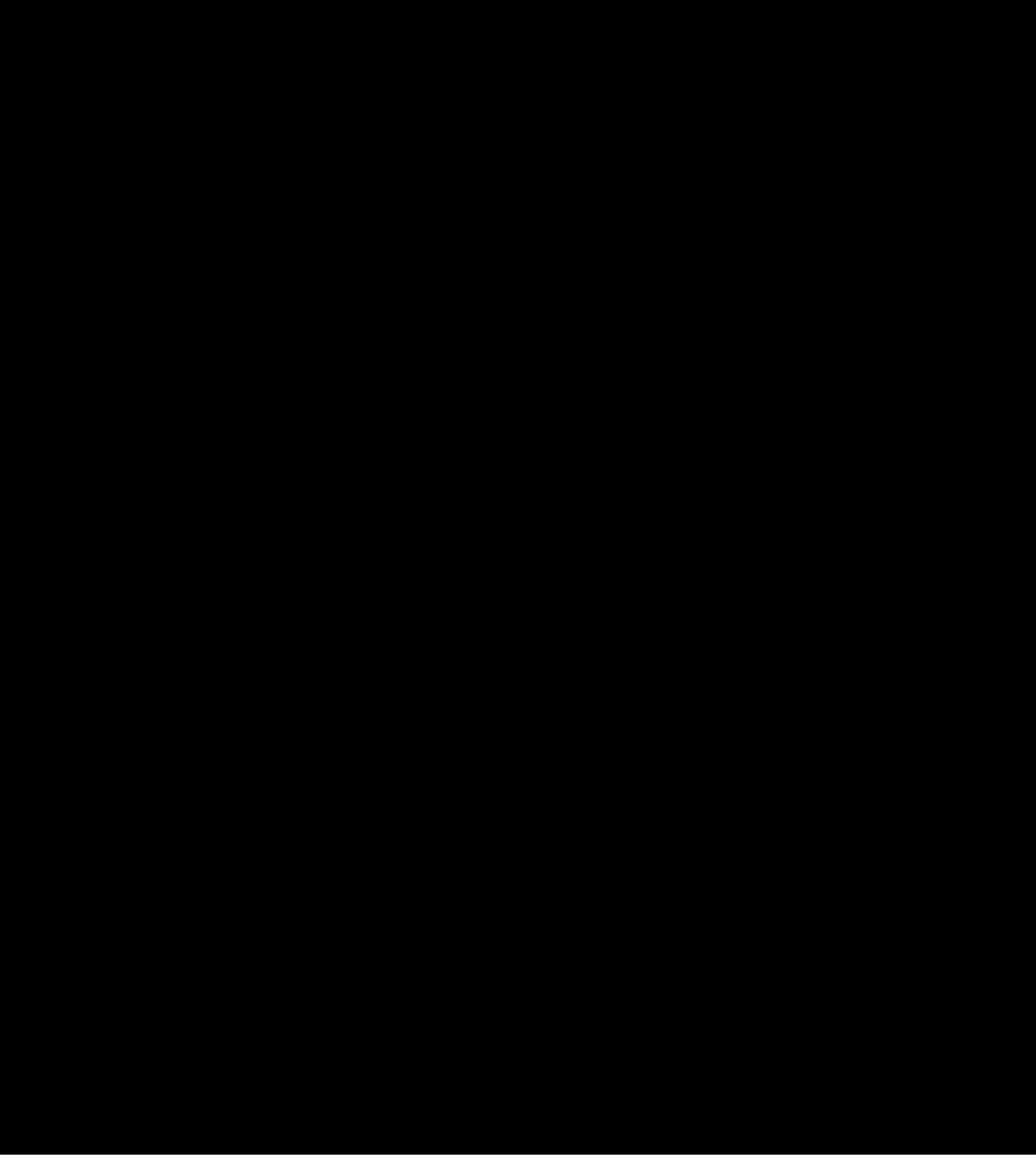




In cooperation with the University of Wisconsin

MADISON, WISCONSIN

- P. L. Brown, "Winter Glaciers",
 Mount Brown & Antarctica, 1960, 1961
 L. E. Brown, "The Icebergs of the Antarctic"

By F. L. BROWNE
Senior Chemist

BEHAVIOR OF HOUSE PAINTS ON DIFFERENT WOODS

By F. L. BROWNE

This discussion is based on a consideration of the general manner, presentation of postural and muscular forces in various art forms and in the behavior of the observer of these in order to present a picture of the behavior and particularly of posture, of the elements for which the observer will be able to make a judgment. However, are there available or will be available information on a scale adequate enough to enable reliable measurements of postural forces, or to make such measurements possible in the systematic analysis of posture, with, for example, the use of pressure (B. 512) or other means to obtain the necessary results.

BEHAVIOR OF HOUSE PAINTS ON DIFFERENT WOODS

By

F. L. Browne, Senior Chemist,
Forest Products Laboratory¹, Forest Service,
U. S. Department of Agriculture.

At least four factors significantly affect the serviceableness of exterior paints on wood, namely, the kind of wood painted, the composition of the paint, the technic of application, and the severity of the climatic and local conditions of exposure. This paper considers only the first of these factors, the kind of wood painted. Even when the best paints and painting procedures are used coatings remain serviceable much longer on some woods than on others. Until further research discloses some practicable means of making paint last at least as long on all woods as it now does on the best of them the bearing of wood properties on paint behavior should be properly understood if maximum satisfaction is to be obtained from painted woodwork.

This discussion is based upon information from two general sources, observation of practices and experience with houses in service and experimentation by means of test fences. Observation of houses in service reveals practical details of paint behavior and particularly of unsatisfactory developments for which the cause and cure should be sought. Real houses, however, are rarely available or suitable for experimentation on a scale adequate enough to develop reliable technical data. Test fences, on the other hand, offer the necessary freedom for systematic variation of woods, paints, technic, and place of exposure (8, 5)². Conditions that lead to unsatisfactory results

¹Maintained at Madison, Wisconsin, in cooperation with the University of Wisconsin.

²Numbers in parentheses are references to publications cited at the end of this paper.

with paint on test fences likewise lead to dissatisfaction on houses. On the other hand certain forms of paint failure observed on houses in which moisture gets into the sidewalls (2) are rarely reproduced on test fences but can be reproduced for study by suitable laboratory devices used in conjunction with test fence exposures (8).

The principal test fence studies by the Forest Products Laboratory from which data are drawn for this discussion are called for convenience:

1. The 1924 Series, on the painting characteristics of softwoods (3).
2. The 1925 Series, on priming and special priming paints (4).
3. The 1927 Thinner Series, on paint thinners and the effect of resins in longleaf pine (7).
4. The 1929 Douglas fir Series, on painting characteristics of Douglas fir (not yet published).
5. The 1930 Hardwood Series, on painting characteristics of hardwoods (11).
6. The 1930 Primer Series, on special priming paints (10).
7. The 1930 Extractive Series, on the effect of extractives in certain woods (not yet published).

These tests were made at 11 stations in different parts of the United States. The test panels were exposed vertically facing south. Supplemental evidence is available from many other series of tests by the Forest Products Laboratory. The results with respect to the painting characteristics of woods are thoroughly in accord with experience as indicated by commercial practices in the selection of woods for building construction in which painting is important and with the writer's observations of houses in service.

Classifications and Properties of Wood

Lumber is cut from trees of many species and the grouping by species or closely related species is retained in merchandising because in general each species has more or less characteristic average properties and finds uses accordingly. For some uses paintability is a property of much importance but as a rule other properties must likewise be considered in choosing lumber for a given use.

Softwoods and hardwoods

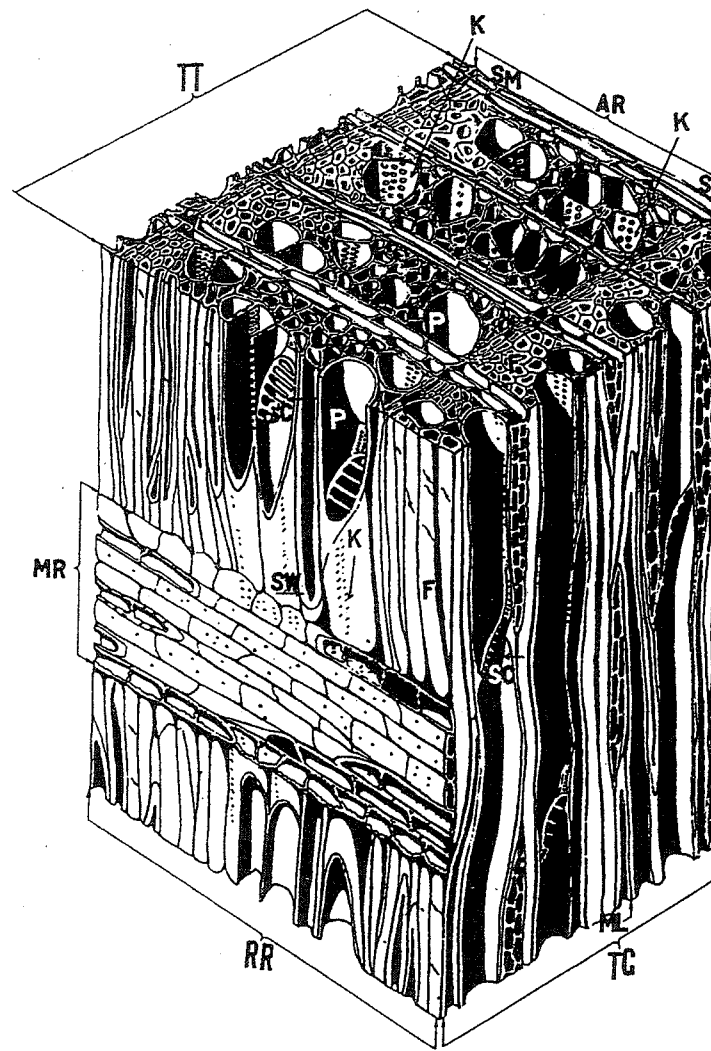
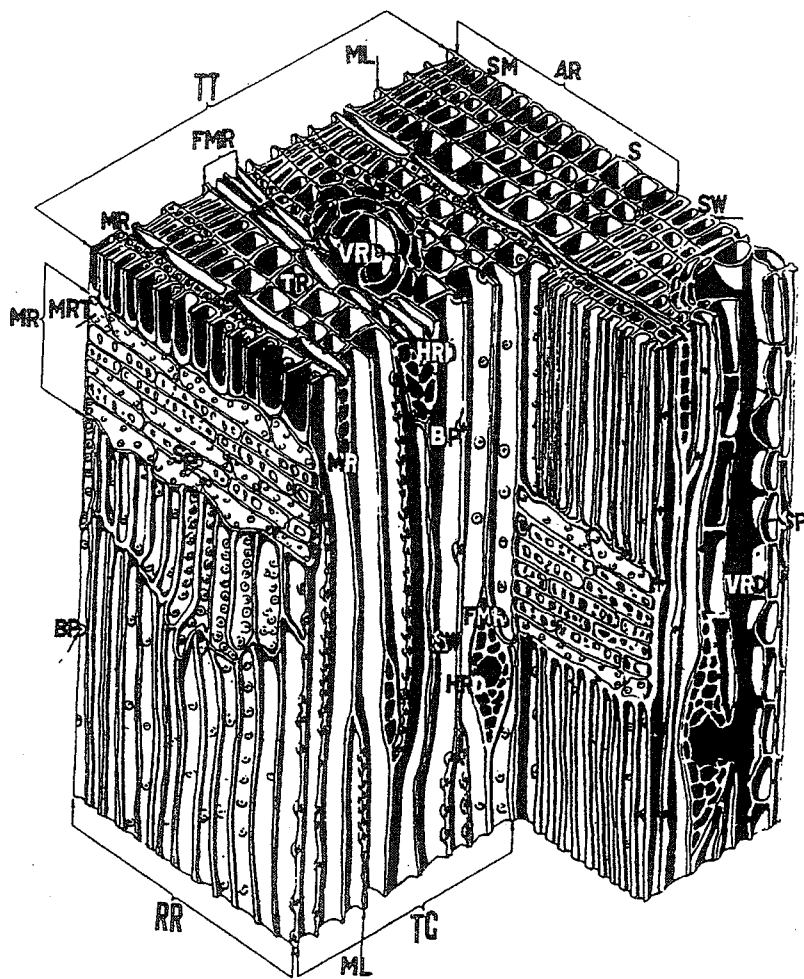
A sharp distinction in practice is made between softwood lumber, which comes from coniferous or needle-leaved trees, and hardwood lumber, which comes from broad-leaved trees. Softwood lumber, however, is not necessarily soft wood; both softwoods and hardwoods vary widely in hardness and softwoods like southern yellow pine are much harder than hardwoods like yellow poplar. In general the higher the specific gravity of the wood the harder it is. As a class the softwoods are more abundant, cheaper, more easily worked with tools, and better suited for the framework and exterior surfaces of buildings than the hardwoods. As a result the softwoods are very much more important than the hardwoods from the point of view of exterior painting. Siding, shingles, exterior trim, and millwork are made predominantly from softwoods although a few of the light-weight hardwoods, such as poplar and basswood, are used for such purposes to a minor extent. Heavier hardwoods such as oak are sometimes used for front doors, door sills, and half-timbering but are more often varnished or stained and varnished rather than painted.

Microscopic structure of wood

Most of the properties of wood are profoundly affected by its characteristic cellular structure. In the softwoods the principal wood cells are the tracheids, which are long hollow cells (fibers) with cellulosic walls, tapered and closed at the ends, and cemented together in a matrix of lignin. The tracheids are roughly 2 to 4 mm. long by less than 0.03 mm. wide and run vertically in the trunk of the tree. There are also ray cells running radially in the trunk which are shorter, and blunter than the tracheids. The hollow centers of the tracheids and ray cells

Figure 1. Microscopic structure of a softwood (left)
and of a hardwood with large pores (right).

The top surface, TT, is transverse (end-grain), TG tangential (flat-grain or plain-sawed), RR radial (edge-grain or quarter-sawed), AR annual growth ring, S springwood, SM summerwood, MR medullary ray, ML middle lamella (lignin) which cements the cellulosic cell walls, SW together. In the softwood TR tracheid, MRT medullary ray tracheid, FMR fusiform medullary ray containing horizontal resin passage HRD, VRD vertical resin passage, BP bordered pit, SP simple pit. In the hardwood F fiber, P pore or vessel, SC open grid at spliced joint in a large pore, K pits.



are not completely isolated from each other because the cell walls contain small pits covered by membranes some of which are known to have tiny openings about 0.00002 mm. in average diameter for intercommunication. Air and liquids can pass through such small openings but the particles of nearly all paint pigments are far too large. In the living tree the tracheids and ray cells provide both mechanical strength and channels for movement of aqueous sap. In air-dry wood the hollows are empty except for air, which can move through the wood freely, though slowly. In some softwoods, such as the pines, spruces, larches, and Douglas fir, there are scattered through the structure certain openings between the cells called resin passages, which run both vertically and radially. The true firs, hemlocks, cedars, cypress, and redwood do not normally have resin passages.

Growth in the living tree trunk takes place at the junction between wood and bark and in temperate climates is confined to the warmer part of the year. Thus each year a new layer of wood known as an annual growth ring is deposited over the wood of previous years. During the early part of the growing season - springwood is formed, which has tracheids with thin walls and large cavities so that it is light in weight and in color, soft, and as much as 80 percent of its total volume when dry may be air-space. Later in the growing season summerwood is formed, which has radially flattened tracheids with thick walls so that it is heavy, darker in color, hard, and as little as 40 percent of its volume may be air-space. Table 1 presents the writer's determinations of the specific gravity of springwood and summerwood whittled from the same annual growth rings in a few samples of some typical softwoods. Although summerwood has only half the capacity of springwood for holding liquids, liquids generally move through summerwood much more readily than through springwood and paint oils penetrate deeper into the summerwood.

Pieces of wood differ widely in the width of their annual growth rings, usually expressed as number of rings per radial inch, and in the proportion of springwood and summerwood in each ring. If the tree grew rapidly the annual rings are wide. The number of growth rings may vary from less than 2 to more than 100 per radial inch. A high ratio of summerwood to springwood makes wood heavy and strong. The summerwood may vary from more than one-half of the annual growth ring to an almost negligible proportion of it.

In hardwoods the function of the tracheids are replaced by two types of wood cells, the fibers, which chiefly

Table 1. Specific gravity of samples of springwood and summerwood of the same annual growth ring in typical softwoods

Wood	Approximate volume of			
	Specific gravity of--		air-space ¹ in--	
	Springwood:Summerwood	Springwood:Summerwood	Percent	Percent
Southern cypress, 1st. sample	0.332	0.941	78	37
Southern cypress, 2d. sample	.282	.905	81	40
Redwood, 1st. sample	.317	.831	79	45
Redwood, 2d. sample	.263	.768	82	49
White fir (commercial)	.295	.901	80	40
Douglas fir	.469	.901	69	40
Ponderosa pine	.307	.843	80	44
Southern yellow pine	.291	.953	80	37

¹Computed on the basis of 1.5 for the specific gravity of wood substance and neglecting correction for the content of extraneous substances of specific gravity differing from 1.5.

provide mechanical strength, and the pores or vessels, which serve as the main channels for movement of liquids in the living tree. In general shape the fibers resemble the softwood tracheids, that is, they are long cells, tapered and closed at the ends but as a rule are much smaller in size than tracheids. Interspersed among the hardwood fibers are the vessels or pores, which may be described as long pipe-lines extending longitudinally through the wood. The pore cells are approximately cylinders open and spliced together at the ends. The pores are considerably larger in diameter than the fibers and are usually the elements that give characteristic appearance or "grain" to the hardwoods. It is convenient to classify the hardwoods on the basis of size and distribution of pores into:

1. Hardwoods with relatively large pores,
 - a. Ring-porous hardwoods
 - b. Diffuse-porous hardwoods.
2. Diffuse-porous hardwoods with relatively small pores.

In ring-porous hardwoods, such as oak, chestnut, and ash, the pores are larger in the early springwood and comparatively small in the summerwood. In diffuse-porous hardwoods, such as walnut, birch, and gum, the pores are more nearly uniform in size and distribution throughout the annual growth ring. The hardwoods with relatively large pores have pores larger than those in birch. In ring-porous hardwoods the variation in size of the pores makes the summerwood denser and harder than the springwood but in diffuse-porous hardwoods there is usually far less contrast in density between summerwood and springwood than there is among softwoods.

In many species both of softwoods and of hardwoods the older wood nearer the center of the tree differs in color and in content of certain chemicals from the wood nearer the bark of the tree. The former is the heartwood, the latter the sapwood. Heartwood is usually less readily permeable to liquids than sapwood, often much more durable against decay, and is usually immune from blue stain fungi.

Commercial grading of lumber

In commerce lumber is first classified by species and then the lumber of each species is divided systematically into grades according to the number and size of defects appearing on the surface of the boards. Writers about painting often confuse classification by species with grading for quality. It is never correct to speak of species A as lumber of higher grade than species B. For certain uses species A may be preferred to species B but as a rule there are other uses for which species B is superior to species A. Even if species A is one that generally holds paint better than species B, high grade lumber of species B is probably better for exterior painting than low grade lumber of species A.

Some of the defects considered in grading lumber and objectionable for painting are knots, knot-holes, pitch pockets, pitch streaks, pitch, and loose grain. Lumber of highest grade admits only boards with minor defects and blemishes. Among the softwoods the four highest grades are known collectively as the select grades. They contain only "lumber of good appearance and finishing qualities" and are the ones most likely to be used where painting is important. The select grades are identified by letters A, B, C, D. In redwood and southern cypress the highest grade is known as "clear heart" and admits no sapwood on the face to be exposed to the weather. Lumber containing defects that impair painting falls into the several common grades identified by numbers 1, 2, 3, 4, and 5.

Grain

Boards cut with their principal surfaces roughly tangent to the annual growth rings of the tree are known as flat-grain or slash-grain boards in the softwood industries and as plain-sawed boards in the hardwood industries. Boards cut with the principal surfaces roughly radial to the annual rings are known as edge-grain or vertical-grain boards among softwoods and as quarter-sawed boards among hardwoods. On flat-grain or plain-sawed boards the bands of summerwood flare out into much larger areas than they do on edge-grain or quarter-sawed boards. The two principal faces of an edge-grain board as a rule are practically alike but those of a flat-grain board are not because the annual growth rings are convex toward the face nearer

the bark of the tree, the bark-side, and concave toward the face nearer the pith of the tree, the pith-side. In many softwoods the pith-side is distinctly inferior for exterior painting because of a tendency to develop during weathering a form of cracking known as loose grain.

Lumber cut mostly from relatively small softwood trees consists predominantly of flat-grain boards. In cutting lumber from large trees that yield a high proportion of clear lumber it is possible to turn out a predominance of edge-grain boards and to sell edge-grain lumber separately from mixed edge- and flat-grain.

Chemical nature of wood

The walls of the wood cells consist chiefly of cellulose and closely related carbohydrates. The cells are cemented together with lignin. The cellulose of all woods is chemically much the same, perhaps identical. The lignin is likewise very similar in all woods. Together the cellulose, its closely related carbohydrates, and the lignin are called for convenience the wood substance. Wood substance is a hygroscopic swelling material whose moisture content and volume come to equilibrium with the relative humidity of the surrounding air. At saturation wood substance contains roughly 30 percent by weight of water and is fully swollen. Green wood always contains more than enough water to saturate the wood substance, the excess remaining as liquid water or water vapor in the air-space within the wood. On drying the free water is removed first. The moisture content when free water is absent but the wood substance is saturated is called the fiber-saturation point. Further drying causes the wood substance to shrink but only part of the shrinkage appears in changes in external dimensions of the board because part is taken up by change in the volume of the cavities in the wood cells. External shrinkage is greatest tangentially to the annual growth rings, somewhat less radially, and very slight longitudinally. Thus edge-grain boards shrink less in width than flat-grain boards and neither kind changes much in length during drying unless the boards contain an abnormal type of wood known as "compression wood". When in the air-dry condition wood is in a partly shrunken condition with its moisture content and dimensions subject to change in response to changes in relative humidity of the air. In their effect on the dimensions of wood, changes in humidity are usually much more important than changes in temperature. The common paint liquids are taken up by wood only as free liquids in the air-space and do not cause any change in dimensions of the wood. Alcohol, however, causes wood to swell slightly.

In addition to wood substance, wood contains extraneous constituents that can be removed fairly easily by extraction with suitable solvents and are very variable in nature and in amount, differing not only between species but often between heartwood and sapwood and in the heartwood in different parts of the same tree. The extraneous constituents are conveniently classified into those soluble in organic liquids like ether and alcohol and those soluble in water.

The ether soluble extractive of longleaf and slash pines is a resin containing turpentine and rosin. Rosin is a substance of acid reaction capable of forming soaps by reaction with basic paint pigments. The other pines, both white pines and yellow pines, contain similar resins in material amounts. Western red cedar, redwood, the true firs, Douglas fir, hemlocks, spruces, and larches ordinarily contain only small amounts of ether soluble extractives except for resins that occur in local deposits in the tree like pitch pockets. Hardwoods do not contain resins like those in the pines. Southern cypress and some of the cedars contain characteristic oils soluble in ether and some of them soluble in linseed oil. These oils are quite different chemically from the piny resins and contain very little material of acid reaction. Alcoholic extracts from wood usually contain most of the ether soluble substances together with some of the water soluble ones.

The water soluble extractives include tannins and other complex organic substances often of an aromatic nature, some of them highly colored carbohydrates, organic acids like formic, acetic and their homologs, traces of organic nitrogen compounds, and mineral constituents of wood ash. Woods in which the heartwood is strongly colored, such as redwood, red cedar, and walnut, owe their color chiefly to extractives of this class.

The boards used for the 1924 Series of tests were analyzed for their content of extractives with the results presented in Table 2.

Table 2. Average content of extractives in the boards of softwoods used for the 1924 Series of paint tests.

Wood	Percent of the dry wood soluble in--				Milligrams of potassium hydroxide required to neutralize extract from 1 gram of dry wood by--		
	Cold water	Hot water	Ethyl alcohol	Ethyl ether	Ethyl alcohol	Ethyl ether	
	:	:	:	:	:	:	:
	:	:	:	:	:	:	:
Alaska cedar	2.8	3.9	4.0	1.3	2.9	0.8	
Port Orford cedar	2.5	4.0	3.8	0.8	2.7	0.4	
Western red cedar	8.0	11.5	13.2	1.4	7.5	1.4	
Southern cypress	1.6	2.0	9.0	5.5	2.3	1.4	
Douglas fir	3.7	5.8	4.3	1.0	5.5	0.7	
White fir (commercial)	2.0	3.1	2.7	0.6	1.4	0.6	
Eastern hemlock	2.9	4.2	5.0	1.2	3.5	1.0	
Western hemlock	2.7	3.8	3.4	0.4	4.7	0.4	
Western larch	14.9	17.0	4.0	1.1	4.6	1.0	
Ponderosa pine	2.4	5.0	5.7	3.3	6.9	3.9	
Sugar pine	4.5	7.2	9.0	4.3	8.5	5.9	
Northern white pine	2.9	5.1	8.0	4.0	6.7	3.7	
Western white pine	2.8	4.3	6.5	3.3	5.6	3.0	
Southern yellow pine	3.5	6.2	8.5	5.2	8.2	7.1	
Redwood	6.4	10.9	11.8	0.7	0.6	0.5	
Sitka spruce	2.7	4.6	3.6	0.6	2.7	0.8	
White spruce (com.)	1.3	2.4	2.2	0.7	1.6	0.7	

Painters often call the bands of summerwood in softwoods "pitch streaks" because they attribute their darker color and hardness to the presence of resin. True pitch streaks, however, do not follow the annual growth rings and affect both springwood and summerwood. Moreover the summerwood of softwoods relatively free from resin is often just as hard and dark in color as that of resinous species (Table 1). Summerwood and springwood of the same growth rings were whittled out of boards of ponderosa pine and southern yellow pine and their content of extractives determined with the results shown in Table 3. Boards of high resin content had more extractives in the springwood than in the summerwood while those of low resin content had a fairly uniform distribution of resin between springwood and summerwood.

Table 3. Content of extractives found in springwood and summerwood of the same annual growth ring in ponderosa pine and southern yellow pine.

Description of wood	Percent of the dry wood soluble in--		
	Cold water	Hot water	Ethyl alcohol
Ponderosa pine, springwood	1.8	3.0	3.53
" " summerwood	1.6	2.8	3.08
Southern yellow pine, springwood	1.6	5.3	4.76
" " " summerwood	1.2	3.3	4.36
Southern yellow pine, springwood	2.0	6.3	25.42
" " " summerwood	1.1	3.9	17.71
Southern yellow pine in which the resin was evident to visual inspection,			
springwood	1.3	6.3	37.10
summerwood	1.2	4.1	24.42

Behavior of Paint on Woods During Application

The first coat of paint applied to new wood is very largely consumed in filling the cavities of those wood cells that were cut open in planing the surface of the boards. Much of the liquid of the priming-coat paint penetrates deeper into the wood because it can pass through the pit membranes in the cell walls and reach the cavities in wood cells beneath the surface. Since woods vary in the volume of cavities presented at the surface and in absorptiveness for liquids they likewise vary somewhat in consumption of priming-coat paint. In comparison, however, with porous materials like plaster, concrete, and stucco, wood consumes relatively little paint because its structure is cellular rather than labyrinthine or sponge-like.

Consumption of paint by different softwoods

During the exposure of the tests of the 1924 Series careful record was kept of the amount of paint consumed (1). There were 44 panels of each wood. Sets of panels were painted by each of 11 painters of whom 4 were professional painters and 7 were technical men or laboratory aids in paint testing laboratories. The average spreading rates for priming-coat paint (square feet covered by 1 gallon of paint) on the different woods and the average specific gravities of the woods are given in Table 4. In general the specific gravity varied directly with the spreading rate, that is, the lower the specific gravity the lower the spreading rate. Low specific gravity, of course, indicates a relatively large proportion of springwood with its larger cavities in the tracheids. There are, however, other factors affecting spreading rates because redwood, Sitka spruce, western hemlock, and Douglas fir had somewhat lower spreading rates than the specific gravity indicates. Paint seems to wet these woods very quickly and the oil is absorbed while the brush sweeps over it, thus encouraging the painter to apply more paint.

It should be emphasized that the extent of the variation in paint consumed is too small to be of much practical importance. Redwood took about 11 percent more and southern pine about 13 percent less priming paint than the average wood. The spreading rates of second-coat and third-coat paint were independent of the nature of the wood so that the variations in total paint consumed amounted to roughly plus or minus 4 percent of that required for the average wood. By mixing the priming paint for redwood with slightly more and that for southern pine with slightly less liquid the variations could be offset entirely.

Personal variations among painters exert far more effect on spreading rates than variations between woods. In the experiments of the 1924 Series the average spreading rate at which the different painters applied priming-coat paint varied from 561 to 869 square feet per gallon. The experienced painters applied paint more generously than the technical men and laboratory aids because the former had an average spreading rate of 604 and the latter 751 square feet per gallon. The writer believes that as a rule priming-coat paint should be applied at 550 to 600 square feet per gallon and subsequent coats at 600 to 650 square feet per gallon for best results. All of the spreading rates for new wood in Table 4 should be regarded as too high for best practice, though they are probably representative of much practical painting and reveal the extent of variation between species reasonably well.

Table 4. - Specific gravities and spreading rates found for priming-coat paint on softwoods when new and after weathering for one year.

Wood	Specific gravity of wood	Approximate volume of air-space in wood ^a	Average spreading rate of priming-coat paint on	
			New wood	Weathered for 1 year
		Percent	Square feet per gallon	
Woods with spreading rates below 640 square feet per gallon:				
Western red cedar	: 0.330 :	73	: 518 :	396
White fir (commercial)	: .362 :	76	: 612 :	379
Sugar pine	: .362 :	76	: 614 :	383
Redwood	: .370 :	78	: 588 :	312
Eastern hemlock	: .375 :	75	: 601 ^b :	411
Sitka spruce	: .395 :	74	: 620 :	398
Western hemlock	: .473 :	68	: 625 :	400
Woods with spreading rates between 640 and 700 square feet per gal.				
Northern white pine	: .474 :	78	: 652 :	363
Port Orford cedar	: .444 :	70	: 673 ^b :	424
Douglas fir	: .495 :	67	: 666 :	319
Woods with spreading rates above 700 square feet per gallon:				
Eastern spruce (commercial)	: .388 :	74	: 750 ^b :	394
Western white pine	: .402 :	73	: 742 :	349
Southern cypress	: .408 :	73	: 738 :	410
Ponderosa pine	: .421 :	72	: 768 :	415
Alaska cedar	: .432 :	71	: 766 :	457
Western larch	: .520 :	65	: 752 :	360
Southern yellow pine	: .531 :	65	: 790 :	393
Average for all woods tested			685	380

^a-Computed by considering that the entire weight of the oven-dry wood is wood substance of specific gravity 1.5. This introduces an error, usually small, in that the extractives in the wood are assumed to have the same specific gravity as wood substance.

^b-Eastern hemlock, Port Orford cedar, and eastern spruce were not represented by full sets of test panels so that the data for these woods are not fully comparable with those for the other woods.

Figure 2. - Photomicrographs of a coating of white lead paint on southern yellow pine, by transmitted light.

The upper view is a transverse (end-grain) section and the lower view a longitudinal section. The paint appears black because it is opaque. The paint penetrates into the cavities of only those tracheids that open into the painted surface because the pigment particles are far too large to pass from one cavity to another. Linseed oil from the paint, however, penetrates far deeper into the wood. Under the microscope oil can be seen filling some of the tracheid cavities in the summerwood below the painted surface but this oil does not show in the photographs because it is transparent.

The discussion so far refers to smoothly planed wood such as the planed side of house siding. Rough surfaces such as the sawed side of bevel siding take much more paint. Weather-beaten wood becomes rough and consumes much paint if subsequently painted. The last column of Table 4 presents data for smoothly planed woods exposed vertically facing south at Madison, Wis. in 1924 and painted one year later after they had become greatly roughened. After weathering all woods seem to be greedy for paint and no relation can be discovered between spreading rate and specific gravity of the wood.

Hardening of paint on different woods.

Ordinarily the time of hardening of paint depends almost entirely on the composition of the paint, the intensity of sunlight, and the temperature and relative humidity of the air. Extractives present in certain woods, however, may retard hardening under certain circumstances (14). In full sunshine and at temperatures above 70°F. paints made with sufficient drier should harden promptly on all native woods provided that the wood is reasonably dry and the relative humidity of the air is not unusually high. Exceptionally oily boards of southern cypress, however, may retard the hardening of linseed oil paints that contain no white lead or zinc sulfide pigments. On redwood and southern cypress containing much more than 20 percent moisture, priming-coat paint may remain liquid for days, especially in the absence of sunshine, at temperatures well below 70°F., and with paints that contain no white lead or zinc sulfide pigment. Unverified reports from industrial sources point to difficulty with hardening of paint under similar conditions on some of the hardwoods that are relatively rich in tannins, such as the oaks, chestnut, and walnut. The identity of the extractives in woods that are responsible for retarded hardening of paint is not yet known. It has been proved that the responsibility lies with some of the extractives because water soluble extract of redwood and alcohol extract of southern cypress have been transferred to white pine and eastern hemlock and imparted to those woods the property of retarding hardening under the circumstances described.

Filler necessary on hardwoods with large pores.

Ordinary painting by hand brushing or spray application does not succeed in filling the large pores in hardwoods that have pores larger than those in birch. The largest pores remain as observable depressions or even as holes in the coating even after three substantial coats of paint have been applied. As time passes

Figure 3. - Large pores in hardwoods are not filled by conventional painting.

Upper view - Chestnut painted with three coats of white lead paint with the large pores still showing as depressions in the coating.

Lower view - Chestnut painted with three coats of lead and zinc paint showing failure of the coating beginning over the large pores.

the disintegration of the coating sets in abnormally early at these points of weakness and shortens the life of the coating. Apparently paint that is fluid enough for application by brush or spray gun is too fluid to plug or bridge large pores adequately. If the large-pored hardwoods must be used under paint coatings they should first receive a wood filler, that is, a pigment paste thinned with volatile thinner for convenient application and then rubbed into the pores shortly after the volatile thinner has evaporated. A smooth, level surface for the reception of subsequent coats of paint can be produced in that way but the extra cost of the filling operation makes the proper painting of large-pored hardwoods relatively expensive.

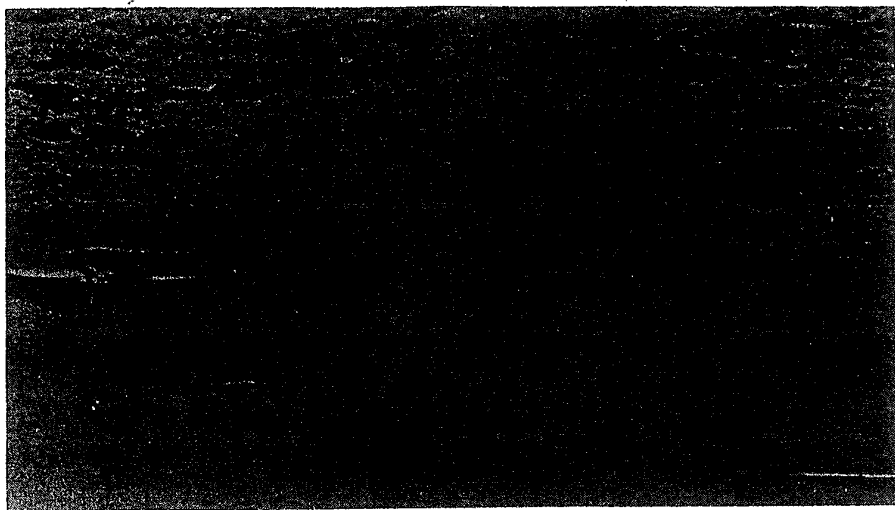
Defects in lumber of low grade.

When lumber is to be cut into smaller pieces for use it is sometimes economical to buy lumber of a common grade, cut out the defects, and obtain clear lumber for the important surfaces. Even then the wood may be somewhat inferior for painting to lumber of the same species in a select grade because the common grades come in considerable proportion from parts of the tree that grew rapidly, have wider growth rings, and do not hold paint quite so well as the wood of somewhat later growth. In building construction, however, where nearly all of the lumber is used with as little cutting as possible, defects in common grades must be covered with paint.

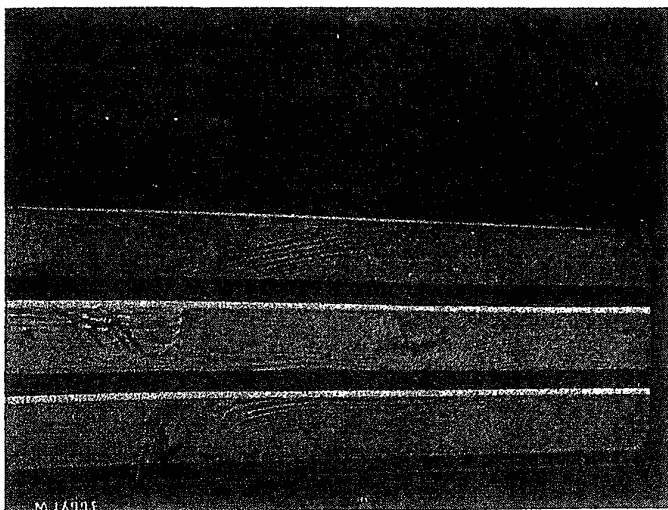
Very small knots may be concealed satisfactorily and may retain paint about as well as the clear wood. Large knots, however, can rarely be concealed because they do not follow the clear wood in swelling and shrinking with changes in moisture content and on weathering they often crack open, breaking the coating with them. Over knots in the pines, both white pines and yellow pines, paint often becomes promptly discolored with a yellow substance that appears to be soluble in linseed oil and the coating over the knot soon becomes brittle and scales off. For that reason it is common practice to shellac knots but the shellac should be applied after putting on the priming-coat paint, not before it. Unfortunately shellac is not so durable for exterior exposure as good paint but somewhat longer life over the knot can be obtained by adding 5 or 6 ounces of castor oil to a gallon of the shellac varnish. When aluminum priming paint is used an extra application over the knots may prove more satisfactory than shellac. It is never desirable to shellac knots in any wood other than a pine because knots in such woods do not discolor or embrittle paint and often hold paint longer than the clear wood.

Figure 4. - Premature failures of paint over defects in lumber of low grade.

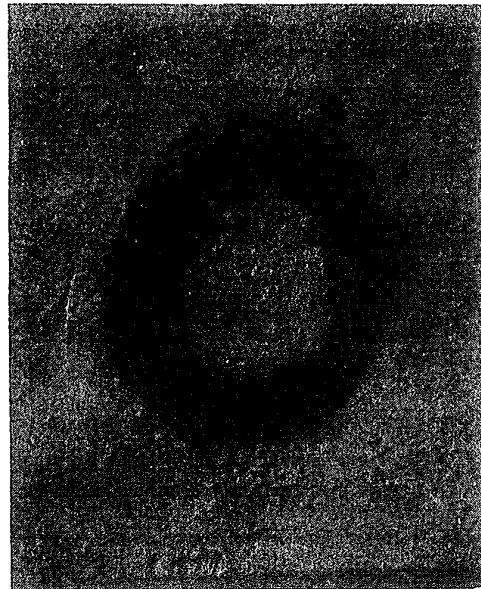
- A - Cracking and flaking of the coating over a pitch streak while the coating is still reasonably sound over the clear wood below the pitch streak.
- B - Unsatisfactory appearance over knots and raised grain even though the coating remains sound. Note that on this wood, which is not a pine, the paint remains intact over the knots although the knots themselves crack badly.
- C - Discoloration and flaking of paint over a knot in one of the pines long before the coating over the clear wood has begun to disintegrate.



A



B



C

Z M 24954 F

Pitch pockets are best painted by cutting them out with a chisel and filling them with good putty after the priming-coat paint has been applied. Knot holes should be puttied in the same way. Pitch streaks may mar the painted surface by exuding resin and embrittling the coating but the writer knows of no method of dealing with them satisfactorily except by rejecting the board or at least that part of it containing the pitch streak. Loose grain likewise is beyond remedy. Wood checks or cracks should be puttied after priming to keep them from acting as centers of early disintegration of the coating.

By the time that proper attention has been given to the defects in common grades of lumber the extra costs for painting it usually make it more expensive than the select grades that are better suited to uses calling for painting. For uses in which good paint service is important select grades of the woods of groups 1 and 2 of Table 6 are best but if cheaper woods must be chosen it will often be better to buy a select grade of a cheaper species than a common grade of a wood of group 1 or 2.

Effect of Woods During Early Life of Paint

As a rule the nature of the wood has little effect on the behavior of paint during its early life, say during the first year or two after application. The composition of the paint, the adequacy of the technic of application, and local and climatic conditions are usually much more important than the kind of wood through this period.

Undesirable early developments over defects in lumber of low grade have already been discussed. Exudation of resin through paint coatings over clear wood sometimes occurs early without impairing the integrity of the coating. It is observed on the pines more often than on other softwoods but has been found occasionally even on softwoods that contain relatively little pine resin. Such exudation is most likely to occur when the lumber has been seasoned at low temperatures and is used soon after manufacturing. Lumber kiln dried at higher temperatures or stored for some time before use is less likely to exude resin because less of the turpentine is left in the resin to make it soft enough to move freely. The oils in Alaska cedar, Port Orford cedar, eastern red cedar, and southern cypress may come through paint and collect in a sticky mass on the surface if there is no circulation of air over the surfaces, as when boards are stacked on top of one another. There is no such occurrence if air circulates over the surfaces because the oils are

slowly volatile. Colored water soluble extractives in western red cedar, redwood, and some of the hardwoods do not come through sound paint coatings unless free water in some way gets into the wood behind the coating. If cracks appear in the coating the coating at the edges of the cracks may be discolored for a short time immediately after a rain storm but the writer has never seen enough discoloration so produced to affect materially the good appearance of the coating.

Occasionally flat-grain boards of softwoods exposed to the weather and painted on the pith-side will develop loose grain and crack the coating within a few months even though there was no evidence of loose grain when the paint was applied. The bark-sides of such boards rarely, if ever, develop loose grain. The pines seldom show loose grain even on the pith side except on floors or other places of severe mechanical wear.

If long life of paint coatings is to be assured the moisture content of lumber must remain always well below the fiber-saturation point. When free water accumulates within the wood early failures of paint may occur that the writer has discussed in detail elsewhere (2).

Effect of Wood Properties on Disintegration of Paint

The deterioration of paint coatings proceeds in successive but overlapping stages as follows (12):

1. The soiling stage. The coating gradually becomes dirty.
2. The flattening stage. The coating loses its gloss.
3. The chalking stage. Dirt may be thrown off more or less completely but colors appear to fade.
4. The fissure stage. Fissures are of two general types, depending upon the nature of the paint:
 - a. Checking. The fissures are at first superficial but later may penetrate entirely through the coating.

- b. Cracking. The fissures pass entirely through the coating when first observed. The coating at the edges of the cracks sooner or later comes loose from the wood and curls outward. As a rule cracking comes at a more advanced stage of deterioration than checking.
- 5. The stage of disintegration. Behavior in the fissure stage determines the form in which disintegration takes place:
 - a. Crumbling, which develops from checking, consists in the falling away of tiny fragments of coating cut off when the fissures become interwoven (reticulate) and penetrate entirely through the coating.
 - b. Flaking, which develops from cracking and curling. The loosened edges of coating that curl outward finally fall off, after which the newly formed edges curl and the process continues progressively. Flaking is usually a more rapid form of disintegration than crumbling.

The soiling, flatting, and chalking stages may be considered the early life of the coating, the fissure stage the later life, and the stage of disintegration the period of paint neglect. Good practice in paint maintenance calls for repainting before the coating has passed far into the period of neglect but unfortunately many buildings are not repainted until the coatings have been neglected for a long time.

The effect of the wood usually appears first after the fissure stage is reached and dominates further developments by the time the stage of disintegration sets in. Up to the fissure stage the coating seems to remain tough and adherent enough to stay intact and follow slight swelling and shrinking of the wood with changing atmospheric conditions. Fissures appear when these properties are lost and the coating becomes brittle, loses its adherence to the wood, and remains clinging to the surface chiefly through mechanical anchorage in the cavities of the wood cells at the surfaces of the boards (6). The situation might be expressed by saying that in its early life the coating sticks to the wood but when the paint has become embrittled with age the wood holds the coating as best it can.

In softwoods the springwood holds the aged coating to better advantage than the summerwood because of the larger cavities in the wood cells (Table 1), not because of a difference in resin content (Table 3). At any rate disintegration proceeds much more rapidly over the summerwood than it does over the springwood and the amount and distribution of summerwood in softwood boards very largely determine how long the coating lasts. On hardwoods the principal factors seem to be the size and distribution of the pores together with the specific gravity of the wood. Repainted coatings behave in much the same way as initial coatings except that the fragments of coating that fall off may be somewhat larger and may not begin to fall off quite so soon.

Specific gravity of wood

Since the proportions of summerwood and springwood very largely govern both the specific gravity and the rate of disintegration of aged paint on softwood boards a definite relation between specific gravity and paint durability on softwoods is to be expected. Such a relation is shown in Figure 5, in which the average durability of the paint coatings on the softwoods tested in the 1924 Series is plotted against the average specific gravity of the boards of those species used in the tests. In general the woods that held aged paint well were the woods of low specific gravity and those that held paint poorly were high in specific gravity. The relation is by no means exact, however, because redwood, southern cypress, Alaska cedar, and Port Orford cedar held paint better and white fir poorer than the specific gravity indicated. Reasons for these discrepancies are suggested in subsequent paragraphs.

Figure 6 presents similar data obtained in the 1930 Hardwood Series. If hardwoods with large pores, hardwoods with small pores, and softwoods are considered separately the general relation between specific gravity and rate of disintegration of coatings applies for the woods within each group but the relation differs for the three groups. On the hardwoods with small pores the coatings lasted longer than they did on wood of equal specific gravity in the other two groups. The end-point of the useful life of a coating as the writer judges it occurs very early in the stage of disintegration, however, and if disintegration is allowed to proceed very far before repainting the comparison between softwoods and hardwoods with small pores changes in favor of the softwoods. On

Figure 5. - Relation between specific gravity
of softwoods and durability of
coatings of house paint.

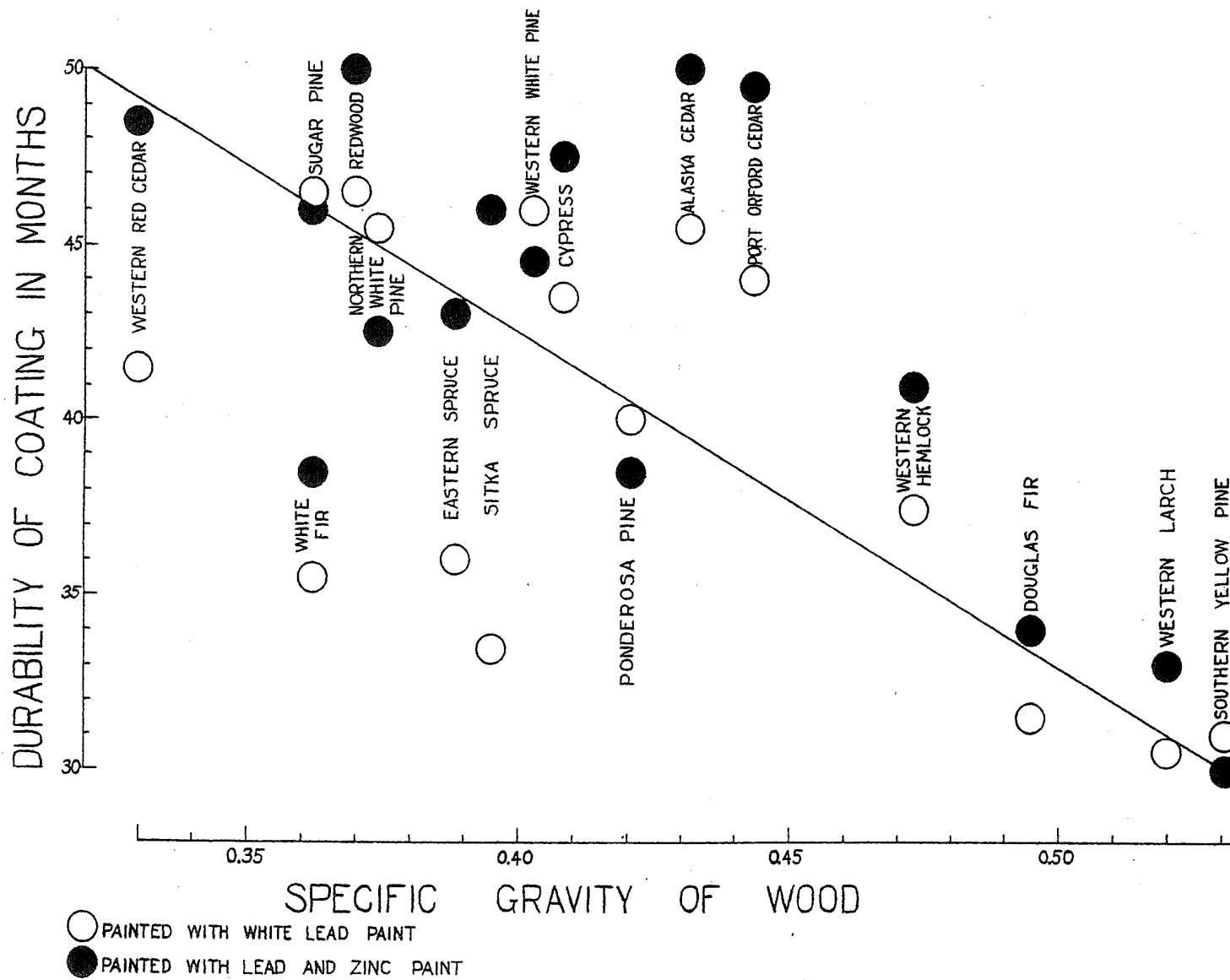


Figure 6. - Relation between specific gravity of wood and durability of paint for (a) softwoods, (b) hardwoods with small pores, and (c) hardwoods with large pores. The enamel finish on hardwoods with large pores failed prematurely because of a faulty combination of pigments in a wood filler used on those woods only, consequently the normal relation of durability to specific gravity was not realized on those woods.

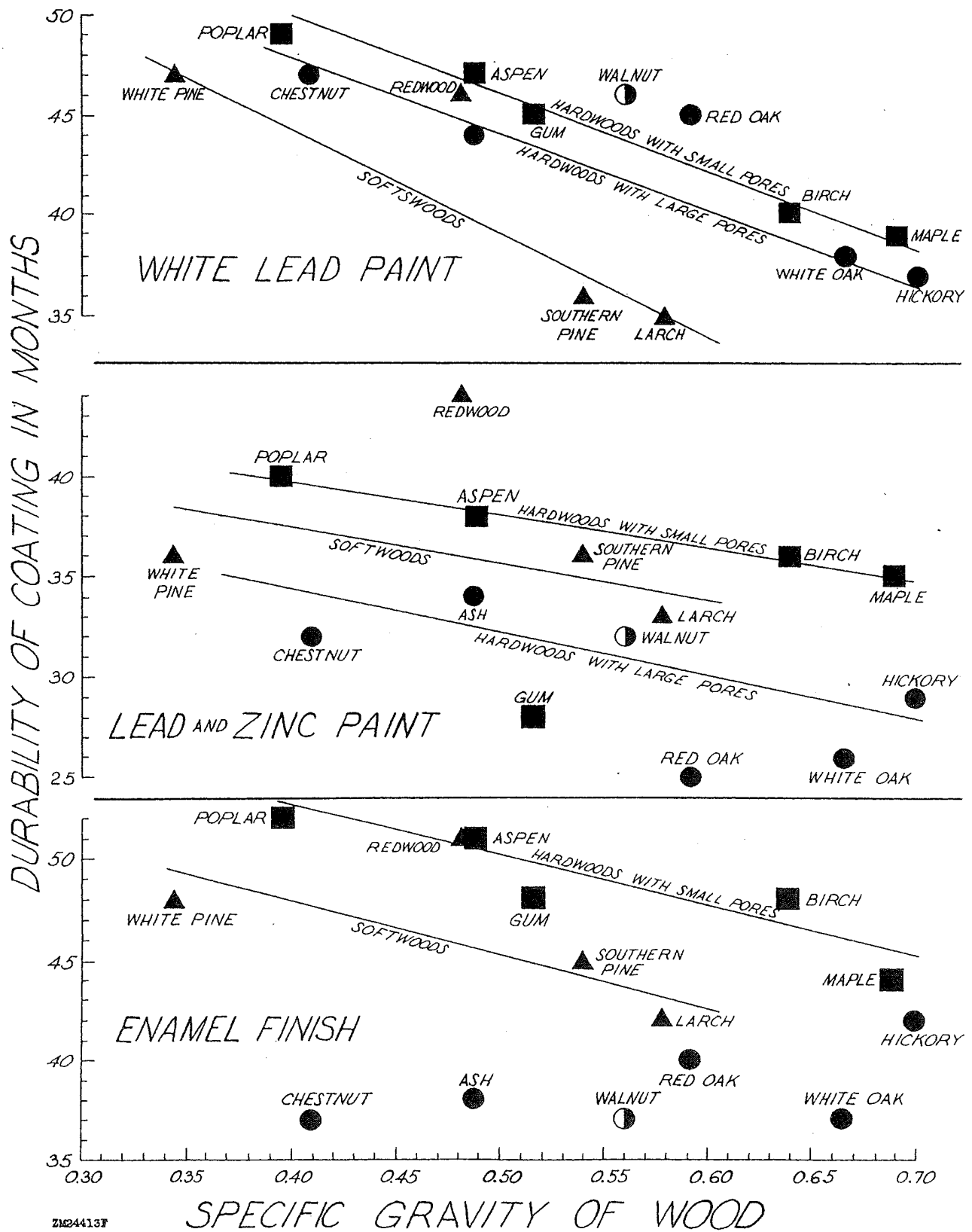
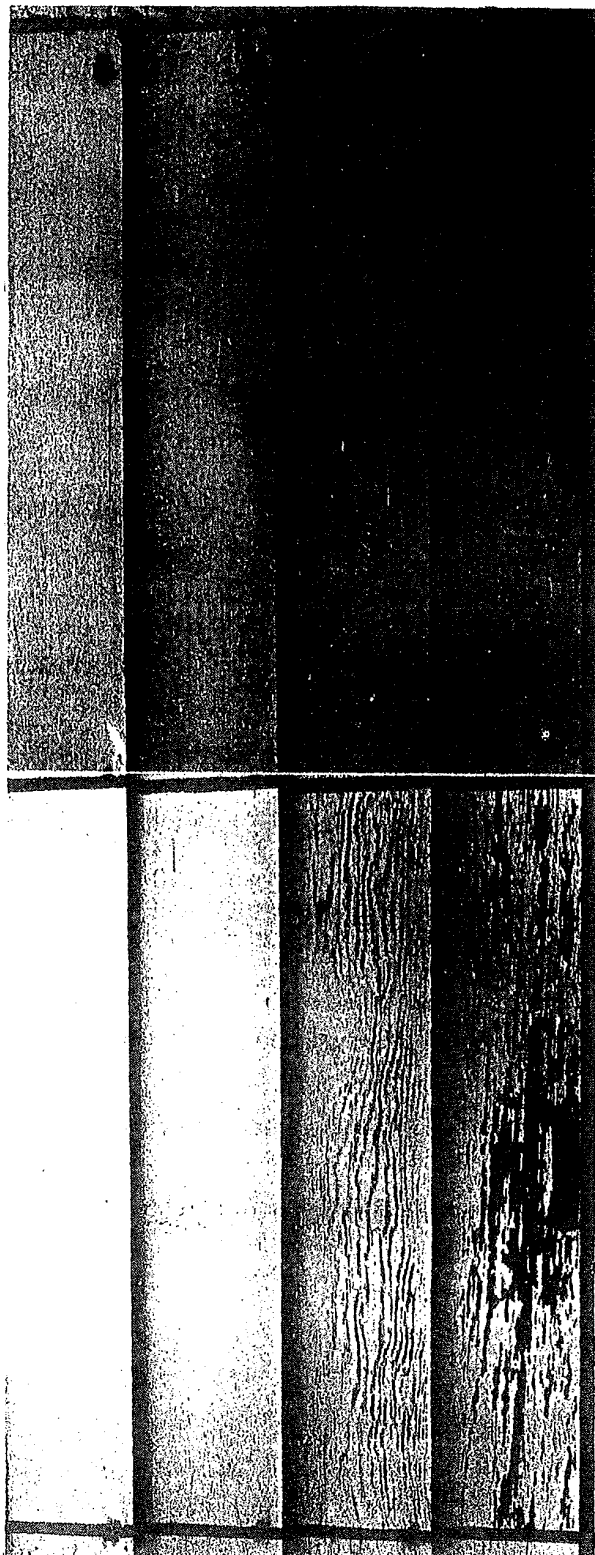


Figure 7. - Effect of specific gravity of softwoods on durability of paint and of special priming paints for the heavier softwoods.

Parts A and B are adjacent areas of the same boards painted with the same kind of paint. The top board is redwood, the second board northern white pine, the third board Douglas fir, and the bottom board southern yellow pine. Part A was painted conventionally, using the white paint properly thinned for the priming coat. Part B was primed with a special primer consisting of flake graphite in long-oil spar varnish. Both parts then received a second and a third coat of white paint.



B

A

4445781

the softwoods disintegration of the coating remains for a long time confined to the bands of summerwood but on the hardwoods with small pores the relatively uniform texture throughout the annual growth ring permits disintegration to spread fairly rapidly over the entire board. For that reason only the lightest hardwoods with small pores should be considered as acceptable as the softwoods for conventional house painting. None of the hardwoods with large pores can be regarded as satisfactory for such purposes because conventional painting leaves the pores unfilled.

Width of annual growth rings in wood

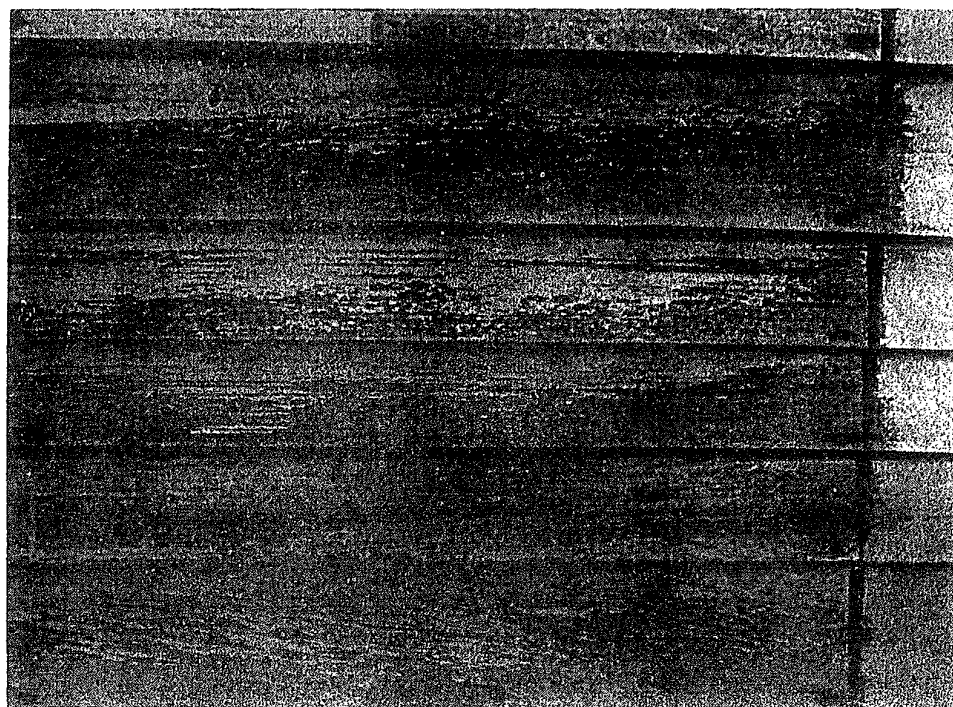
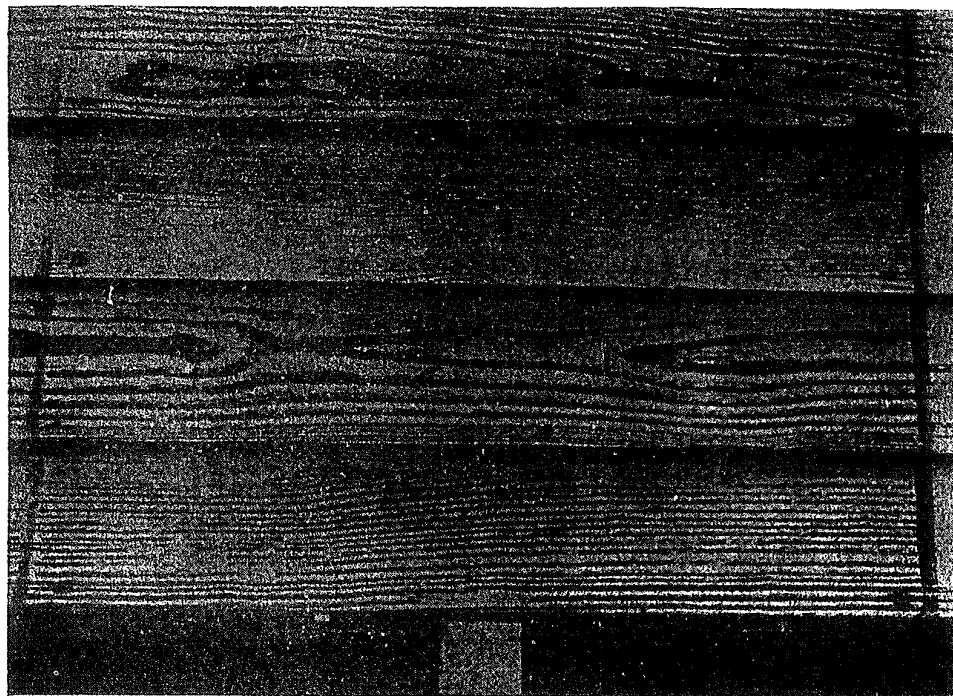
Among softwoods the distribution as well as the amount of summerwood affects the disintegration of paint. For the same ratio of summerwood to springwood the individual bands of summerwood are narrower the greater the number of annual growth rings per radial inch, that is, the less rapidly the wood grew. In Figure 1 the departures from the general relation between specific gravity and durability are largely attributable to such differences in width of annual rings. Many of the boards of white fir used in the 1924 Series of tests contained "compression wood", which is an abnormal type of wood in which there is a high proportion of summerwood but it is lighter in weight than normal summerwood. The white fir likewise tended to have few annual rings per inch. These facts account adequately for earlier disintegration of the coatings on the white fir than the specific gravity indicated. On the other hand all of the boards of Alaska cedar and Port Orford cedar had very many annual rings per inch, as did many of the boards of redwood and southern cypress. These woods therefore would be expected to hold paint longer than woods of similar specific gravity but fewer rings per inch.

Among the diffuse-porous hardwoods the width of the annual growth rings seems to have very little bearing upon the rate of disintegration of coatings as would be expected from the fact that there is little difference in texture between springwood and summerwood. On the ring-porous hardwoods, all of which have large pores, the width of the growth rings likewise seems to be of minor importance.

Figure 8. - Characteristic forms of paint disintegration on softwoods and on hardwoods with small pores.

Upper view - Badly neglected coating of lead and zinc paint on southern yellow pine. Disintegration is still largely limited to the bands of summerwood.

Lower view - Similarly neglected coating of lead and zinc paint on yellow birch. Disintegration of the coating has laid bare much larger areas of the wood.



Z M 24366 F

Grain of wood

Edge-grain boards of softwoods present much narrower bands of summerwood on the painted surface than flat-grain boards of similar specific gravity and rings per radial inch. For that reason coatings last longer on edge-grain boards of softwoods. Among the hardwoods, however, there seems to be less difference in the rate of disintegration of paint on quarter-sawed and plain-sawed boards, especially among the hardwoods with small pores.

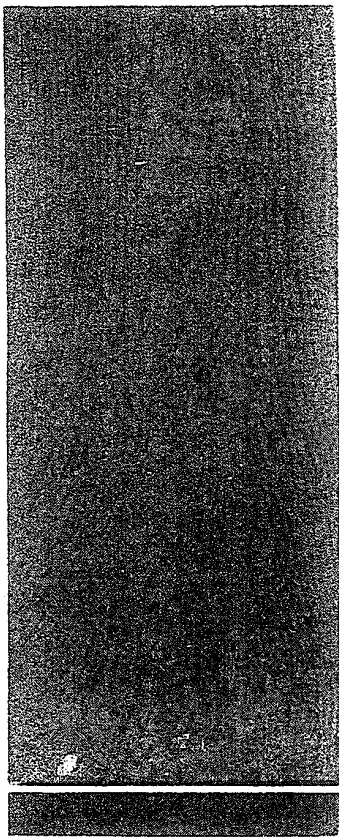
Variation within species

Different boards of the same species, even different boards from the same tree, may vary widely in specific gravity and in number of annual growth rings per inch. The durability of paint varies correspondingly. Account is not taken of such variations in the commercial grading of lumber, except in structural timbers of some species where mechanical strength rather than paintability is the object in view. Whenever it is practicable to buy lumber on special specifications or to cull over a large supply of boards for those best suited for painting it is possible to take advantage of the variation in specific gravity, grain, and rings per inch to select boards materially better for painting than the general average for the species.

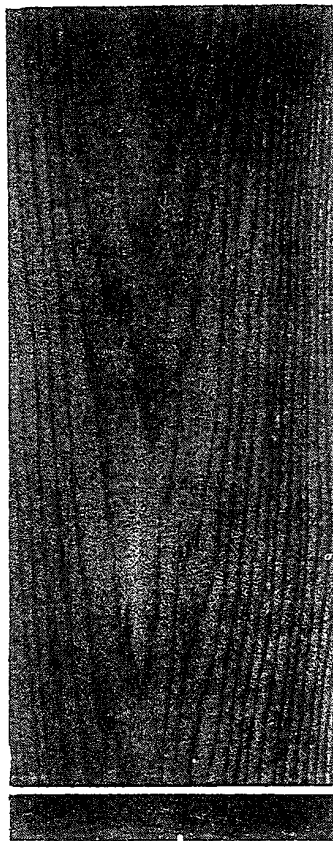
Results of the 1929 Douglas fir Series of tests illustrate the possibilities in selection of lumber for painting. Five shipments of Douglas fir siding were obtained, four representing so-called "red" and "yellow" Douglas fir each sub-divided into "soft" and "dense" types, and the fifth representing a special selection of Douglas fir for good painting characteristics. "Red" and "yellow" Douglas fir in "soft" and "dense" types are traditional classifications by lumbermen but they are not recognized in the present methods of grading for sale. When the specific gravity and ring count of the boards were determined the average values and ranges in these properties were much the same for the four groups and the average durability of the coatings was likewise much the same. On the group specially selected for painting, however, the durability of the coatings was better than the average for the other four shipments, namely 44 months as compared with 38 months. When the boards of all shipments were reclassified according to the measured specific gravity and further subdivided into flat-grain and edge-grain boards the data of Table 5 were obtained. Edge-grain

Figure 9. - Variation in properties within a species.

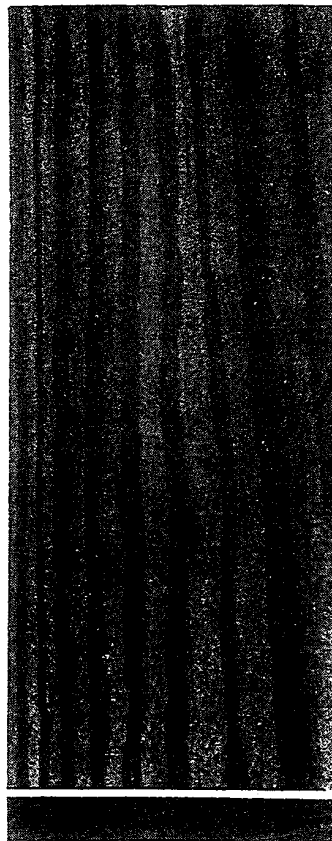
These four boards of ponderosa pine were taken from test-panels after the paint coatings had worn out and were resurfaced to reveal the wood. Boards A and B held paint well, boards C and D poorly. Board A had 36 annual rings per inch, specific gravity 0.40; B had 27 rings, specific gravity 0.48; C had 6 rings, specific gravity 0.48, and D had 15 rings, 0.73.



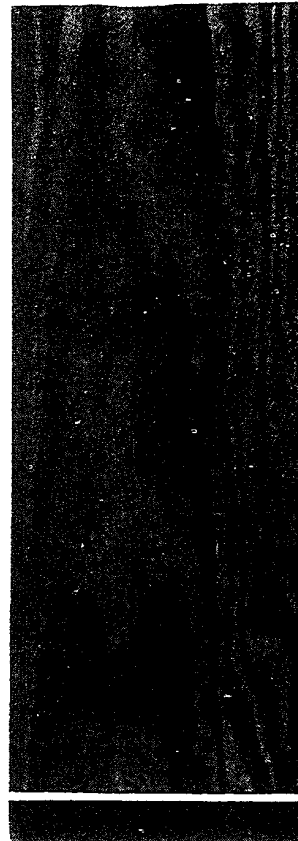
A



B



C



D

Z 13215 F

boards held paint longer than flat-grain boards of similar specific gravity and boards of low specific gravity held paint longer than boards of the same grain but high specific gravity.

Table 5. Variation in durability of paint coatings on Douglas fir classified by grain and by specific gravity

Specific gravity of wood	Average durability of coatings on	
	Flat-grain boards	Edge-grain boards
	<u>Months</u>	<u>Months</u>
Below 0.5	41	44
0.5 to 0.6	38	39
Above 0.6	29	37

Extractives in wood

Certain extractives in wood of some species undoubtedly affect the durability of coatings but in general the effect of such extractives is small in comparison with the effects of such physical characteristics as specific gravity, ring count, grain, and grade. This fact should be emphasized because the importance of extractives in wood is grossly exaggerated in much of the literature on painting.

It is difficult to account for the position of redwood, southern cypress, Alaska cedar, and Port Orford cedar in Figure 5 and of redwood in Figure 6 wholly on the basis of the high ring count in the lumber of those species used in the 1924 Series and the 1930 Hardwood Series of tests. Some of the boards of redwood and southern cypress had relatively few annual rings per inch and yet held paint longer than the specific gravity indicated. In the 1930 Extractive Series the cold water extract of redwood and the alcohol extract of southern cypress were transferred to boards of eastern hemlock before painting. Disintegration of the coatings was definitely retarded by the redwood extract but the results with the cypress extract were not so conclusive. It is possible that the ingredient in redwood responsible for the good effect on paint retention is the same one that retards hardening of paint under poor drying conditions. If so the close

botanical relation between redwood and cypress suggests that the same substance or one similar to it may occur in cypress among its water soluble extractives rather than its alcohol soluble ones and that more significant results might have been obtained with the water rather than the alcohol extract of cypress.

Figure 5 reveals a difference between the pines and the softwoods other than the pines in the relative durability of pure white lead paint and of lead and zinc paint. On each one of the pines the pure white lead paint outlasted the lead and zinc paint but the lead and zinc paint outlasted the white lead paint on all other softwoods. The same tendency appears in Figure 6 in that redwood and white pine held white lead paint about equally long but redwood held lead and zinc paint much longer than white pine, but the tendency is not so clearly shown for southern yellow pine and western larch. With the two latter woods the high proportion of summerwood dominates paint disintegration so much that minor effects of extractives are often obscured but the tendency for paints containing zinc oxide to disintegrate faster on the pines of lighter weight than on other softwoods of similar specific gravity has run consistently through many series of tests by the writer. The data of Table 2 strongly suggest a connection between the ether soluble extractives of acid reaction present in the pines and the relative rate of disintegration of paints that do and do not contain zinc oxide. The suggestion was confirmed in the 1930 Extractive Series of tests when it was found that transfer of the alcohol extract of ponderosa pine to eastern hemlock impaired the durability of lead and zinc paint but did not affect that of white lead paint. It is further in line with an opinion prevailing among paint experts that paints containing zinc oxide should be made with linseed oil in which there is no more than a very moderate amount of free acids although linseed oil of materially higher acid number is considered suitable for making white lead paste paint.

The effect of the extractives in the pines seems to be due chiefly to the nature rather than to the amount of extract present in the wood. Since a very small volume of paint is placed on a relatively large volume of wood it may well be that the least resinous boards of a pine contain enough of the reactive substance to complete whatever reaction takes place in the paint, in which case boards containing still more resin would act no differently. In the 1927 Thinner Series of tests boards of southern yellow pine were sampled for determination of their content of ether soluble extractive and then painted for observation. The variations in durability of white lead and of lead

and zinc paint followed closely the variations in specific gravity and ring count of the boards but were independent of the content of ether extract, which varied from about 1 to nearly 20 percent by weight of the wood.

Classification of Woods for Painting

Table 6 presents a classification of native woods according to their desirability for exterior house painting by conventional methods. Most of the woods are classified on the basis of the 1924 and the 1930 Hardwood Series of tests together with observations of the woods in use on houses or other practical service. A few less important woods that were not tested are classified according to their physical and chemical properties and their similarity to some of the woods tested. Average shipments of lumber of a select grade in mixed flat- and edge-grain are assumed. Lumber specially selected for superior painting characteristics as pointed out in the preceding discussion may be entitled to a higher rating than that given the species in Table 6.

It was found in the 1925 Series of tests and in other tests (13) that the differences between woods of groups 1 and 2 on the one hand and groups 3 and 4 on the other in their effect on durability of paint cannot be reduced materially by altering the proportions of pigments, linseed oil, and turpentine in the conventional priming-coat paint or by substituting special volatile thinners for the turpentine. The generous use of volatile thinners in priming coats for woods like southern yellow pine and Douglas fir, though often recommended, is distinctly bad practice. On the other hand numerous tests (4, 9, 10) have shown that certain special priming paints used in place of the conventional priming paint add materially to the durability of paint on woods of groups 3 and 4. When such woods are to be painted results more nearly comparable to those obtainable on woods of groups 1 and 2 will be obtained if one of these special priming paints is used.

The most satisfactory special priming paint so far discovered for this purpose is aluminum priming paint. It consists of 1-3/4 to 2 pounds of dry aluminum powder of standard varnish grade in 1 gallon of very long-oil spar varnish. If desired 2 pounds of commercial paste aluminum of 1-1/2 pounds of dry aluminum powder of standard lining grade may be used in place of the standard varnish powder. Aluminum priming paint, if properly applied so that the grain of the wood is entirely

Table 6. Classification of Native Woods for Ability to Hold Aged Coatings of House Paint

Paints of type A are those that fail by checking and crumbling, such as pure white lead paint; those of type B fail by cracking, curling, and flaking, such as paints containing zinc oxide mixed with other pigments.

Group: No. :	Description of group	Common name	Botanical name	Representative specific gravity ^a
1	Woods on which paints of types A and B disintegrate slowly	<u>Softwoods:</u> Alaska cedar Incense cedar ^b Northern white cedar ^b Port Orford cedar Southern cedar ^b Western red cedar Southern cypress Redwood	Chamaecyparis nootkatensis Libocedrus decurrens Thuja occidentalis Chamaecyparis lawsoniana Chamaecyparis thyoides Thuja plicata Taxodium distichum Sequoia sempervirens	0.42 .35 .29 .40 .31 .31 .42 .41
2	Woods on which paints of type A disintegrate slowly but those of type B disintegrate somewhat more rapidly than they do on woods of group 1	<u>Softwoods:</u> Northern white pine Sugar pine Western white pine	Pinus strobus Pinus lambertiana Pinus monticola	.34 .35 .36
3	Woods on which paints of types A and B disintegrate more rapidly than they do on woods of group 1	<u>Hardwoods:</u> Aspen Basswood ^b Cottonwood ^b Magnolia ^b Yellow poplar <u>Softwoods:</u> White fir Eastern hemlock Western hemlock Lodgepole pine ^b Ponderosa pine Eastern spruce Engelmann spruce Sitka spruce	Populus sp. ^c Tilia glabra Populus sp. ^c Magnolia sp. ^c Liriodendron tulipifera Abies sp. ^c Tsuga canadensis Tsuga heterophylla Pinus contorta Pinus ponderosa Picea sp. ^c Picea engelmannii Picea sitchensis	.35 .32 .32 to .37 ^c .40 to .46 ^c .38 .35 .38 .38 .38 .38 .37 .31 .37

(table continued on next page)

Table 6.---Classification of Native Woods for Ability
to Hold Aged Coatings of House Paint (cont.)

Paints of type A are those that fail by checking and crumbling, such as pure white lead paint; those of type B fail by cracking, curling, and flaking, such as paints containing zinc oxide mixed with other pigments.

Group: No. :	Description of group :	Common name :	Botanical name :	Representative specific gravity ^a :
4 :	Woods on which paints of types A and B disintegrate more rapidly than they do on woods of group 3 :	<u>Hardwoods:</u> Beech ^b Birch Black gum ^b Maple Red gum Tupelo gum ^b <u>Softwoods:</u> Douglas fir Norway pine Southern yellow pine Tamarack ^b Western larch	Fagus grandifolia Betula sp. ^c Nyssa sylvatica Acer sp. ^c Liquidambar styraciflua Nyssa aquatica Pseudotsuga taxifolia Pinus resinosa Pinus sp. ^c Larix laricina Larix occidentalis	0.56 0.45 to 0.60 ^c 0.46 .44 to .57 ^c .44 .46 .45 .44 .45 to .64 ^c .49 .48
5 :	Woods unsuitable for conventional house painting because wood filler is required to fill the pores properly :	All hardwoods with pores larger than those in birch, such as ash, chestnut, elm, hickory : oak, walnut :		

^a Average specific gravity for the species (based on oven-dry weight and volume when green) listed in U.S. Dept. of Agriculture Technical Bulletin No. 158, "Comparative Strength Properties of Woods Grown in the United States." Within any species individual boards may vary widely from the average specific gravity.

^b Species not included in comparative paint tests but classified according to similarity in properties to one or more of the species that were tested.

^c More than one species of the family known by the same common name. In many cases commercial shipments of lumber bought under the common name will contain boards from two or more of the species. For example, southern yellow pine lumber may contain boards from one or more of the following: loblolly pine (Pinus taeda), longleaf pine (Pinus palustris), pitch pine (Pinus rigida), shortleaf pine (Pinus echinata), and slash pine (Pinus caribaea).

concealed, greatly retards crumbling or flaking of paint from the bands of summerwood, thereby minimizing the discrepancies in durability between different woods. Graphite priming paint made by adding 1 pound of flake graphite to 1 gallon of long-oil spar varnish seems to have much the same effect as aluminum primer but there is as yet much less background of experience with graphite primers than with aluminum primers. Because of their dark color at least two coats of white or light-colored paint are usually required over aluminum or graphite primers.

Acknowledgement

Exposure of the Forest Products Laboratory's test panels at stations other than Madison, Wisconsin, was made possible by the cooperation of the following:

U. S. Bureau of Standards.
Bureau of Chemistry and Soils, U.S. Department of Agriculture.
National Lead Company.
New Jersey Zinc Company.
Pittsburgh Plate Glass Company.
W. P. Fuller Company.
Denver and Rio Grande Western Railroad.
Southern Pacific Railroad.
University of Florida.
University of Washington.
North Dakota Agricultural College.

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