KILN DRYING SINKER HEARTWOOD FROM YOUNG-GROWTH WESTERN HEMLOCK: PRELIMINARY EVALUATION

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Introduction

Western hemlock (Tsuga heterophylla (raf.) Sarg.) is a major timber species in the Pacific Northwest and may be considered a favored species in future forest management plans. Hemlock's even-textured wood has excellent properties for dimension and shop lumber, but the logs often contain shake and the lumber can be difficult to kiln dry to uniform moisture content.

Kozlik (1970) reported that shake and wide variations in moisture content of kiln dried boards of western hemlock are commonly associated with sinker heartwood, also called wetwood, sinker, or heavywood. Analysis by Schroeder and Kozlik (1972) revealed western hemlock sinker heartwood to be higher than normal heartwood in moisture content, specific gravity, and chemical extractives known as lignans. Kozlik, Krahmer, and Lin (1972) demonstrated that the slower drying rate of western hemlock sinker heart could be attributed to the higher amounts of extractives. Removal of these extractives with acetone, ethanol, and presteaming increased the drying rate of sinker heart. Electron microscopy showed heavy incrustations of extractives on the bordered pits of sinker heart and light incrustations on similar pits in normal heartwood and extracted sinker heart. However, the comparative influence of extractives on the properties of normal heartwood and sinker heartwood is not as yet entirely clear. In a microscopic and chemical examination of cellular deposits in tracheids of western hemlock, Krahmer, Hemingway, and Hillis (1970) could not establish a relationship between lignan concentration and location of wetwood zones.

Infection of wood, by bacteria, in the stems of living western hemlock trees may be responsible for the formation of sinker heart and the resultant shake and drying problems. Anaerobic bacteria have been associated with similar-type sinker heart in eastern hemlock, which is also difficult to dry to a uniform moisture content without shake or honeycomb (Hann and Ward, 1972). Schroeder and Kozlik (1972) reported bacteria to be present in western hemlock lumber with sinker heart and Wilcox and Oldham (1972) found a consistent association of bacteria with sinker heart or wetwood in living white fir trees.

To look into some of these relationships, a cooperative research effort was initiated between the Forest Research Laboratory at Oregon State University and the U. S. Forest Products Laboratory. The purpose was to explore a possible correlation of drying problems in sinker heart with stem infections by bacteria. Because sinker heart is wide-spread in old-growth western hemlock timber, we started by examining an old-growth tree. Anaerobic bacteria were present in the sinker heart and sapwood to sinker transition zone, but no bacteria were detected in the middle and outer sapwood. Board samples cut from this tree were dried in an experimental kiln. Noninfected sapwood was easily dried to an average moisture of 15 percent without the formation of shake or honeycomb. Boards with bacterial sinker heart developed shake during drying and retained internal wet pockets with moisture contents exceeding 25 percent.

There is speculation that young-growth western hemlock is generally free of sinker heartwood. If so, the related processing problems would disappear with the final harvesting of remaining old-growth stands. The present paper reports the results of additional research on young-growth western hemlock for sinker heart and related drying characteristics.

Materials and Methods

The quality of young-growth western hemlock was evaluated by visiting several logging sites in both the Cascade and Coastal Mountain ranges east and west of Corvallis, Oregon. Nonsuppressed trees up to 120 years of age were considered representative of young-growth timber. Sinker heart did occur in the butt logs of some trees of this age class, but not to the extent observed in older trees. Because occurrence of sinker heart in young-growth hemlock appears to vary by site, a study tree was selected from a stand where about half the hemlock trees had early stages of sinker formation and the remainder had normal sapwood and heartwood. This stand is located in the Snow Peak area of Cascade Range east of Albany, Oregon. The stand can best be described as a two-storied forest of 100- to 110-year-old hemlock with one or two trees per acre of 800-year-old Douglas-fir. Although many hemlock trees were developing sinker heartwood, the heartwood in the butt logs of the ancient Douglas-firs was generally sound and no wet heart was observed.

The young-growth hemlock selected for the study was a 115-foot tall dominant tree in the younger portion of the forest. The tree had a diameter of 25 inches at breast height and was 105 years old. Two 24-inch-long bolts were taken, one at 18 inches above the ground line and the other at 52 feet.

The lower bolt contained both sapwood and normal heartwood, separated by a broad ring of sinker heartwood (fig. 1). A discolored
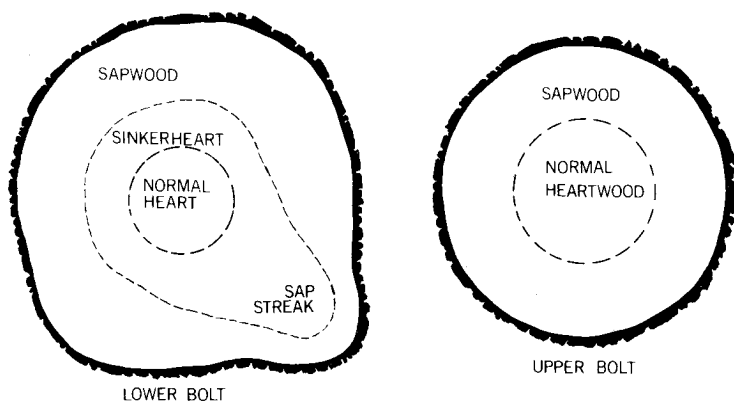
Figure 1. Schematic of end sections of 2-foot-long bolts cut
from a 105-year-old western hemlock tree.   Lower
bolt was cut at 18 inches above ground line and upper
bolt at 52 feet.   Sinker heartwood was infected with
anaerobic bacteria.   The sap streak was infected with
both bacteria and fungi, and could be traced to a
mechanical root injury.   Normal heart and sapwood
was non-infected.

sap streak occurred in one quadrant of the lower bolt, and could be
traced to a mechanical injury to one of the main lateral roots. The stem
of sinker heart had a spatial cone-shaped configuration similar to that
described by Pong and Wilcox (1974) for sinker heart in white fir. The
hemlock sinker heart tapered and disappeared with stem height so that
the upper bolt contained only sapwood and normal heartwood. Both
bolts were wrapped in plastic sheets, hauled to Oregon State University,
and stored in a refrigerated chamber.

For old-growth representation, 2-inch dimension lumber, freshly
sawed from hemlock logs 250 years and older, was collected at the
Willamette Industries, Inc., Dallas, Oregon. These logs were cut from
an adjacent stand in the Snow Peak area.

A total of 54 sample boards, 1.75 inches thick by 6 inches wide
and 22.5 inches long, were cut from the hemlock bolts and dimension
lumber. Immediately after cutting, each sample board was measured
for resistance to a pulsed electronic current using a battery-operated
"Shigometer" (Shigo and Shigo, 1974). A total of six resistance measure-
ments, three across each end, were taken for each sample board. Two
insulated, steel moisture meter electrodes were spaced 2 inches apart
and driven 1/8 inch into the wood in order to take individual resistance
measurements. After measuring resistance, each sample board was
end coated and placed in a small experimental dry kiln at the Forest
Research Laboratory at Oregon State University.

During sample board preparation, green wood sections matching
each sample board were taken for determination of green moisture
content, growth rate, and specific gravity.

A procedure combining microbial isolation techniques with use
of the scanning electron microscope (SEM) was employed to detect and
evaluate the role of bacteria in sinker heart formation. Details of this
procedure are described by Sachs, Ward, and Kinney (1974). Paired
samples were taken from the butt and upper stem sections of the sample
tree. Additional paired core samples were taken from living hemlock
trees in both young-growth and old-growth stands. Some SEM samples
were taken from selected green and kiln-dried old-growth boards
collected at the mill, but microbial culture samples were not isolated
from this material because the anaerobic bacteria in sinker heart tend
to die during log storage. The critical-point drying technique was used
on all SEM wood samples to preserve the original condition of the
margo of bordered pits (Sachs and Kinney, 1974).

Fifty-four green sample boards of western hemlock were dried to
6 to 9 percent average moisture contents under the schedule outlined in
table 1. All boards were periodically weighed during drying in order to
determine drying rates.

Table 1. Kiln schedule for drying green board samples of western
hemlock.

| Time | Temperatures | |
Hr.	Dry bulb °F	Wet bulb °F
0-4	Warm up	Warm up
4-8	180	176
8-31	180	170
31-73	180	164
73-227	180	152

Sinker heartwood and bacteria. --Sinker heartwood was judged to be present, either completely or partially, in 25 of the 54 sample boards. Determination of green wood containing sinker heart was based on appearance, odor, and relatively low resistance to a pulsed electric current. The judgments were substantiated during drying when boards with large amounts of sinker heart were consistently higher in moisture content than boards without or with less than one-half sinker heart.

Laboratory cultivation of wood isolations from the sample tree and standing trees of both young- and old-growth timber showed viable, anaerobic bacteria were present in all sinker heart. Rarely were fungi detected. The most active cultures of bacteria were isolated from the transition zones of sapwood to sinker heart. The sap streak in the young-growth tree (fig. 1) was inhabited by a mixed population of bacteria and mold-type fungi. Neither bacteria nor fungi were isolated from sapwood and normal heartwood, nor were micro-organisms detected in these tissues with the SEM.

Drying times. -- After 4 days of drying there was considerable variation in the average moisture content of the sample boards. Forty-nine boards, approximately 90 percent of the sample, had dried below the maximum allowable moisture content of 19 percent. Of the six samples still above 19 percent moisture content, three boards (two from the tree, one from old-growth) averaged 20 percent moisture content and three boards (all from old-growth) ranged from 28 to 36 percent moisture content.

Although all sinker heartwood from hemlock will dry more slowly than sapwood and normal heartwood, we believe that sinker heart can be subdivided into two classifications, namely; light (easy-to-dry) sinker and heavy (hard-to-dry) sinker. Light sinker will have dried to below 25 percent when sapwood has reached an average moisture content of 13 to 17 percent, while heavy sinker will still be above 25 percent moisture content.

The differences between light and heavy sinker heartwood need to be more clearly defined by additional study. It appears, though, that light sinker is an early stage in sinker heart formation. Observations with the SEM indicate narrow zones or streaks of nonbacterial sapwood or normal heartwood interspersed within the sinker wood tissue. Heavy sinker heart appears to be either an advanced stage in sinker heart formation or a more complete invasion of xylem tissue by bacteria. Observations made at several logging operations indicate that when sinker heart is present in young- and second-growth timber, it may be the light type. More extensive sampling and drying tests will be needed to support these observations.

Table 2 lists the average moisture content of the sample boards during various stages of drying. The boards have been grouped according to timber type, varying amounts of sapwood, normal heartwood, and types of sinker heartwood. Also, boards containing the sap streak noted in figure 1 have been left separate. As indicated in table 2, normal heartwood dried below the required 19 percent moisture content in 2 days, while heavy sinker heart required 6 days. Most sinker boards and boards containing a mixture of sinker with either sapwood

Table 2. Moisture content of normal and microbially infected wood from young- and old-growth western hemlock at various stages of drying.

Type of wood	Associated micro-organisms	Number of samples	Average board moisture content					
			Initial	51 hr	74 hr	98 hr	144 hr	227 hr
			Pct	Pct	Pct	Pct	Pct	Pct

YOUNG-GROWTH

Lower stem

Sapwood--100 percent	None	10	131	35	19	13	8	7
Sap--65 percent, Sapstreak--35 percent	Mixed[1]	4	95	27	16	11	8	6
Sap--60 percent, Sinker--40 percent	Bacteria	5	100	34	22	16	10	7
Sinker--60 percent, Heart--40 percent	Bacteria	5	107	38	27	19	11	7

Upper stem

Sapwood--100 percent	None	7	153	31	16	10	7	6
Heartwood--100 percent	None	2	53	16	11	9	7	7
Sap--50 percent, Heart--50 percent	None	4	97	22	14	11	9	8

OLD-GROWTH

Sapwood--100 percent	None	3	185	43	19	10	7	6
Heartwood--100 percent	None	2	55	17	12	9	7	6
Sap--60 percent, Heart--40 percent	None	1	69	25	16	11	8	7
Sap--70 percent, Sinker--30 percent	Bacteria	2	105	30	20	14	9	7
Heart--50 percent, Sinker--50 percent	Bacteria	2	100	29	20	14	9	7
Sinker-light[2]	Bacteria	4	146	45	28	17	10	7
Sinker-heavy[3]	Bacteria	3	155	63	47	33	18	9
	Total	54						

[1]Mixed population of bacteria and fungi. Sapstreak originating from root injury.
[2]Apparently early stage of sinker formation, generally easy to dry.
[3]Older or more advanced stage of sinker formation, generally harder to dry.

or normal heartwood dried to the required moisture content in 4 days but normal heartwood and some sapwood boards were dried down to 9 to 11 percent.

Drying rates and wood anatomy. -- To better understand the drying characteristics of infected and noninfected wood, drying rates were calculated from the slopes of average drying curves of representative boards according to the following arrangement:

Sapwood	averages of 19 samples
Normal heartwood	averages of 4 samples
Light sinker	averages of 4 samples
Heavy sinker	averages of 3 samples

Figure 2 shows four drying rate curves plotted from these sample averages.

From green to 10 percent moisture content, sapwood dried at the fastest rate while both types of sinker heart dried at the slowest rates. The light sinker heart dried faster than the heavy sinker until about 30 percent moisture content was reached; then both types of sinker dried to 10 percent moisture content at the same rate. Normal heartwood dried initially at rates comparable to light sinker heartwood, but at about 20 percent moisture content both normal heartwood and sapwood dried at equal rates.

These data indicate that the anatomical characteristics of the wood as well as the initial green moisture content will determine the time required to kiln-dry western hemlock. Some sapwood boards will have higher green moisture contents than sinker boards, yet will dry to the required 19 percent moisture content much sooner than the sinker boards. For example, from this study two sapwood boards with green moisture contents of 188 percent and 142 percent were dried to 11 percent and 12 percent respectively after 98 hours. During the same drying period, two sinker boards with initial green moisture contents of 189 and 151 percent dried to 28 percent and 34 percent respectively.

Use of the SEM provides valuable clues to the differences in drying rates. Bordered pits in the tracheids of noninfected wood are shown (fig. 3) where the sapwood pits are not aspirated, while those in normal heartwood are aspirated. The open, net-like margo of sapwood pits should permit easy moisture flow. A light coating of extractives covers the aspirated pits of normal heartwood, which explains the slow rate of moisture loss during early drying. Krahmer and Cote (1963) felt that the warty layer on the inner surface of the pit border in hemlock may permit some moisture movement under the aspirated torus.

The bordered pits of both light and heavy sinker heart were aspirated (fig. 4) with evidence of bacterial invasion. The bordered pits of heavy sinker heart were generally more heavily incrusted with extractives, reducing the possibility of moisture movement through a warty layer interface between torus and pit border. Aspirated pits in light sinker heart may still have a visible warty layer and, even though infected with bacteria, some moisture flow appears possible.

Schroeder and Kozlik (1972) postulated that the only manner in which above-normal extractive amounts could be deposited would be for some type of injury to have occurred on the cambial side of the heartwood-sapwood boundary because the heartwood is physiologically dead. It was further suggested that shake rather than bacteria was the
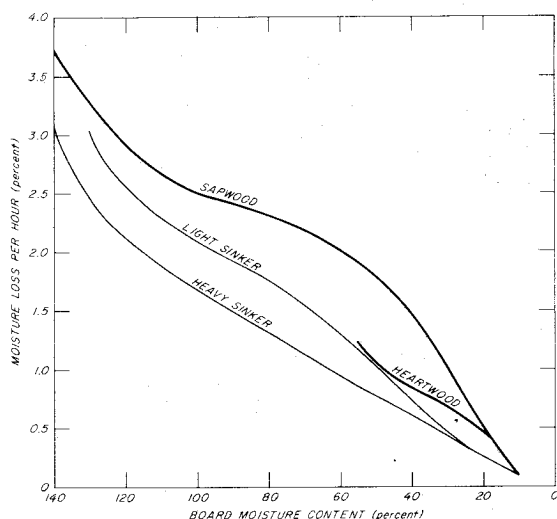
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Figure 2. Rates of moisture loss during the kiln drying of 7/4-
inch thick western hemlock.   Both types of sinker heart
dried at a slower rate than sapwood.   Aspirated bordered
pits probably contributed to the relatively slow initial
drying of normal heartwood, but the rate increased with
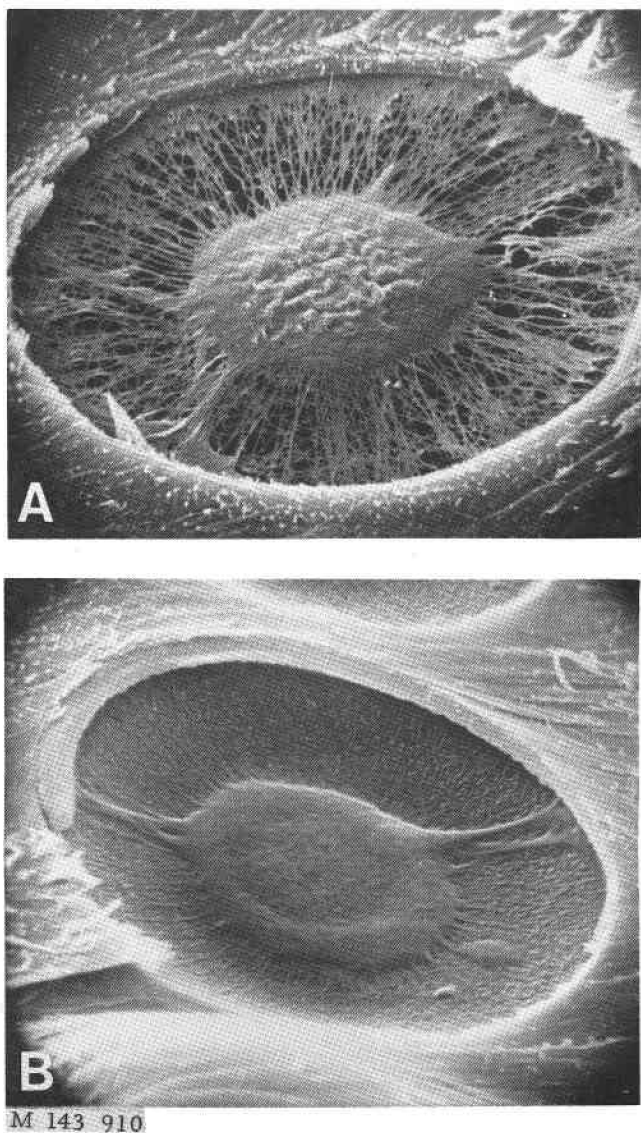loss of free moisture and rupture of tori.

M 143 910

Figure 3.   Scanning electron micrographs of bordered pits in
normal wood of western hemlock: A, sapwood pit
with central nonaspirated torus and open network of
microfibrils in surrounding margo; B, heartwood pit
with aspirated torus folded inward to block pit apera-
ture.   Torus and microfibrillar strands on pit cavity
are incrusted with a light coating of extractives.
Both SEM samples fixed in the green condition.
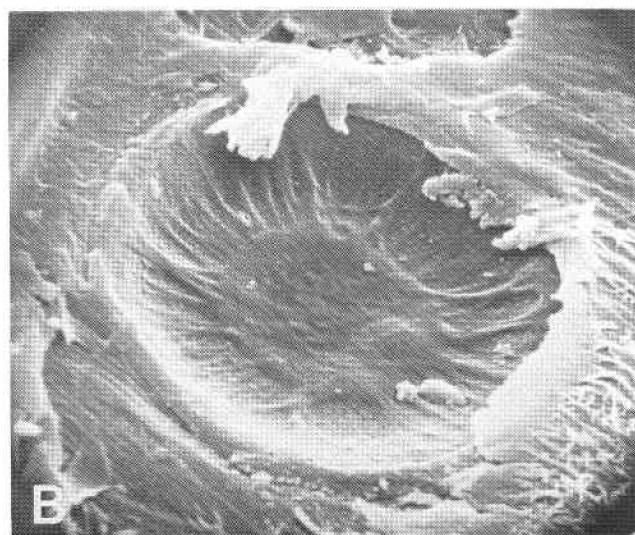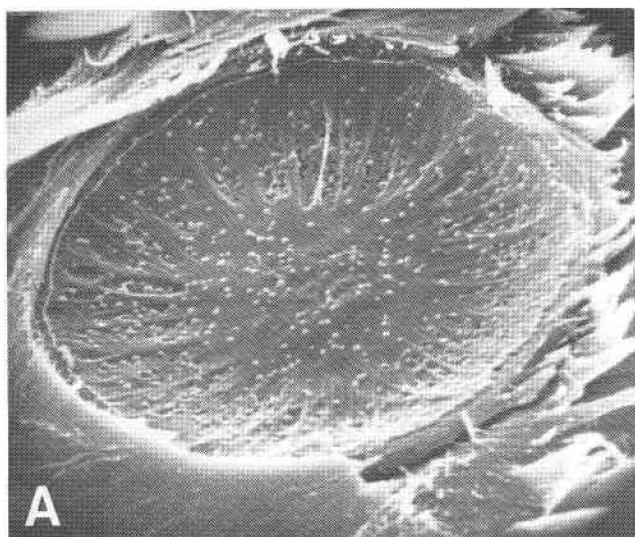
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Figure 4.   Scanning electron micrographs of aspirated bordered pits
in sinker heartwood of western hemlock: A, light sinker
heartwood pit with anaerobic, spherical-shaped bacteria
on torus and interspersed in margo; B, heavy sinker heart-
wood with massive incrustation of extractives and bacteria
on torus and margo.   Both SEM samples fixed in green
condition.

causal agent stimulating extractives production and ultimately sinker heartwood. The location and physical nature of lignan deposits in western hemlock heartwood indicated to Krahmer et al. (1970) that the biosynthesis of these extractives took place at the sapwood-heartwood boundary in the ray cells contiguous with the occluded tracheids.

Observations from this study support the hypothesis of injury to sapwood, but reject the idea of the causal agent being shake rather than bacteria. We find that shake can be absent from sinker heart, especially in second-growth trees, yet bacteria and above-normal moisture content and incrustations of extractives will invariably be found. Reasons for considering bacteria as causal agents for shake as well as sinker heart formation will be discussed later.

The invariable occurrence of anaerobic bacteria in the transition zone of a sapwood to sinker heart in living hemlock trees suggests a likely cause for increased production of extractives by the tree. These bacteria may be injuring still viable sapwood parenchyma cells, either by direct attack on the cell membranes or indirectly through production of toxic, metabolic byproducts. Evidence of bacterial attack or close association with ray parenchyma cells is shown in figure 5. The tracheid-to-ray pit membranes of normal heartwood and sapwood are usually clean and intact (fig. 5A). In figure 5B, the pit membrane of a ray cell located in sap-to-sinker transition wood has bacteria attached to it when viewed from the tracheid lumen.

Heavy incrustations of extractives on bordered pit membranes occur much more frequently in heavy sinker wood than in light sinker wood. Also, many tracheids scattered throughout light sinker will be free of bacteria and have nonaspirated bordered pits (fig. 6A). Part of the cellular incrustations in sinker heartwood may consist of such microbial byproducts as bacterial slime or polysaccharides, which could contribute to the absorption and retention of moisture. Presumedly, as bacterial colonies increase and spread to adjoining tracheids, extractive incrustation, wood moisture absorption, and pit aspiration increase with a subsequent decrease in drying rates.

Bordered pit membranes in normal heartwood are apparently quite brittle and often will not withstand prolonged viewing by the SEM electron beam without cracking. Kiln drying also tends to rupture the membranes of normal heartwood pits (fig. 6B). When normal heartwood is fixed in a green condition and subjected to critical-point drying, the bordered pit membranes will be brittle but intact. If kiln-dried, normal heartwood samples are prepared in the same way, many bordered pit membranes will be ruptured when first viewed under the SEM. This could explain an increase in rate of moisture loss from normal heartwood during kiln drying.

Shake in kiln-dried hemlock lumber. --Ring shake was present in sinker heartwood of sample boards from the old-growth timber and sinker heart of the sample young-growth tree. These results, together with observations from other drying experiments, suggest that anaerobic bacteria rather than the dry-kiln operator is responsible for ring shake in dried hemlock lumber. Hunt (1963) also suggested that the kiln operator not be blamed for shake in hemlock; he believed that shake was inherent in some pieces that would open up whether air dried, kiln dried, or dried in place after use.

Hemlock trees appear more likely to be invaded by anaerobic bacteria and develop sinker heart than neighboring Douglas-fir trees. As these bacteria are established in the tree, they produce enzymes that weaken bonds between wood cells so that rupture is likely under relatively mild stresses.

Laboratory tests with "wild" cultures of anaerobic bacteria isolated from sinker heart of both western and eastern hemlock trees showed that these bacteria are strong producers of pectin-degrading enzymes (J. C. Ward and E. McCoy, unpublished work). This suggests that the bacteria associated with sinker heart attack the chemical bonding in the compound middle lamella, which is relatively rich in pectic substances. Once weakened, this bacterially affected sinker wood is prone to rupture at the compound middle lamella from stresses harmless to non-infected wood.

Meyer and Leney (1968) reported shake in standing trees of western hemlock and true fir generally occurs as a rupture of the compound middle lamella, but they did not describe their wood samples as other than "apparently" normal. Thus, in line with observations on northern red oak (Ward et al., 1972) and certain species of eastern hardwoods and conifers (Hann and Ward, 1972), it appears shake is most likely to develop in the bacterial sinker heart of western hemlock when the tree is subjected to stem growth stresses, bending action of the wind, or freezing. Sinker heart is prone to ring failure or tree shake (fig. 7) from shrinkage stresses under drying conditions not normally harmful to nonbacterial wood.

Characteristics for Presorting. --Kozlik (1972) found that the problem of nonuniformity of final moisture content cannot be remedied by altering the kiln schedule. He proposed sorting sinker boards out on the green chain before drying. This would permit drying sinker heart and normal heartwood under different kiln schedules, thus reducing variability in the final moisture content of each charge. Kozlik and Hamlin (1972) showed that visual segregation of sinker and normal heartwood can be accomplished with a high degree of accuracy on the green chain. However, visual sorting is not always practical in high-production mills. Wood characteristics that might be useful for automatic machine sorting are always being considered in studies of sinker heartwood. Sinker heartwood in hemlock was reported by Kozlik, Krahmer, and Lin (1972) to have a higher specific gravity and initial moisture content than normal heartwood. They also reported parallel capacitance was highest in sinker heartwood, somewhat lower in normal heartwood, and lowest in sapwood at a given moisture content.

Our data (table 3) support previously reported studies where sinker heart had a higher green moisture content than normal heartwood. Density distinctions were not as sharp, but normal heartwood density tended to be lower than sinker heart densities. However, there were no sharp distinctions between sapwood and sinker heartwood moisture content and some sapwood boards would be higher in moisture than sinker boards.

Resistance to a pulsed electric current seems to be the most promising wood characteristic that could be used to distinguish sinker heartwood from sapwood and normal heartwood. Resistance measurements with the Shigometer were independent of moisture content above
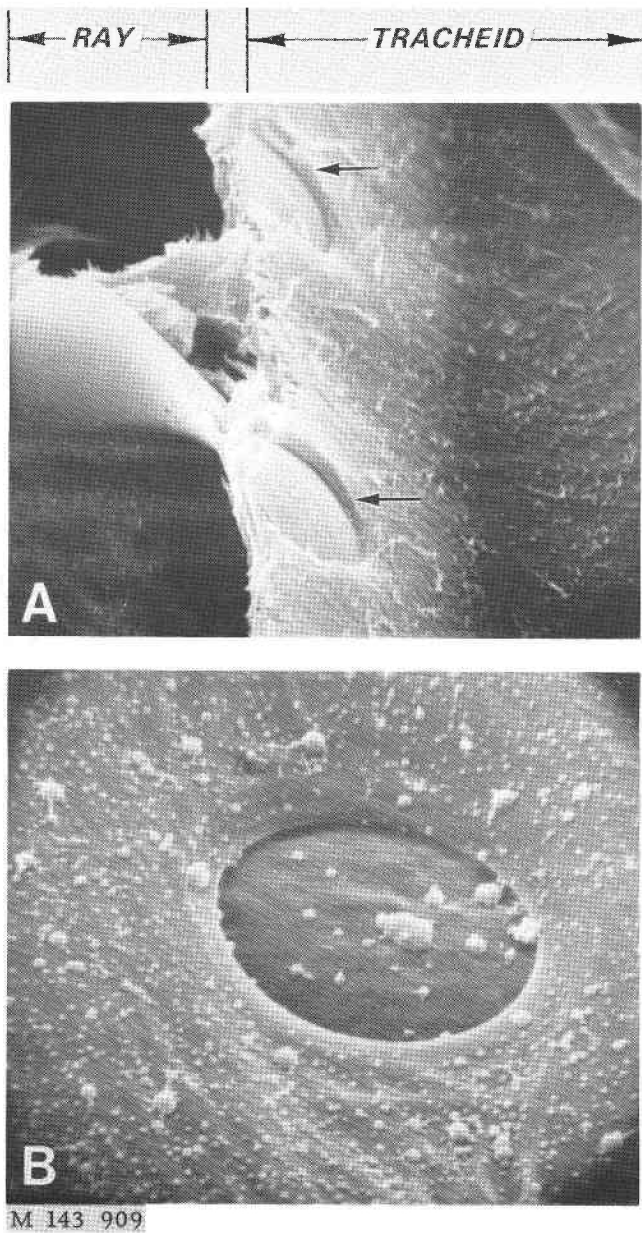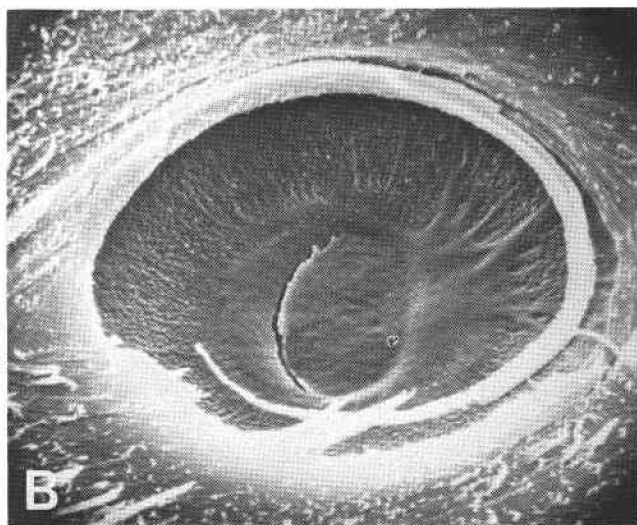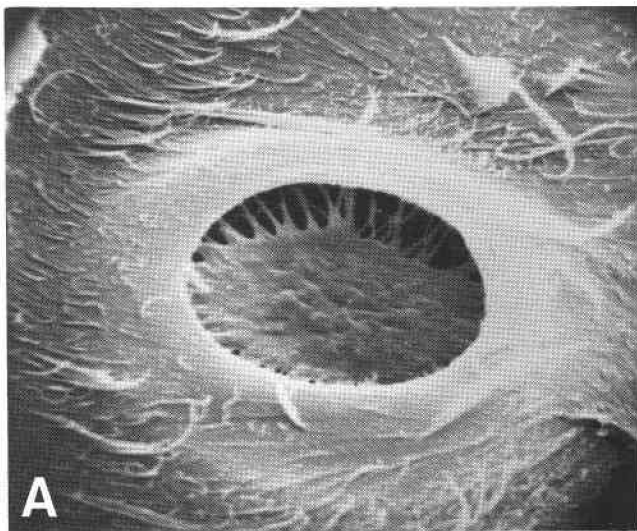
Figure 5. Scanning electron micrograph of tracheid-ray parenchyma pitting in western hemlock: A, non-infected heartwood with no bacteria present on membrane surfaces (arrows) as seen from tracheid side; B, sinker heartwood with anaerobic spherical bacteria on pit membrane and warty layer of tracheid wall. Both SEM samples fixed in green condition.

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Figure 6.   Scanning electron micrographs of bordered pits of western
hemlock with openings for moisture movement: A, bordered
pit in tracheid of light sinker heartwood; SEM sample fixed
in green condition; B, ruptured torus at pit aperature of
tracheid in normal heartwood after kiln drying; SEM sample
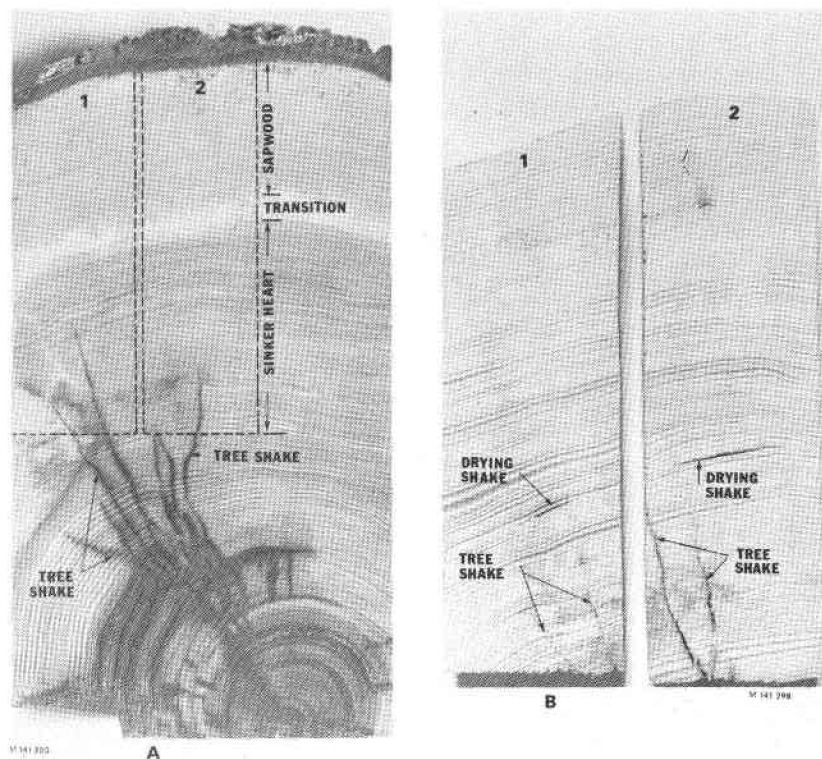fixed in dried condition.

Figure 7.   Old-growth western hemlock containing bacterial sinker heartwood before and after kiln drying: A.   Cross-section from green log showing area where 1-3/4-inch-thick sample boards were taken; B.   Cross-sections taken from sample boards after kiln drying. Ring failure or drying shake developed in sinker heartwood, but not in sapwood.

Table 3. Comparison of normal and microbially infected western hemlock with respect to the moisture content density, growth rates, and electrical resistance of green wood.

Type of wood	Micro-organisms present	Moisture content (green) Average	Range	Density[1] Average	Range	Growth rate Average	Range	Average resistance Normal wood Sap	Heart	Micro-bial
		Pct	Pct			Rings/inch		1.000 Ohms		
NORMAL WOOD										
Sapwood	None	148	104-204	0.40	0.34-.48	9	5-18	104	--	--
Heartwood	None	56	40-72	.40	.37-.43	8	6-12	--	109	--
Mixed: Sap and Heart	None	88	67-110	.38	.36-.42	6	6-7	134	117	--
All normal wood	None	119	40-204	.40	.34-.48	8	5-18	108	112	--
MICROBIALLY INFECTED										
Mixed: Sap and Sap streak	Fungi, bacteria	95	75-108	.46	.46-.47	6	5-7	97	--	47
BACTERIAL										
Mixed: Sap and Sinker	Bacteria	103	88-121	.45	.41-.49	14	7-39	98	--	40
Mixed: Heart and Sinker	Bacteria	106	88-136	.45	.39-.55	9	5-19	--	55	32
Sinker	Bacteria	148	123-189	.43	.39-.50	11	5-20	--	--	23
All bacterial	Bacteria	120	88-189	.44	.39-.55	12	5-39	98	55	29
						Average all resistance.............		106	94	30

[1] Based on green volume and ovendry weight.
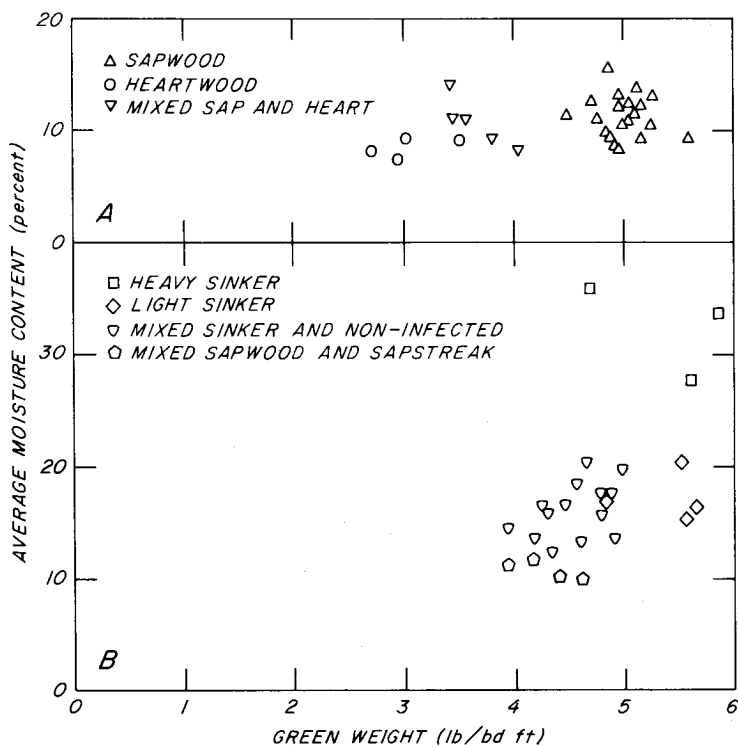
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Figure 8. Comparison of average moisture content of western
hemlock boards after 98 hours of kiln drying with the
green weight of the boards before drying: A is non-
infected wood; B is microbially infected wood.

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the fiber-saturation point of the wood, and green sinker heart was lower in resistance than green sapwood and normal heartwood not associated with sinker heart. Heartwood associated or mixed with sinker heart in a board had lower resistance values but not as low as the adjacent sinker wood.

Weighing green boards, as outlined by Salamon (1970), has been done by some mills to sort for drying to a uniform final moisture content. This indicates weighing green boards would be useful for sorting normal heartwood from sinker heartwood and also sapwood. Weighing is not helpful when sorting sinker boards from sapwood boards (fig. 8). Nevertheless, a sorting system combining weighing and resistance measurements might sort green boards into sapwood, sinker, and heartwood classes with a high degree of accuracy. An obstacle to such a combined sorting system might be the mixtures of sinker heart and normal wood within individual boards, as described by Kozlik and Hamlin (1972).

Summary and Conclusions

1. Sinker heartwood will occur in young-growth western hemlock trees, but not as frequently nor as extensively throughout the stem as in old-growth timber. Previous investigations have been chiefly concerned with distinguishing sinker heartwood from normal heartwood because of the enormous volumes of hemlock lumber being sawed from old-growth stands. Future drying studies should be concerned with distinguishing sinker heartwood from sapwood in young-growth timber.

2. Bacteria have definitely been associated with the formation of sinker heartwood in young-growth as well as old-growth hemlock and will have to be considered in future forest management plans. It appears that these bacteria can become established in sapwood that is declining in vigor, such as at the sapwood-heartwood boundary. In old-growth timber the reasons for decline in sapwood resistance to bacterial invasion are apparently age-related. In young-growth trees, adverse site conditions may be more important. For western hemlock, the invasion and successful establishment of anaerobic bacteria in the inner sapwood of the living tree probably stimulates increased production of extractives from viable parenchyma cells. These extractives, together with bacterial slime and debris from cellular degradation, may account for increased moisture absorption in the living tree and decreased drying rates of the resultant lumber. Aspiration of bordered pit pairs may also be increased by bacterial enzymes.

3. Drying rates for sinker heartwood in both early and advanced stages of formation were definitely slower than drying rates for sapwood and normal heartwood. Throughout the entire kiln cycle, sapwood exhibited the fastest rate of moisture loss, while normal heartwood had an initial rate comparable to rates for sinker heart. Drying rate for normal heartwood increased and finally coincided with sapwood rates at about 30 percent average moisture content. In the green wood condition, sapwood tracheids have open, nonaspirated bordered pits; sinker heartwood has closed, aspirated pits with heavy incrustations of extractives, thus explaining the slower drying rate of sinker heart. Normal heartwood also has aspirated bordered pits with a thin coating of extractives over the torus and margo, but these aspirated membranes

are brittle and apparently rupture during kiln drying. This could explain the greatly increased drying rate of normal heartwood as drying progresses.

4. Ring failure or tree shake are invariably located in sinker heartwood. Also, tree shake and ring failure are anatomically similar in that they occur as ruptures in the compound middle lamella of both tracheids and ray cells. The anaerobic bacteria associated with sinker heart formation may also be responsible for shake; the bacteria produce pectin-degrading enzymes which selectively attack the compound middle lamella, thus weakening the bonds between the wood cells.

5. There are economic advantages for identifying and segregating green lumber containing sapwood, sinker heart, and normal heartwood before kiln drying. The electrical properties of green wood appear promising for developing a system to separate sinker boards from normal boards. Resistance to a pulsed electric current was lower in sinker heartwood than in sapwood and normal heartwood, regardless of variations in moisture content above the fiber saturation point.

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