (74) and Pillow & Luxford (58) and Pillow (54) indicate general relationships between stem deviation and the amount of compression wood for Pinus species but Low (39) in a comprehensive study of compression wood in Scots Pine, and McElwee & Zobel (45) studying compression wood in Pinus serotina, similarly failed to obtain meaningful relationships between stem deviation and the amount of compression wood in a tree.

The wide range of variation in the percentage of compression wood in individual stems of any one deviation class (Table 8) largely explains the failure to obtain valid relationships.

It appears that the amount of compression wood in breast-height cross sections may provide more reliable estimates of total tree compression wood. Breast-height values have frequently been found to be representative of total tree values for a variety of
identities (Einspahr et al. 17, Zobel et al. 75) and in this study a correlation of 0.836 was obtained for breast-height compression wood compared to total tree compression wood. The associated regression accounted for 60.06% of the variation in total tree compression wood (page 100). Low (39) obtained similar results for the same relationship.

There have been no previous comparisons of compression wood formed in different tree species, or varieties of the same species. A marked morphological difference in stem form existed between the Kamloops and coastal provenances, and it was expected that the coarser and more deformed coastal stems would contain greater amounts of compression wood. Although coastal stems showing pronounced stem deviation did contain greater amounts of compression wood, their numerical representation in the coastal stands was not great, (only 17.12% of stems had Z measurements in excess of 20") and no difference was found between the amounts of compression wood formed in the inland and coastal provenances (page 76). Stands had twice been thinned (to C/D grade) and probably greater proportions of the more deformed stems were removed. Consequently, the differences between the provenances may well be increased in unthinned stands, but differences appear unlikely to attain significance (page 78).
In examining compression wood anatomy in some detail, Low (39) and Kienholtz (34) found, for Scots Pine and Mountain Hemlock respectively, that the orientation of compression wood reflected the orientation of the vigorously growing top portion of the stem. This portion of the stem tended to "overcorrect" in opposite directions at succeeding heights in the stem, and compression wood, forming on the true lower side on each occasion was produced in a zig-zag fashion up the stem. Mergen (46) obtained similar results for Tsuga canadensis when the terminal shoot was artificially bent away from its normal position. In Pinus contorta, and especially in the coastal provenances, compression wood was formed almost exclusively on the original lower side, and no zig-zag effect was apparent. A single zone of compression wood could often be traced through several cross-sections up the stem, and occasionally up the whole stem, whilst maintaining virtually identical orientation in all sections in which it appeared (Plate 3). This was not unexpected as there was no morphological evidence of "overcorrection" in the stands.

It must be concluded that this species is not prone to overcorrection, but it is felt that if artificial changes in leader orientation were artificially induced the distribution of compression wood would reflect the change of orientation, notwithstanding the
pronounced tendency of *Pinus contorta* to form compression wood on the original lower side of the stem.

Compression wood tended to be more diffuse in the Kamloops stems (page 107 and Plate 2) but occasionally zones of heavier compression wood, showing similar orientation behaviour, could be traced through succeeding cross-sections.

There are conflicting reports as to the amounts of compression wood formed at different heights in the stem. Paul & Smith (1950), Hale & Perem (1922), Pillow et al. (59), Pillow (54), Kienholtz (54) and Pillow & Luxford (58) report a concentration of compression wood in the butt portion of various conifer species, whilst Pillow & Luxford (58) found the amount of compression wood in *Pinus clausa* to be almost constant at all heights in the stem, and Low (39) found compression wood to increase from ground level to breast-height (about 28%) and then to remain relatively constant to timber height at about 24%. In this study, results were similar to those obtained by the latter, with an increase in compression wood from 26.95% at ground level, to a maximum of 40.40% at 34" and then a gradual decrease to 26.53% at a height of about 21' (page 103). There is a concentration of compression wood in the butt-swept portion of the stem i.e. to a height of about 8', and it is suggested
(page 104) that compression wood is of a functional nature in causing the stem to become erect and is therefore concentrated in that zone where deformation is greatest, and the maximum straightening effect is required.

The direction of lean or butt-sweep was not found to be randomly distributed in the stands (page 114), 91.52% of the total number of stems in all stands showed some degree of stem deviation, and 30% leaned away from, but not diametrically opposite, the prevailing wind direction.

Low (39), Fielding (18), and others, comment that stem deviation frequently predominates away from the prevailing wind direction, and it is concluded that wind has a primary effect on the orientation of stem deviation, and probably on the formation of stem deviation.

5.3 Possible Effects of Compression Wood on the Utilisation of These Stands: Owing to the small size of the stems, and poor form especially of the coastal provenances, it is unlikely that these stands would be considered for utilisation as saw-timber. In the unlikely event of their being used as saw-timber, serious degrade would undoubtedly result in almost all boards sawn from the stems. Perem (51) found that even mild forms of compression wood had an
adverse effect on wood strength properties, and A.J. du Toit (68) found timber quality to be adversely affected by compression wood even in full sized clear grades (page 36). It was found, for the 40 sample trees, that at no height in the stem could a utilisable length of timber be removed without it containing some compression wood. In addition to this, excessive deformation of the butt log in many of the stems would result in a considerable loss of volume, and it must be concluded that such stands of *Pinus contorta* would be virtually useless for saw-timber purposes.

It appears that the adverse effects of compression wood, particularly on sulphite pulp quality, are not entirely confined to the effects of compression wood itself (page 39). Green & Yorston (21) found, for Black Spruce & Balsam Fir, that apparently normal wood lying between zones of actual compression wood and the pith were "acid susceptible", and showed typical compression wood properties, whilst Watson & Dadswell (71) report, for *Pinus radiata*, that pulp prepared from wood on the opposite side of the tree to compression wood tends to be "acid susceptible". For both sulphate and sulphite pulps, up to 10% lower pulp yields were obtained, and strength values were reduced in pulps prepared from compression wood. Lower strength values were also found for groundwood pulps (Pillow et al. 59).
It is for these reasons that estimates of actual compression wood are of academic interest only in the utilisation of timber containing compression wood. Further, it is considered that the estimated volumes of compression wood in the stands - 33.60% for coastal stands and 29.25% for inland stands - are conservative estimates of the effects of compression wood, in that they represent zones of visible compression wood only, and their effects under acid pulping processes especially, may be extended to the opposite wood. In addition to this, the stands had twice been thinned, and it is likely, with thinning concentrated on the stems of poorer form, that in the coastal stands particularly, the volume of compression wood may be higher in unthinned stands.

Sulphate and sulphite pulps prepared from compression wood have higher bleach requirements (Curran 10, Dadswell et al. 14) and the consumption of all chemicals is higher (Curran 10). The latter states for sulphite pulps prepared from compression wood of *Pinus taeda* that... "the pulp from compression wood was practically unbleachable".

It is difficult to estimate the effects of the compression wood in these stands, although Curran (10) found with a 20% furnish of *P. taeda* compression wood sulphite pulp in a newsprint run that differ-
ences in pulp properties were evident to an appreciable degree in the newsprint produced. It appears that under sulphate pulping processes, satisfactory grades of paper can be obtained even with up to 50% compression wood in the raw material (Watson & Dadswell 74), but raw material, even with relatively small amounts of recognisable compression wood, when prepared under acid cooking conditions, will show considerable reductions in pulp yields and paper quality.

It is reasonable to conclude that the amounts of compression wood found in these Pinus contorta stands exceeds acceptable limits for pulp mills concentrating on the production of high quality papers prepared under acid cooking conditions.

It is recommended that further investigation is made into compression wood in Pinus contorta stands, and that the effects of compression wood on pulps prepared under acid cooking conditions is further examined.
**LIST OF REFERENCES.**

* Background Literature Only - Not Included in Text.

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</table>

- Stresses and Strains in Growing Timber. For. J. 12, 68-79.
- Svensk Papp. Tidn. 1966. 69 (17), 547-548.


What is Reaction Wood? Aust. For. 15, 22-23.


Examples of Spiral Compression Wood (in Spruce from Sweden and Alaska). Tree Ring Bull. 6, 21-22.


Wood and Pulp Properties as Determined from Slash Pine Increment Core and Whole Tree Measurements. Silvae Genet. 11, 68-77


Pinus contorta and Its Variations. Baileya 7, 7-10.

Problems in Dating Rings of California Coast Redwood. Tree Ring Bull. 6 (3), 20-21.


Variation in Lodgepole Pine With Reference to Provenances Planted in Great Britain and Ireland. Forestry XXXIX (1), 30-39.


APPENDICES
APPENDIX 1.

PLATES.
PLATE 1. Section B, Tree No. 2.
Typical triangular shaped zone of moderate to pronounced compression wood in coastal stem.

Note 1. Compression wood appears as distinctive darker bands in the annual rings.

2. Arrows in all plates represent the original lower side of the stem.
Typically diffuse zones of predominantly slight to moderate compression wood in Kamloops stems. Section of left shows considerably greater formation of compression wood.
PLATE 3. Sections, B,D, 2, 10, Tree No. 68.

Shows constancy of orientation and outline of compression wood, with height up the stem, in coastal trees.
APPENDIX 2.

STATISTICS:

Method of Comparison of Stratified Sample Means.
COASTAL PROVENANCES: (4 classes of 5 stems each)

Total Number of stems in the 4 classes is:

\[ N_1 + N_2 + N_3 + N_4 = N \]

Mean %age of compression wood of 5 trees in each class is:

\[ \bar{Y}_1, \bar{Y}_2, \bar{Y}_3, \bar{Y}_4. \]

Estimate of mean of stand

\[ = \frac{1}{N} \left( \frac{N_1 \bar{Y}_1 + N_2 \bar{Y}_2 + N_3 \bar{Y}_3 + N_4 \bar{Y}_4}{5} \right). \]

\[ SE_2 = SE \text{ of mean} \]

\[ = \frac{S}{N} \sqrt{\left\{ \frac{N_1^2 N_2 + N_2^2 N_3 + N_3^2 N_4 + N_4^2}{5} - N \right\}} \]

INLAND PROVENANCE: (2 classes of 10 stems each)

Estimate of Mean of stand

\[ = \frac{1}{N} \left( \frac{N_1 \bar{Y}_1 + N_2 \bar{Y}_2}{10} \right) \]

\[ SE_1 = SE \text{ of mean} \]

\[ = \frac{S}{N} \sqrt{\left\{ \frac{N_1^2 + N_2^2}{10} - N \right\}} \]

S.E. of differences between mean

\[ = \sqrt{SE_1^2 + SE_2^2} \]

Significance of difference found by comparing:

Difference in means

\[ \sqrt{S^2} = \sqrt{ \text{sum of four coastal corrected sums of squares} + \text{sum of 2 inland corrected sums of squares} } \]

\[ = \frac{34}{34} \]
APPENDIX 3.

FORT WILLIAM PULP AND PAPER MILL

ROUND CONIFER PULPWOOD SPECIFICATIONS
Pulpwood Specification.

Curvature.

All pulpwood must be reasonably straight, i.e. at no place must a line drawn between the mid points of top and bottom diameters be more than $1\frac{1}{2}$" outside the curve of the log. In the case of pulpwood lengths with swept butts, it is permissible to chamfer at the butt end, or to cross cut in the sweep to reduce the curvature to within the acceptable limit as long as the overall length of the log is not reduced to below 8 ft. Logs with more than one curve are acceptable only if the curves lie in the same plane.
APPENDIX 4.

DISTRIBUTION OF PLOTS
**LEGEND:**

Auchterawe ex Ruttlewood Origin  Nos. 1, 2, 5, 6, 9.
Coast U.S.A. Origin  Nos. 3, 4, 7, 8, 10.
East of Kamloops Origin  No. 11.
APPENDIX 5.

ORIGIN OF PROVENANCES
**ORIGIN OF PROVENANCES**

**PLOT NUMBERS AND TREE NUMBERS**

### COASTAL PROVENANCES

<table>
<thead>
<tr>
<th>Origin</th>
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<th>Tree Numbers (inclusive)</th>
</tr>
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<tbody>
<tr>
<td>Auchterawe</td>
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<td>1 - 7</td>
</tr>
<tr>
<td>ex</td>
<td>2</td>
<td>8 - 17</td>
</tr>
<tr>
<td>Ruttle-wood</td>
<td>5</td>
<td>36 - 44</td>
</tr>
<tr>
<td>Beaufort</td>
<td>6</td>
<td>45 - 50</td>
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<tr>
<td></td>
<td>9</td>
<td>73 - 80</td>
</tr>
<tr>
<td>Coast U.S.A (probably</td>
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<td>Long Beach Wash.)</td>
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<td>26 - 35</td>
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### INLAND PROVENANCE

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APPENDIX 6.

SUMMARIES OF RESULTS
APPENDIX  6.1

FIELD DATA. ALL TREES.
APPENDIX 6.1.1

Field Measurements of Deviation from Foot of Pole (z), and Direction of Initial Lean or Butt-Sweep.

COASTAL PROVENANCES. ALL TREES. * denotes sample tree

<table>
<thead>
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<th>Direction of Lean or Sweep</th>
<th>Tree No.</th>
<th>Z&quot;</th>
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### APPENDIX 6.2.2

#### Correction Factors

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