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EFFECTIVENESS OF PAINTS AS PROTECTIVE COATINGS FOR WOOD

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EFFECTIVENESS OF PAINTS AS PROTECTIVE COATINGS FOR WOOD[1]

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Coatings of paint and varnish retard the exchange of moisture between wood and its environment, their effectiveness varying widely with the nature of the coating material, the adequacy with which it is applied, and, in the case of coatings exposed to the weather, with its age. In previous publications (2, 9, 16)[2] it was pointed out that the effectiveness of coatings against moisture exchange measures accurately their value as protective coatings and a technic of measuring the effectiveness objectively was described. Such methods of quantitative evaluation of serviceableness, independent of personal judgments by inspectors, should prove especially useful in paint technology, which has long suffered badly from lack of them. Although the dominant considerations in serviceableness of paint coatings are usually maintenance of the integrity and appearance of the coating rather than protection of the wood, protection may prove to bear directly upon maintenance of integrity inasmuch as failure in integrity is occasioned not alone by change in intrinsic properties of the coating itself but also by extrinsic stresses acting on the aged coating, among which may be the movement of the wood in response to changing moisture conditions.

Interest has lately been focused upon the effectiveness of coatings against moisture because of the development of mill-priming and of back-priming (11, 17). Back-priming has protection against moisture as its only objective. Mill-priming is urged for protection against moisture during shipment and storage and for superior maintenance of protection and coating integrity after erection and application of finishing-coat paints. Because of these new developments study of the effectiveness of coatings against moisture must consider not only completed paint jobs

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[1]Presented before the Paint and Varnish Division of the American Chemical Society at the 85th meeting, Washington, D. C., March 26-31, 1933, and at the 91st meeting, Kansas City, Mo., April 13-17, 1936.

[2]Numbers in parentheses refer to citations listed at the end of the paper.

consisting of two or three coats of one kind of paint, but the effectiveness of priming coats alone and of special priming paints followed by finishing coats of ordinary paint. The experiments described in this report furnish data for discussion of these new developments.

Experimental Procedure

Moisture-excluding effectiveness was measured by the Forest Products Laboratory method (2, 9) on test specimens of southern yellow pine, Douglas fir, northern white pine, and redwood. The specimens were 5/8 by 4 by 8 inches in size with rounded edges and corners. They consisted entirely of clear heartwood. Coatings were applied to all surfaces of the specimens after the wood had been brought to equilibrium at 60 percent relative humidity and 80° F. Moisture movement through the coatings was measured by the gain in weight of the specimens after transferring them from 60 percent humidity to a damp air chamber for 1 week.

Since the coatings tested range in effectiveness from very high to very low it was necessary to select the wood specimens very carefully and to divide them into sets of closely matched specimens, each set having its own uncoated control specimen to serve as a basis for calculating the effectiveness of the coatings applied to the other specimens of the set. The experiments required 1,344 specimens, divided into 21 sets of 16 matched specimens for each of the four species.

Matching of test specimens was accomplished as follows: The raw material consisted of 1 by 6 inch by 16 foot boards of clear southern yellow pine, 1 by 6 inch by 12 or 14 foot boards of clear Douglas fir, 1 by 12 inch by 16 foot boards of No. 2 common northern white pine, and 2 by 6 inch by 16 foot planks of clear redwood. Each board was selected carefully by visual inspection for uniformity in density, resinousness, and width of growth rings throughout its length. All the southern pine, Douglas fir, and white pine boards were flat grain. The redwood planks were edge grain. Each board was given a reference number and was then cut into test specimens; each specimen was marked with the number and position in the board from which it was cut. The specimens were then placed in a room at 60 percent relative humidity until they attained constant weight.

Specimens containing knots or other defects were rejected and each of the remaining specimens was weighed. Each species was then divided into 21 sets of 16 specimens each, taking the 16 from one board provided that they were sufficiently uniform in weight. The least uniform set accepted was one of southern pine in which the range in weight of the specimens was 218 to 245 grams, a variation of ± 5.8 percent from the average. In order to keep the variation in weight within that limit some sets of specimens were taken from two or even from three different boards but in that case care was taken to see that the boards were very similar in width of growth rings and angle of intersection of the surfaces with the growth rings. Of the 21 sets of specimens for each species, 20 sets of white pine, 11 of redwood, 16 of Douglas fir, and 11 of southern pine came entirely from one board each; the remaining sets came from two boards except four sets of southern pine and one of redwood, which came from three boards. For the 21 sets of each species the average variation in weight was ± 4.1 percent for southern yellow pine, ± 3.5 percent for northern white pine, ± 2.5 percent for Douglas fir, and ± 1.9 percent for redwood.

All of the specimens were then transferred to a damp air chamber for 1 week and the increase in weight determined in order to make sure that the specimens within each set were reasonably uniform in absorption. The specimens were then reconditioned in the 60 percent humidity room before painting.

The 21 sets of matched specimens of each species were then assigned to seven series of sets, each series consisting of three groups. The series were designated respectively the "100 series", "200 series", etc., up to the "700 series" and the groups within each series were designated respectively the "A group", "B group", and "C group". Since each set contained 16 matched specimens of which one was required for the unpainted control specimen for the set, there were 15 specimens in each set available for coating. Of these two were assigned as painted controls by means of which the validity of comparisons between series could be established, leaving 13 specimens in each set available for painting with coatings to be studied. Accordingly the primers and paints to be tested were divided into seven series of 13 paints each corresponding to the seven series of sets of specimens.

Of the three groups of sets within each series the "A group" was assigned to the testing of priming coats alone, before and after exposure to the weather. The "B group" was assigned to tests in which the priming-coat paints were covered with two coats of white lead linseed oil paint, tests being made after the application of each coat and then after exposure to the weather for successive intervals of 6 months. The tests on group B reveal the contribution made by special primers to the effectiveness and maintenance of effectiveness of completed paint jobs in which the finishing coats are the same throughout; it will be shown from the results that this contribution by primers can not be determined from the effectiveness of the primer before it has been covered with a succeeding coat of paint. The "C group" was assigned to tests in which different paints were each applied in 3-coat work and tested after each coat and after exposure to the weather for successive intervals of 6 months. Unpainted control specimens, however, were never exposed to the weather but were always held in 60 percent relative humidity while the painted specimens were on the exposure racks.

During the progress of these experiments the Forest Products Laboratory moved into a new building in which a newly equipped set of rooms of constant temperature and humidity is provided. The new equipment permits closer control of conditions than was possible in the former quarters. In the old damp-air chamber the readings varied from a relative humidity of 95 percent to a relative humidity of nearly 100 percent; in the new room it is held at approximately 97 percent. For conditioning the specimens before subjecting them to damp air and for storage of unpainted controls while the painted specimens are exposed to the weather they were formerly placed in a room at approximately 60 percent relative humidity; they are now placed in a room held closely at 65 percent. In these experiments all tests for effectiveness before exposure to the weather and tests of group A after 6 weeks exposure were made in the old equipment.

Calculation of Effectiveness Rating

The degree to which coatings retard the exchange of moisture between wood and its environment is expressed in terms of their effectiveness ratings. The moisture absorbed by a coated specimen during 7 days in 97 percent relative humidity expressed as a percentage of the moisture absorbed by a matched specimen of uncoated wood during the same interval in 97 percent humidity is taken as the effectiveness rating of the coating. Since the moisture movement through very ineffective coatings, like that into uncoated wood, depends upon the weight of the specimen and the kind of wood while the movement through very effective coatings depends almost entirely upon the surface area of the specimen regardless of its weight or species, comparison of coatings that differ greatly in effectiveness can be made fairly only if the effectiveness of each coating has been determined with coated and uncoated specimens of nearly the same weight, species, and dimensions.

The effectiveness ratings recorded in this report are averages of the four ratings determined separately for southern yellow pine, Douglas fir, northern white pine, and redwood, except where otherwise stated.

Second- and Third-Coat Paints for Group B

All painted specimens of group B, except certain of series 600 to be described later, received the same second- and third-coat paints, the composition of which is recorded in Table A.

Table A.--Second- and third-coat paints for specimens of group B

Composition	Second-coat	Third-coat
Basic carbonate white lead (87 lbs.), gallons	1.53	1.53
Raw linseed oil, gallons	2.18	3.93
Turpentine, gallons	1.50	.125
Paint drier, gallons	.125	.125
Pigment volume, percent	41.3	28.0

Paints for Painted Control Specimens

In order to provide a basis for comparing coatings tested in different series and to indicate the degree of reproducibility of the results, one specimen of each set throughout the seven series was painted with white lead linseed oil paint and a second specimen with a white lead paint made with a Bakelite paint oil (Bakelite Corporation formula XV-2196). The composition of these paints is recorded in Table B.

Table B.--White lead paints for painted control specimens

Composition	Primer (Group A,B,C)	Second-coat (Group C)	Third-coat (Group C)
Linseed oil paint, X02			
Basic carbonate white lead (87 lbs.), gallons	1.53	1.53	1.53
Raw linseed oil, gallons	4.68	2.42	3.93
Turpentine, gallons	1.75	1.30	.125
Paint drier, gallons	.125	.125	.125
Pigment volume, percent	24.60	38.80	28.00
Bakelite oil paint, X03			
Basic carbonate white lead (87 lbs.), gallons	1.53	1.53	1.53
Nonvolatile in paint oil, gallons	4.68	2.18	3.93
Mineral spirits, gallons	.68	.32	.59
Turpentine, gallons	1.00	1.18	---
Paint drier, gallons	.15	.15	.15
Pigment volume, percent	24.60	41.30	28.00

The 100 Series -- Aluminum Paints

Paints were made with two forms of aluminum powder: dry, polished powder of the degree of fineness designated "standard varnish grade", and commercial paste aluminum powder. The paste consisted of 60 percent by weight aluminum and 40 percent mineral spirits; the powder was of finer particle size than standard varnish grade. Each of the following paints was applied as primer on specimens of groups A, B, and C of the 100 series, and as second- and third-coat paints on specimens of group C.

No. 104 -- 2 lbs. of paste aluminum in 1 gal. of varnish A.
No. 105 -- 2 lbs. of paste aluminum in 1 gal. of Bakelite varnish (50-gal. length in oil, 89.5 percent nonvolatile by weight).
No. 106 -- 2 lbs. of dry aluminum in 1 gal. of varnish A.
No. 107 -- 1.07 lbs. of dry aluminum in 1 gal. of varnish A.
No. 108 -- 2 lbs. of dry aluminum in 1 gal. of Bakelite varnish.

No. 109 -- 1.07 lbs. of dry aluminum in 1 gal. of Bakelite varnish.

No. 110 -- 2 lbs. of dry aluminum in 1 gal. of ester gum varnish of 75-gal. length in oil and 49 percent nonvolatile.

No. 111 -- 2 lbs. of dry aluminum in 1 gal. of ester gum varnish of 33-gal. length in oil and 49 percent nonvolatile.

No. 112 -- 2 lbs. of dry aluminum in 1 gal. of commercial glycerol-phthalate synthetic drying oil vehicle for aluminum paint.

No. 113 -- 2 lbs. of dry aluminum in 1 gal. of "4-lbs. cut" white shellac varnish and 0.04 gal. of castor oil.

No. 114 -- 2 lbs. of dry aluminum, 1 gal. of raw linseed oil, and 0.03 gal. of paint drier.

No. 115 -- 2 lbs. of dry aluminum in 1 gal. of nitrocellulose-rezyl resin wood lacquer.

The 200 Series -- White Linseed Oil Paints

This series, together with the 300 and 400 series, is designed to demonstrate the contribution to effectiveness against moisture movement made by the kind of pigment in linseed oil paint. Paints were made with each of nine opaque white pigments and with five different mixtures of white pigments or of white and inert pigments. No white pigment other than white lead, of course, is commonly used as the sole pigment in linseed oil house paint, but the behavior of the single-pigment paints is of interest from the point of view of theories of paint formulation.

The proper proportioning of pigments and liquids in making paints for the purpose of comparing different pigments and pigment mixtures is subject to controversy. Until the distribution of particle size of the different pigments and their state of dispersion in mixtures of linseed oil and turpentine are better understood formulation must remain arbitrary. For the present the writer believes that paints for fair comparison should be mixed with constant ratios by volume of total pigment, drying oil, and thinner except for a few colored pigments for which an extra amount of thinner is necessary to make the paint brushable. Accordingly all of the white paints were mixed in the proportions given in Table 2 for white lead linseed oil paint, No. X02. The volumes of the pigments were calculated from the bulking values published by Gardner (14).

The pigments tested in series 200 were:

No. 202 -- Basic carbonate white lead.
No. 204 -- Basic sulfate white lead (subsequently found to contain 6.8 percent zinc oxide).
No. 205 -- 35 percent leaded zinc oxide.
No. 206 -- Mixture of 35 percent by weight basic sulfate white lead and 65 percent zinc oxide, lead-free.
No. 207 -- Zinc oxide, lead-free.
No. 208 -- Timonox (antimony oxide).
No. 209 -- Titanium oxide.
No. 210 -- Titanox B (25 percent titanium oxide, 75 percent barium sulfate).
No. 211 -- Zinc sulfide.
No. 212 -- Lithopone (28 percent zinc sulfide, 72 percent barium sulfate).
No. 213 -- 60 percent by weight basic carbonate white lead, 30 percent zinc oxide, lead-free, 10 percent asbestine.
No. 214 -- 60 percent by weight titanox B, 30 percent zinc oxide, lead-free, 10 percent asbestine.
No. 215 -- 40 percent by weight lithopone, 45 percent leaded zinc oxide, 7.5 percent silica, 7.5 percent asbestine.
No. 216 -- 21.3 percent by weight basic carbonate white lead, 24.6 percent zinc oxide, lead-free, 45.9 percent barium sulfate (blanc fixe), 8.2 percent asbestine.

The 300 Series -- Colored Linseed Oil Paints

The colored pigments were tested as single-pigment paints only. Most of them are commercially practicable in that form except that the more expensive ones would then make paint cost too much. The proportions by volume of pigments, linseed oil, and turpentine were the same as in series 200 and in white lead paint No. X02 except that, in the cases stated, extra amounts of turpentine in addition to those given in Table B were added to make brushable paints.

No. 304 -- Iron oxide red (99 percent ferric oxide), 2d-coat mixed with 0.86 gal. and 3d.-coat with 1.64 gal. extra turpentine.
No. 305 -- Spanish oxide (85 percent ferric oxide, balance silicates).
No. 306 -- Venetian red (40 percent ferric oxide, balance calcium sulfate).

No. 307 -- Venetian red (9 percent ferric oxide, 12 percent calcium sulfate, 79 percent calcium carbonate).
No. 308 -- Yellow oxide (92 percent ferric oxide monohydrate, 6 percent calcium sulfate, 1 percent silica and alumina, 1 percent free moisture).
2d.-coat mixed with 0.25 gal. and 3d.-coat with 1 gal. extra turpentine.
No. 309 -- French ochre (18 to 24 percent ferric oxide, 48 percent silica, 20 percent alumina, loss on ignition 10 percent).
No. 310 -- Chrome yellow, light.
Primer mixed with 1.39 gal., 2d.-coat with 2 gal., 3d.-coat with 3.14 gal. extra turpentine.
No. 311 -- Chrome yellow, orange.
No. 312 -- Prussian blue.
No. 313 -- Lampblack.
Primer mixed with 2.78 gal., 2d.-coat with 7.13 gal., 3d.-coat with 4.74 gal. extra turpentine.
No. 314 -- Graphite.
Graphite was considered a leaf-shaped pigment like aluminum and was accordingly mixed in the proportion of 1.9 lbs. per gal. of linseed oil containing drier.
No. 315 -- Red lead.
No. 316 -- Litharge.
The litharge was stirred into the liquids without first grinding with oil in the paint mill.

The 400 Series -- Inert Pigments and Mixtures of Aluminum with Granular Pigments

The 400 series was in two parts, the first of which consisted of single-pigment linseed oil paints made with inert (transparent) pigments mixed in the same proportions by volume as Series 200 and white lead paint No. X03.

No. 404 -- Asbestine.
No. 405 -- Silica.
No. 406 -- Barytes.
No. 407 -- Blanc fixe.
No. 408 -- China clay.
No. 409 -- English chalk.

The second part of series 400 consisted of aluminum, a leaf-shaped pigment, and granular pigments in linseed oil (No. 416 in Bakelite vehicle) made by mixing equal volumes of aluminum paint No. 114 (or No. 108) and granular pigment paints as follows:

No. 410 -- Aluminum and white lead, No. 114 and No. 202.
No. 411 -- Aluminum and red lead, No. 114 and No. 315.
No. 412 -- Aluminum, white lead, zinc oxide, asbestine, No. 114 and No. 213.
No. 413 -- Aluminum and zinc oxide, No. 114 and No. 207.
No. 414 -- Aluminum and iron oxide, No. 114 and No. 304.
No. 415 -- Aluminum and asbestine, No. 114 and No. 404.
No. 416 -- Aluminum and white lead in Bakelite vehicle, No. 108 and No. 503.

The 500 Series -- Vehicles with and without Granular Pigments

The 500 series was designed to study the effect of different paint vehicles on moisture movement through paints and through coatings of the vehicles alone, without pigments. The vehicles were linseed oil, 33-gal. ester gum varnish (see No. 111), 75-gal. ester gum varnish (see No. 110), Bakelite varnish (see No. 105), and Bakelite paint oil (see No. X03). The pigments were basic carbonate white lead, iron oxide (see No. 304), and asbestine. The proportions by volume of pigments and nonvolatile part of the vehicle were always the same as in series 200 and in white lead paint No. X02 but the proportions of thinner in the paints made with varnish vehicles were, of course, higher in order to make the paints brushable. The two ester gum varnishes already contained sufficient thinner to attain that end. The Bakelite paint oil, however, contained only 11 percent volatile by weight, which was sufficient for white lead paint but for iron oxide paint additions of turpentine were required in amounts of 2.3 gal. for primer, 2.13 gal. for second-coat, and 2.6 gal. for third-coat paint, and for asbestine paint, 1.3 gal. for primer, 1.17 gal. for second-coat and 0.94 gal. for third-coat paint.

No. 502 -- White lead in linseed oil.
No. 503 -- White lead in Bakelite paint oil.
No. 504 -- White lead in 75-gal. ester gum varnish.
No. 505 -- White lead in 33-gal. ester gum varnish.
No. 506 -- Iron oxide in Bakelite paint oil.
No. 507 -- Iron oxide in 75-gal. ester gum varnish.

No. 508 -- Iron oxide in 33-gal. ester gum varnish.
No. 509 -- Asbestine in Bakelite paint oil.
No. 510 -- Asbestine in 75-gal. ester gum varnish.
No. 511 -- Asbestine in 33-gal. ester gum varnish.
No. 512 -- Bakelite paint oil.
No. 513 -- Bakelite varnish (see No. 105).
No. 514 -- 75-gal. ester gum varnish.
No. 515 -- 33-gal. ester gum varnish.
No. 516 -- Linseed oil containing paint drier.

The 600 Series -- Pigment Concentration

The 600 series was designed to reveal the effect of variation in the ratio of pigment to drying oil on the effectiveness against moisture movement. Three paints were used, white lead in linseed oil, white lead in Bakelite paint oil, and white paint No. 214 (titanox B, zinc oxide, asbestine). The concentration of pigment is expressed in terms of pigment volume, which is the percentage of pigment by volume in the nonvolatile part of the paint (pigment plus drying oil). For purposes of calculation it is assumed that the drying oil does not change in volume during drying and hardening of the paint coating.

The 600 series differs from all other series in that the second- and third-coat paints on group B, instead of being white lead paint, were paints of the same pigment composition as the priming-coat paint and mixed always in the proportions by volume given for white lead paint No. X02 in Table B. For group C the second- and third-coat paints were identical with the primers both in composition of pigment and in proportions of pigments and liquids.

Basic carbonate white lead in linseed oil:

No. 602 -- Pigment volume 24.6 percent.
No. 604 -- Pigment volume 29.0 percent.
No. 605 -- Pigment volume 33.0 percent.
No. 606 -- Pigment volume 38.7 percent.
No. 607 -- Pigment volume 43.0 percent.
No. 608 -- Pigment volume 47.7 percent.

Titanox B, zinc oxide, asbestine in linseed oil:

No. 609 -- Pigment volume 29.0 percent.
No. 610 -- Pigment volume 33.0 percent.
No. 611 -- Pigment volume 38.7 percent.
No. 612 -- Pigment volume 43.0 percent.
No. 613 -- Pigment volume 47.7 percent.

Basic carbonate white lead in Bakelite paint oil:

No. 603 -- Pigment volume 24.6 percent.
No. 614 -- Pigment volume 29.0 percent.
No. 615 -- Pigment volume 38.7 percent.
No. 616 -- Pigment volume 47.7 percent.

The 700 Series -- Spray Application

Mill priming of lumber is usually done by spray application followed by forced drying at moderately high temperature. It is also customary to add more thinner to aluminum paint when it is sprayed. The 700 series was designed to determine whether these factors affect the resistance of the coating to moisture movement. Primers for groups A, B, and C and second- and third-coat paints for group C were applied by the tool indicated in the following list but second- and third-coat paints for group B were always applied by brush.

No. 702 -- White lead linseed oil paint, brushed.
No. 704 -- White lead linseed oil paint, sprayed.
No. 705 -- White paint No. 213, sprayed.
No. 706 -- White paint No. 214, sprayed.
No. 707 -- Aluminum paint No. 104, sprayed.
No. 708 -- Aluminum paint No. 108, sprayed.
No. 709 -- Aluminum paint No. 108 thinned with 0.25 gal. of mineral spirits, sprayed.
No. 710 -- No. 709 force dried at 160° F. for 1 hour.
No. 711 -- Aluminum paint No. 110, sprayed.
No. 712 -- Aluminum paint No. 110 thinned with 0.25 gal. of mineral spirits, sprayed.
No. 713 -- No. 712 force dried at 160° F. for 1 hour.
No. 714 -- Aluminum paint No. 112, sprayed.
No. 715 -- Aluminum paint No. 112 thinned with 0.25 gal. of turpentine, sprayed.
No. 716 -- No. 715 force dried at 160° F. for 1 hour.

RESULTS -- PART I

Groups A, B, and C Before Exposure to Weather

The measurements of effectiveness of the different coatings within each series are closely comparable because they were made on matched specimens of wood. The ratings reported in Table C are the averages of the four ratings obtained on each of the four species of wood. The grouping of the paints within each series was designed to bring together the kinds of paint between which closest comparisons are desired. Comparison of a paint tested in one series with a paint tested in another series is somewhat less reliable but the degree of uncertainty on that score can be gaged by the results with the two painted controls that were included in all series, painted respectively with white lead linseed oil paint and with white lead Bakelite oil paint.

Table C.--Average effectiveness ratings of primers alone (group A), primers followed by two coats of white lead (group B), three coats of similar paint (group C).

Key to Symbols: E^1, effectiveness of primer only; E^1_6, effectiveness of primer after exposure to the weather for 6 months; E^2, effectiveness after applying second coat; E^3, effectiveness after applying third coat.

No.	Description of primer	Group A: E^1	Group A: E^1_6	Group B: E^1	Group B: E^2	Group B: E^3	Group C: E^1	Group C: E^2	Group C: E^3
Series 100:									
102	White lead in linseed oil.	27	...	27	63	72	23	62	73
103	White lead in Bakelite oil	72	...	69	83	84	66	86	92
	Aluminum paints:								
104	Paste aluminum, varnish A.	70	68	70	83	85	71	87	92
105	Paste in Bakelite varnish.	77	75	79	65	90	75	92	94
106	2 lbs. powder, varnish A.	45	50	37	84	88	47	92	94
107	1 lb. powder, varnish A...	18	22	12	71	80	18	79	89
108	2 lbs. powder, Bakelite varnish	42	42	39	[illegible]	91	34	88	95
109	1 lb. powder, Bakelite varnish...............	20	20	17	73	84	12	77	90
	2 lbs. powder in:								
110	75-gal. ester gum varnish.	12	16	8	62	86	6	61	90
111	33-gal. ester gum varnish.	24	26	20	83	91	16	90	98
112	Glyceryl-phthalate varnish	16	19	14	73	86	9	81	93
113	Shellac-castor oil........	18	8	21	71	87	11	78	92
114	Raw linseed oil...........	12	18	15	64	82	15	57	77
115	Kettle bodied linseed oil.	30	36	24	75	84	24	84	89
116	Nitrocellulose lacquer....	9	...	11	71	86	10	31	43
Series 200:									
203	White lead in Bakelite oil	63	...	64	78	79	68	86	89
	White pigments in linseed oil:								
202	Basic carbonate white lead.	21	27	18	61	68	19	63	73
204	Basic sulfate white lead..	14	16	13	56	69	15	49	69
205	35% leaded zinc oxide.....	26	34	27	64	72	29	63	72
206	Mixture of 204 and 207	30	[illegible]	32	65	72	32	70	75
207	Zinc oxide, lead-free. ..	34	39	40	67	73	36	68	75
208	Antimony oxide............	23	25	17	60	68	21	63	68
209	Titanium dioxide.........	20	19	20	61	68	23	60	63
210	Titanium-barium pigment...	27	23	20	59	68	22	60	64

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Table C.--Average effectiveness ratings of primers alone (group A), primers followed by two coats of white lead (group B), three coats of similar paint (group C). (Continued)

No.	Description of primer	Group A E^1	Group A E^1_6	Group B E^1	Group B E^2	Group B E^3	Group C E^1	Group C E^2	Group C E^3
	Series 200 (continued):								
	White pigments in linseed oil (continued):								
211	Zinc sulfide	21	16	17	60	68	21	61	65
212	Lithopone	20	12	19	58	67	20	51	55
213	Mixture of 202, 207, 404	24	21	32	67	72	33	71	74
214	Mixture of 210, 207, 404	20	20	21	62	69	24	65	70
215	Mixture, 212, 205, 404, 405	28	22	30	65	70	32	73	75
216	Mixture, 202, 207, 404, 407	26	26	25	64	70	27	67	73
	Series 300:								
302	White lead in linseed oil	21	...	10	63	71	13	56	69
303	White lead in Bakelite oil	60	...	55	80	80	58	84	86
	Colored pigments in linseed oil:								
304	Iron oxide red	24	36	21	63	70	23	53	56
305	Spanish oxide	12	19	11	61	69	12	34	53
306	Venetian red, 40% Fe_2O_3	7	38	5	60	69	7	25	45
307	Venetian red, 9% Fe_2O_3	5	13	6	63	72	6	55	62
308	Iron oxide yellow	24	35	21	62	68	24	55	63
309	Yellow ochre	15	32	10	61	70	14	39	52
310	Chrome yellow, lemon	29	46	25	65	69	26	49	56
311	Chrome yellow, orange	17	37	11	61	69	18	47	62
312	Prussian blue	14	29	10	60	69	17	46	58
313	Lampblack	19	34	22	67	71	27	38	58
314	Graphite	4	24	4	69	75	10	58	64
315	Red lead	19	34	10	66	72	19	56	67
316	Litharge	-2	...	-9	60	83	1	12	60
	Series 400:								
402	White lead in linseed oil	24	...	17	57	68	16	56	67
403	White lead in Bakelite oil	61	...	60	78	80	61	84	88
	Transparent pigments in linseed oil:								
404	Asbestine	15	26	9	59	68	7	37	55
405	Silica	8	17	1	61	71	14	46	69
406	Barytes	16	22	9	57	67	5	53	60
407	Blanc fixe	23	27	16	55	60	14	47	60
408	China clay	13	27	6	60	68	7	34	55
409	English chalk	12	22	8	57	68	6	44	59

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Table C.--Average effectiveness ratings of primers alone (group A), primers followed by two coats of white lead (group B), three coats of similar paint (group C). (Continued)

No.	Description of primer	Group A		Group B			Group C		
		$\underline{E}^1$	$\underline{E}^1_6$	$\underline{E}^1$	$\underline{E}^2$	$\underline{E}^3$	$\underline{E}^1$	$\underline{E}^2$	$\underline{E}^3$
Series 400 (continued):									
	Aluminum and granular pigments:								
410	Mixture of 114 and 202..........	8	25	4	60	73	9	72	74
411	Mixture of 114 and 315..........	12	20	3	60	75	6	65	75
412	Mixture of 114 and 213..........	15	23	5	62	75	1	65	78
413	Mixture of 114 and 207..........	25	37	13	67	75	12	63	77
414	Mixture of 114 and 304..........	15	22	4	58	74	8	61	73
415	Mixture of 114 and 404..........	16	25	7	61	72	8	53	67
416	Mixture of 108 and 203..........	36	37	33	77	80	40	88	90
Series 500:									
	Vehicles without pigments:								
516	Linseed oil.....................	3	8	0	38	63	3	5	21
514	75-gal. ester gum varnish..	0	6	0	38	62	5	14	35
515	33-gal. ester gum varnish..	0	6	0	41	64	12	37	65
512	Bakelite paint oil..........	0	8	0	35	62	12	47	66
513	Bakelite varnish............	0	7	2	40	62	12	49	73
	White lead in:								
502	Linseed oil.....................	18	20	15	53	70	19	61	75
504	75-gal. ester gum varnish..	8	20	7	48	67	3	62	83
505	33-gal. ester gum varnish..	22	20	23	57	70	23	85	91
503	Bakelite paint oil..........	62	61	57	75	81	65	86	81
	Iron oxide red in:								
507	75-gal. ester gum varnish..	33	43	34	61	70	39	75	82
508	33-gal. ester gum varnish..	28	31	30	58	69	33	82	88
506	Bakelite paint oil..........	3	12	3	42	63	8	64	81
	Asbestine in:								
510	75-gal. ester gum varnish..	0	11	5	50	66	14	50	70
511	33-gal. ester gum varnish..	20	19	18	55	67	30	66	83
509	Bakelite paint oil..........	21	31	25	63	74	30	60	78
Series 600: (On group B the 2d. and 3d. coat paints have the same pigments as the primer and pigment volumes 38.8 and 28.0 percent respectively.)									
	White lead in linseed oil:								
602	Pigment volume 24.6%..........	19	17	17	52	68	20	55	66
604	Pigment volume 29.0%..........	16	17	14	54	68	18	51	62
605	Pigment volume 33.0%..........	21	22	18	53	68	24	53	63
606	Pigment volume 38.7%..........	26	23	21	55	69	25	55	63
607	Pigment volume 43.0%..........	25	21	22	55	71	26	56	64
608	Pigment volume 47.7%..........	27	23	23	59	71	26	60	67

(Continued on next page)

Table C.--Average effectiveness ratings of primers alone (group A), primers followed by two coats of white lead (group B), three coats of similar paint (group C). (Continued)

No.	Description of primer	Group A E^1	Group A E^1_6	Group B E^1	Group B E^2	Group B E^3	Group C E^1	Group C E^2	Group C E^3
	Series 600: (On group B the 2d. and 3d. coat paints have the same pigments as the primer and pigment volumes 38.8 and 28.0 percent respectively.) (Continued)								
	Titanium pigment, ZnO, asbestine:								
609	Pigment volume 29.0%........	30	35	27	55	69	26	57	63
610	Pigment volume 33.0%........	28	35	25	53	68	25	56	63
611	Pigment volume 38.7%........	34	32	30	57	69	30	57	67
612	Pigment volume 43.0%........	33	28	30	56	68	30	57	66
613	Pigment volume 47.7%........	29	23	28	55	70	23	57	66
	White lead in Bakelite paint oil:								
603	Pigment volume 24.6%........	64	59	64	85	89	66	84	87
614	Pigment volume 29.0%........	58	48	57	82	88	60	82	88
615	Pigment volume 38.7%........	39	32	37	81	88	40	83	87
616	Pigment volume 47.7%........	41	27	38	80	89	45	84	85
	Series 700:								
702	White lead in linseed oil...	16	...	13	53	73	13	47	72
703	White lead in Bakelite oil..	61	...	61	77	83	60	84	88
	Paints applied by spray gun:								
704	No. 702 sprayed.............	4	3	1	48	75	3	44	68
705	No. 213 sprayed.............	14	11	24	62	78	25	61	73
706	No. 214 sprayed.............	14	16	15	56	76	23	58	72
707	No. 104 sprayed.............	29	24	38	77	84	40	73	84
708	No. 108 sprayed.............	4	1	16	83	88	18	69	85
709	No. 108, thinned, sprayed...	-4	-7	-4	69	87	7	72	86
710	No. 709 force dried.........	1	17	10	69	85	14	72	84
711	No. 110 sprayed.............	-9	6	8	62	85	4	51	83
712	No. 110, thinned, sprayed...	-5	5	3	54	85	1	19	67
713	No. 712 force dried.........	-3	-3	-2	56	84	-3	25	63
714	No. 112 sprayed.............	3	0	4	67	85	8	66	85
715	No. 112, thinned, sprayed...	6	-4	22	59	86	-2	31	77
716	No. 715 force dried.........	4	-2	3	67	85	-6	38	65

Effectiveness of Primers

It has been generally assumed that protection of the wood is attained in painting primarily by application of the priming coat and that additional coats serve chiefly for appearance and durability. Back-priming depends entirely on that assumption as does mill-priming also in so far as it aims to protect lumber during shipment, storage, and erection. The results, however, show that nearly all of the primers tested were very low in effectiveness even when the same paint applied in three coats proved very effective indeed. Moreover there was often no connection between the relative effectiveness of paints as primers alone and their relative effectiveness in two or three coats. For example, aluminum paints Nos. 110 and 112 proved much more effective in 2- or in 3-coat work than corresponding coatings of the common white paints, Nos. 202 and 213 to 216 inclusive, yet as primers alone the white paints were more effective than the aluminum paints. When, however, the two aluminum primers were covered with two coats of a white paint, such as white lead, the resulting coating was more effective than a 3-coat job with the white paints alone. In other words these aluminum primers, although not particularly effective by themselves, contributed materially to high effectiveness in the completed paint job.

Four aluminum primers, Nos. 104, 105, 106, and 108, proved unusually effective even as priming coats alone. Primers 106 and 108 owe their high effectiveness to the nature of the varnish vehicles because white lead primer No. 502, made with a very similar vehicle, proved even more effective than aluminum primer No. 108. But without any pigment, Nos. 512 and 513, or with iron oxide pigment, No. 506, this vehicle was very ineffective as a primer alone. In aluminum paints Nos. 104 and 105 the nature of the aluminum powder is also a potent factor in effectiveness, the fineness of the powder probably being the determining property. In another series of tests not included in this report it was found that the substitution of standard lining for standard varnish aluminum powder gave much the same comparative results as those found between aluminum paints Nos. 104 and 106.

It is evident that special primers can be made that will protect wood effectively when used as primers alone and will make good foundations for highly effective and durable coatings when covered by ordinary paints. Aluminum primer does not meet these dual requirements unless the grade of aluminum powder and the nature of the varnish vehicle are much more closely specified than is now customary. If the vehicle is wisely chosen, white primers of high effectiveness can also be obtained but it remains to be determined whether such primers will also have the property of retarding the flaking of paint coatings from conspicuous bands of summerwood that is the principal merit of good aluminum primers for wood (4, 6).

In another publication (7) it is shown that the primers used in these experiments are much more effective in keeping moisture out of wood when tested by exposing them to a spray of water simulating rain for 18-1/2 hours than when exposed to 97 percent relative humidity for 1 week.

Theory of Wood Priming

In general each successive coat of paint applied to wood improves the effectiveness of the coating against moisture movement but the increments attributable to each of the successive coats are very unequal. One of the coats, usually the second, seems to achieve the major portion of the final effectiveness. For example, the effectiveness of white lead paint on specimens 202C attained 19 percent for the primer, jumped to 63 percent with the second coat, and then increased only to 73 percent with the third coat. Aluminum paint No. 106 jumped from 47 to 92 percent between the primer and second coat and then increased only to 94 percent with the third coat. On the other hand with aluminum paint No. 104 the major portion of the effectiveness was attained with the primer, 71 percent. Again, with litharge added to linseed oil without grinding, No. 316C, the effectiveness of the successive coats was 1, 12, and 60 percent, respectively, the jump occurring between the last two coats. Oils and exterior varnishes without pigments, Nos. 512 to 516, built up effectiveness slowly and rarely attained great effectiveness even in three coats.

Edwards (10) explained the characteristic jump in effectiveness at one point in the process of building up a coating by studying the relation between the thickness of a coating and the rate at which moisture diffuses through it, which he defined as the permeability. The reciprocal of the permeability is the impedance to moisture movement. In general, the impedance is directly proportional to the thickness of the coating, provided the coating consists of the same kind of paint throughout. For coating 202C in Table C the effectiveness for three coats was found to be 73, corresponding to an impedance of 3.65; if the three coats were uniform in thickness the impedance for two coats would be 2.44 and for one coat 1.22 corresponding to effectiveness ratings of 60 and 18 respectively, which agree closely with the observed ratings of 63 and 19. Similar calculations for paint 104C for which the observed effectiveness was 92, 87, and 71 for three, two, and one coat respectively, lead to theoretical ratings of 89 and 76 for two coats and one coat, again agreeing reasonably well.

Some of the data, however, depart from the principle of proportionality between impedance and thickness far too seriously to be accounted for by experimental inaccuracies. The discrepancy usually takes the form of lower effectiveness for the priming coat than computation from the effectiveness of three coats indicates, though the effectiveness of two coats usually conforms to the theory. Thus for No. 106C an effectiveness of 94 for three coats agrees with the value 92 found for two coats but one coat should have a rating of 82 instead of 47 as found. Difference in thickness of the coats does not account for the discrepancy because the primer was in fact thicker than the other two coats. Many of the aluminum primers reveal a similar discrepancy between the observed and calculated effectiveness.

A paint primer is subject to a process of filtration and impoverishment in liquid because paint liquids penetrate wood measurably but pigments enter only as far as the cavities in those wood cells that have been cut open in planing the wood surface (5, 15). With a priming coat this loss of liquid may easily rob the pigment of enough non-volatile oil to form a continuous matrix, in which case the film is porous and directly permeable to moisture-laden air. It is well known, of course, that an inadequate primer takes oil from the succeeding coat of paint to fill these spaces left when its own oil was absorbed by the wood. It seems probable that aluminum primer, because of the leafing action and the relatively low volume concentration of the pigment, is more sensitive to such impoverishment than primers made of granular pigments unless the vehicle has been bodied sufficiently to restrain its penetration into the wood without the assistance of pigmentation. At any rate the fact that in these tests aluminum primer often proved relatively ineffective as a primer alone but contributed notably to the effectiveness of the completed coating is probably due to porosity of the film of the primer until resupplied with liquid from the next coat of paint.

Few primers made with granular pigments in these experiments exhibited materially lower effectiveness than that calculated from the effectiveness of three coats of the paint. All the granular pigment primers were mixed with a reasonably high proportion of pigment and were applied generously enough to insure adequacy as primers for holding out succeeding coats. If they had been thinned unduly and brushed out too far as is so often done in practice they probably would have shown the same failure to attain the effectiveness calculated from that of the 3-coat jobs which was observed with some of the aluminum primers.

RESULTS -- PART II

Weathering Tests of Groups B and C

All specimens of groups B and C, representing complete paint jobs, were exposed to the weather at 45 degrees facing south at Madison, Wis., and tested for effectiveness and inspected for integrity of the coating at intervals of 6 months during a total exposure of 3 years. The results appear in Table 1.

Correction for Unexposed Backs of Specimens

Only one side of the painted specimens was fully exposed to the weather when they were in position on the exposure racks but both sides were subject to absorption of moisture while they were hanging in the 97 percent room to determine the effectiveness. On the freshly painted specimens the effectiveness, of course, was the same for both sides but after exposure to the weather the two sides differed materially. The effectiveness measured is the average of the exposed and unexposed sides. For that reason the changes in effectiveness caused by weathering were in fact materially greater than the data of Table 1 show.

Visual inspection of the painted specimens at the end of 36 months showed that the coatings on the backs of nearly all specimens were still glossy, free from fissures, intact, and similar in appearance to young coatings except that many of the white paints were distinctly yellow as would be expected from repeated exposure to 97 percent humidity without subsequent exposure to direct sunlight. It is therefore reasonable to suppose that the effectiveness of the coatings on the backs of the specimens remained approximately the same as it was initially. If that assumption is correct the changes in effectiveness of the exposed faces were just twice the changes recorded in Table 1 and the effectiveness of the exposed face of a specimen at any time $\underline{E}_T^F$, can be computed from the formula:

$$\underline{E}_T^F = 2\ \underline{E}_T - \underline{E}_0$$

where $\underline{E}_T$ and $\underline{E}_0$ are the ratings recorded in Table 1 for $\underline{T}$ months and 0 months, respectively.

To test the validity of the assumption that the effectiveness of the unexposed backs of the painted specimens remained relatively unchanged certain specimens at the conclusion of the exposure test were painted on the exposed faces with three coats of aluminum paint. These specimens, together with their unpainted controls were seasoned in 65 percent relative humidity and tested for effectiveness in the usual way with the results recorded in the third column of Table 2. The fourth column gives the calculated effectiveness of the coatings on the backs of the specimens, assuming that the freshly applied aluminum paint on the faces was 90 percent effective. In most cases the effectiveness of the old coating on the backs of the specimens agrees satisfactorily with the effectiveness of the entire coating initially,

Table 1 -- Average effectiveness of coatings against moisture movement at intervals during exposure to the weather at 45° facing south, and summary of visual observations of the deterioration of the coatings

Key to Symbols: E_0, E_6 etc., average effectiveness rating on four woods determined at the age in months indicated by the subscript.

E^F_{end}, average effectiveness rating calculated for the exposed faces at the last time of test (in series 200 group B at age 30 months). Effectiveness of unexposed backs taken from Table 2 if recorded there, otherwise assumed equal to E_0.

Integrity recorded as durability in months or rating at 36 months. G, good; F, fair; P, poor; B, bad. SP, southern pine; DF, Douglas fir; WP, white pine; RD, redwood. Blank spaces mean specimen rated better than poor when removed from test prior to age 36 months. Under chalking, checking, cracking are recorded the ages when the defects were first observed without a magnifying glass. Cracking refers to sigmoid cracking only.

Reference No.	Description of the primer for group B and of all three coats for group C	GROUP B -- Primer plus two coats of white lead paint: Average effectiveness ratings								Integrity				GROUP C -- Three coats of paint of the kind described: Average effectiveness ratings											Integrity			
		E_0	E_6	E_{12}	E_{18}	E_{24}	E_{30}	E_{36}	E^F_{end}	SP	DF	WP	RD	E_0	E_6	E_{12}	E_{18}	E_{24}	E_{30}	E_{36}	E^F_{end}	Chalking	Checking	Cracking	SP	DF	WP	RD
Series 100:																												
102	White lead in linseed oil	72	80	73	71	62	43	52	32	28	26	F-	F	73	85	75	72	67	41	49	25	6	12		28	32	F-	F
103	White lead in Bakelite oil	84	87	84	82	83	70	70	56	34	34	F	F	92	95	92	93	94	90	88	84	12			P+	G	G	G
	Aluminum paints:																											
104	Paste aluminum in varnish A	85	88	84	84	82	74	76	67	36	F	F	F	92	94	88	89	89	87	86	80				G	G	G	G
105	Paste aluminum, Bakelite varnish	90	91	88	87	80	70	76	62	30	36	F	F	94	95	85	91	91	90	90	86				F-	G	G	G
106	2 lb. powder, varnish A	88	89	86	86	80	73	77	66	P+	F-	F	F	94	95	91	92	92	89	88	82				G	G	G	G
107	1 lb. powder, varnish A	80	84	76	76	70	55	59	38	36	P+	F	F	89	91	82	82	82	75	74	59				G	G	G	G
108	2 lb. powder, Bakelite varnish	91	91	88	89	84	73	76	61	35	P+	F	F	95	96	91	91	92	90	90	85				G	G	G	G
109	1 lb. powder, Bakelite varnish	84	86	82	82	73	56	63	42	32	34	F	F	90	93	85	85	85	80	79	68				F-	G	G	G
	2 lb. powder in:																											
110	75-gal. ester gum varnish	86	88	83	80	74	63	67	48	36	36	F	F	90	93	87	87	87	83	83	76				G	G	G	G
111	33-gal. ester gum varnish	91	92	87	84	77	62	70	49	24	27	F	F	98	97	93	93	91	88	90	82				34	G	G	G
112	glyceryl-phthalate varnish	86	86	86	86	78	67	69	52	P+	30	F	F	93	95	89	89	91	87	86	79				G	G	G	G
113	shellac-castor oil	87	86	55					23	12	12	12		92	90	70					48				12	12		
114	raw linseed oil	82	86	81	80	76	65	66	50	P+	F-	F	F	77	85	75	75	77	70	69	61				F	G	G	G
115	kettle bodied linseed oil	84	87	82	82	80	70	72	60	P+	F-	F	F	89	92	85	85	86	83	79	69				G	G	G	G
116	nitrocellulose lacquer	86	88	53					20	12	12	12		43	55	38					23				12	6	12	
Series 200:																												
203	White lead in Bakelite oil	79	86	79	82	81	66	64	49	32	32	F	F	89	93	92	92	91	87	88	87	12			36	G-	G	G
	White pigments in linseed oil:																											
202	Basic carbonate white lead	68	78	71	68	59	38	46	8	28	24	F-	F	73	79	75	75	65	47	49	25	6	12		28	28	F	F
204	Basic sulfate white lead	69	79	68	58	54	38		7	30	24	F	F	69	78	75	68	59	44	45	21	6		12	28	36	F	F
205	35% leaded zinc oxide	72	81	71	66	61	43		14	24	24	24	24	72	80	78	75	66	50	47	22	6		24	28	P+	F	F
206	Mixture of 204 and 207	72	81	74	68	59	43		14	24	24	24	24	75	81	80	74	62	47	45	15	6		24	26	36	P+	F
207	Zinc oxide, lead-free	73	83	74	69	61	45		17	21	24	24	24	75	82	80	73	63	49	47	19	12		24	26	P+	P+	F
208	Antimony oxide	68	81	69	72	66	52	52	36	F-	36	F	F	68	74	65	68	62	55	54	40	6			G-	G-	G	G
209	Titanium dioxide	68	78	71	69	57	43	50	18	36	36	F	F	63	66	48	45	40			17	6			18	18	24	22
210	Titanium-barium pigment	68	76	66	62	55	39	48	10	36	36	F	F	64	68	55	53	46			28	6			18	18	24	18
211	Zinc sulfide	68	76	70	70	61	45	51	22	36	P+	F	F	65	69	56	48	44			23	6	12		20	24		24
212	Lithopone	67	77	67	65	59	42	51	17	30	36	F	F	55	55	47	39	38			21	6	18		20	24		24
213	Mixture of 202, 207, 404	72	82	69	60	56	38		4	21	21	24	24	74	82	80	78	70	54	51	28	12	24		26	F	36	F
214	Mixture of 210, 207, 404	69	81	67	57	55	38		7	21	21	24	24	70	79	77	77	81	70	62	54	6		30	F+	F+	F+	F+
215	Mixture of 212, 205, 404, 405	70	79	69	55	52	35		0	21	21	24	24	75	82	78	66	56	35	41	7	6	12		25	36	F-	F-
216	Mixt. 202, 207, 404, much 407	70	79	69	58	52	36		2	21	21	24	24	73	80	77	69	58	42	44	15	6	18		26	36	P+	F-
Series 300:																												
302	White lead in linseed oil	71	77	71	68	60	39	41	11	28	30	F	F	69	76	76	71	62	38	37	4	6	12		34	30	F	F
303	White lead in Bakelite oil	80	85	81	82	79	66	65	50	30	F	F	F	86	90	90	89	88	84	81	76	12			P+	F	G	G
	Colored pigments in linseed oil:																											
304	Iron oxide red, 99% Fe_2O_3	70	77	71	70	69	61	44	18	F	F	F	F	56	63	58	61	60	50	45	34	18			G	G	G	G
305	Spanish oxide, 85% Fe_2O_3	69	76	72	71	70	62	60	51	F	F	F	F	53	55	51	52	55	39	37	21	18			G	G	G	G
306	Venetian red, 40% Fe_2O_3	69	76	71	70	67	55	54	39	F	F	F	F	45	55	54	56	56	42	36	27	18			G-	G-	G-	G-
307	Venetian red, 9% Fe_2O_3	72	77	75	70	66	53	51	30	F	F	F	F	62	65	62	63	60	51	48	34	12			F+	F+	F+	F+
308	Iron oxide yellow, 92% $Fe_2O_3 \cdot H_2O$	68	75	70	68	67	58	56	44	F	F	F	F	63	66	60	65	56	46	41	19	30			P+	P+	F+	F+
309	Yellow ochre, 18-24% Fe_2O_3	70	76	73	72	71	61	58	46	F	F	F	F	52	58	54	55	54	42	42	32	18			F	F	F	F
310	Chrome yellow, lemon	69	75	73	72	71	62	61	53	F	F	F	F	56	71	60	64	61	57	55	54	36+			G	G	G	G
311	Chrome yellow, orange	69	79	73	72	71	61	61	53	30	30	30	30	62	73	71	74	72	68	65	68	24			F	F	F	F
312	Prussian blue	69	76	72	73	71	59	55	41	F-	F	F-	F	58	65	62	65	61	54	47	36	6			P+	F+	F+	F+
313	Lampblack	71	77	71	73	73	63	60	49	30	30	30	30	58	60	56	61	56	50	47	36	18			G	G	G	G
314	Graphite	75	80	76	75	75	65	61	47	F-	F-	P+	F-	64	67	64	66	62	56	50	36	18			G	G	G	G
315	Red lead	72	82	76	71	62	37	39	6	20	27	P+	P+	67	73	78	81	67	53	47	22	18	30		21	36	F	F
316	Litharge	83	89	82	73	66	43	42	1	28	30	F	F	60	70	58	54	40	28	19	12	18	30		F	F	F	F

Z M 27799 F

Table 1 continued

Reference No.	Description of the primer for group B and of all three coats for group C	GROUP B -- Primer plus two coats of white lead paint: Average effectiveness ratings E_0	E_6	E_{12}	E_{18}	E_{24}	E_{30}	E_{36}	E^F_{end}	Integrity SP	DF	WP	RD	GROUP C -- Three coats of paint of the kind described: Average effectiveness ratings E_0	E_6	E_{12}	E_{18}	E_{24}	E_{30}	E_{36}	E^F_{end}	Chalking	Checking	Cracking	Integrity SP	DF	WP	RD
Series 400:																												
402	White lead in linseed oil	68	76	71	73	59	41	38	8	27	36	F	F-	67	76	70	67	54	41	49	31	6	12		28	30	P+	F
403	White lead in Bakelite oil	80	85	80	79	80	64	60	40	27	P+	F	F	88	91	88	93	89	74	84	80	12			P+	G-	G-	G-
	Transparent pigments in linseed oil:																											
404	Asbestine (magnesium silicate)	68	77	71	73	69	51		34					55	59	49	43	30			5	6			24	24		
405	Silica	71	79	74	73	65	45		19					69	70	59	55	40			11	6			24	24		
406	Barytes (barium sulfate)	68	76	71	70	55	38		8	24				60	64	43	34	32			4	6			18	24		
407	Blanc fixe (barium sulfate)	60	78	70	69	57	38		16	27				60	63	46	41	32			4	6			18	24		
408	China clay	68	77	72	75	66	46		24					55	59	41	47	35			15	6			24	24		
409	English chalk ($CaCO_3$)	68	76	72	73	60	41		14					59	64	37	31	27			-5	6	18		18	24		
	Aluminum and granular pigments:																											
410	Al and white lead, 114 and 202	73	80	76	76	73	61	53	33	F	F	F	F	72	74	72	76	69	64	64	56				F	F	F	F
411	Al and red lead, 114 and 315	75	83	79	75	65	51	48	21	27	P+	F	F	75	83	79	86	79	70	69	63				30	F	F	F
412	Al, lead, zinc; 114 and 213	75	83	72	65	57	42		9	24	24	24	24	78	81	79	84	79	76	73	48				F	F	F	F
413	Al and ZnO, 114 and 207	75	83	76	73	66	51		27	24	24	24	24	77	81	81	84	80	80	75	73				F	F	F	F
414	Al and Fe_2O_3, 114 and 304	74	80	76	77	77	71	63	52	F	F	30	F	73	76	72	77	70	72	64	55				G	G	G	G
415	Al and asbestine, 114 and 404	72	79	75	75	72	63	54	36	F	F	F-	F	67	67	61	66	57	55	59	51				G	G	G	G
416	Al, lead, Bakelite, 108 and 203	80	85	81	83	80	70	60	40	P+	F	F	F	90	89	93	95	91	92	90	90				F	F	F	F
Series 500:																												
	Vehicles without pigments:																											
516	Linseed oil	63	72	67	55	53	48		33		24			21	21	10					-1				12	12	12	12
514	75-gal. ester gum varnish	62	72	65	54	50	41		20	24	24			35	32	17					-1				6	6	6	6
515	33-gal. ester gum varnish	64	73	68	59	52	44		24	24	24			65	55	31					-3		6		6	6	6	6
512	Bakelite paint oil	62	70	64	55	49	43		24	27	29			66	63	50	46				26				15	18		
513	Bakelite varnish	62	71	67	58	52	44		26	30	29			73	69	59	57				41				15	18		
	Basic carbonate white lead in:																											
502	Linseed oil	70	77	73	68	59	48	45	20	28	32	F	F	75	77	73	69	62	42	47	19	6	12		27	28	F	F
504	75-gal. ester gum varnish	67	75	69	61	56	42		17	26	30			83	84	66	53	46			9	6	12		18	21		
505	33-gal. ester gum varnish	70	77	72	64	52	42		14	24	28			91	91	70	65	52			13	6			12	18		
503	Bakelite paint oil	81	84	83	83	84	72	72	63	30	F	F	F	91	91	91	93	92	77	82	73	12			24	F	G	G
	Iron oxide red in:																											
507	75-gal. ester gum varnish	70	77	73	73	73	62	61	52	F-	F-	F	F	82	79	76	78	82	73	78	74	6			F	F	G	G
508	33-gal. ester gum varnish	69	76	73	71	66	59	58	47	36	P+	F	F	88	84	79	83	82	68	75	62	6			30	P+	G	G
506	Bakelite paint oil	63	71	65	61	58	48	47	31	F-	F-	F	F	81	79	75	80	84	73	77	73	6			G	G	G	G
	Asbestine in:																											
510	75-gal. ester gum varnish	66	74	69	64	49	40		14	27				70	65	52	43				16	6		12	15	18		
511	33-gal. ester gum varnish	67	75	71	66	52	42		17	26	30			83	76	54	48				13	6		12	15			
509	Bakelite paint oil	74	80	78	76	79	68	63	52	P+	P+	F	F	78	75	71	73	67	44	44	10	6		12	21	33	36	36
Series 600: (On group B the 2d- and 3d-coat paints have the same pigments as the primer and pigment volumes of 38.8% and 28.0% respectively; on group C the 2d- and 3d-coat paints have the same pigments and the same pigment volumes as the primer.)																												
	White lead in linseed oil:																											
602	Pigment volume 24.6%	68	77	72	72	63	42	47	26	24	P+	F	F	66	76	70	68	64	41	45	22	6	12		33	35	F	F
604	Pigment volume 29.0%	68	77	72	72	63	40	42	16	27	F-	F-	F-	62	73	67	61	55	35	39	26	6	12		32	30	P+	F
605	Pigment volume 33.0%	68	77	73	72	61	41	44	20	27	36	F-	P+	63	73	68	62	55	36	38	20	6	12		30	30	P+	F
606	Pigment volume 38.7%	69	77	72	71	57	37	44	19	24	36	F-	P+	63	75	68	57	43	32	39	20	6			28	30	P+	F
607	Pigment volume 43.0%	71	78	73	71	59	38	47	23	24	36	F-	P+	64	75	66	53	46	31	38	22	6			26	28	P+	F
608	Pigment volume 47.7%	71	79	75	72	58	37	44	17	24	26	P+	F	67	76	68	60	36	29	36	20	6			26	26	P+	F
	Titanium-barium pigment, zinc oxide, asbestine in linseed oil:																											
609	Pigment volume 29.0%	69	78	77	82	86	74	71	73	36	F	F	F+	53	75	72	74	80	68	63	73	6		30	36	F-	F-	F
610	Pigment volume 33.0%	68	78	77	80	85	74	76	84	P+	F	F	F+	63	73	71	72	79	66	63	63	6		30	P+	F-	F-	F
611	Pigment volume 38.7%	69	78	78	80	85	72	69	69	P+	P+	F	F	67	76	75	73	73	59	48	34	6		30	36	P+	F-	F
612	Pigment volume 43.0%	68	78	78	81	84	67	61	54	34	35	F	F	66	76	74	70	61	38	40	26	6		30	24	36	P+	F
613	Pigment volume 47.7%	70	79	78	80	85	68	59	48	36	35	36	P+	66	76	72	58	48	26	28	12	6		30	24	30	24	F
	White lead in Bakelite oil:																											
603	Pigment volume 24.6%	89	93	91	90	97	85	93	97	P+	G	G	G	87	90	88	79	95	81	89	**91**	12			P+	G	G	G
614	Pigment volume 29.0%	88	92	92	90	97	84	88	88	P+	G	G	G	87	91	89	88	96	82	88	88	12			30	G	F	G
615	Pigment volume 38.7%	88	93	91	90	97	82	86	84	30	G	G	G	87	91	87	84	87	56	55	40	12			24	F	P+	G
616	Pigment volume 47.7%	89	93	87	79	81	78	69	49	18	F	G	G	85	90	86	80	64	28	29	22	12			18	36	36	G

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Table 1 continued

Reference No.	Description of the primer for group B and of all three coats for group C	GROUP B -- Primer plus two coats of white lead paint												GROUP C -- Three coats of paint of the kind described														
		Average effectiveness ratings								Integrity				Average effectiveness ratings											Integrity			
		E_0	E_6	E_{12}	E_{18}	E_{24}	E_{30}	E_{36}	E^F_{end}	SP	DF	WP	RD	E_0	E_6	E_{12}	E_{18}	E_{24}	E_{30}	E_{36}	E^F_{end}				SP	DF	WP	RD
Series 700:																												
702	White lead in linseed oil	73	75	71	63	58	42	48	23	34	36	F-	F	72	73	69	63	53	35	37	2	6	12		27	30	F-	F
703	White lead in Bakelite oil	83	84	84	90	86	73	81	79	36	F	F	F	88	90	89	80	91	85	88	88	12			34	F	G	G
	Paints applied by spray gun:																											
704	No. 202 sprayed	75	75	71	61	55	38	52	29	36	36	F	F	68	71	66	64	52	30	41	14	6	12		30	36	F	F
705	No. 213 sprayed	78	81	74	75	61	44	58	38	24	24	24	24	73	79	75	64	73	60	50	27	6	24		24	P+	F	P+
706	No. 214 sprayed	76	80	69	76	55	40	46	16	24	24	24	24	72	74	79	58	78	69	68	64	6		30	24	F-	F-	F-
707	No. 104 sprayed	84	85	80	82	82	71	77	70	F-	F-	F-	F-	84	86	81	80	83	78	84	84				F	F	G	G
708	No 108 sprayed	88	89	87	82	89	78	73	58	F-	F-	F-	F-	85	87	82	84	84	77	87	89				F	F	G	G
709	No. 108 thinned and sprayed	87	88	84	84	84	71	69	51	F-	F-	F-	F-	86	89	86	80	86	80	87	88				F	F	G	G
710	No. 709 force dried	85	85	82	80	78	62	60	35	36	F-	F-	F-	84	86	80	78	80	74	80	76				F	F	G	G
711	No. 110 sprayed	85	87	80	79	75	64	67	49	F-	F-	P+	F-	83	84	83	74	82	79	82	81				F	F	G	G
712	No. 110 thinned and sprayed	85	83	75	65	66	57	58	31	F-	F-	F-	F	67	68	63	65	66	59	65	63				F	F	G	G
713	No. 712 force dried	84	84	74	58	66	54	60	36	F-	F-	F-	F	63	63	58	66	59	51	54	45				F	F	G	G
714	No. 112 sprayed	85	86	83	80	82	72	69	53	F-	F-	F-	F	85	86	83	79	84	80	88	91				F	F	G	G
715	No. 112 thinned and sprayed	86	86	84	70	81	70	69	52	F-	F-	F	F	77	77	71	78	72	60	73	69				F	F	G	G
716	No. 715 force dried	85	87	83	61	78	68	71	57	F-	F-	F-	F	65	69	63	77	64	57	61	57				F	F	G	G

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column 2 of Table 2. Specimens 316C, however, are notable exceptions in that the effectiveness of the coating over the unexposed backs fell from 60 to 26 during the 36 months of testing. This paint was litharge stirred in linseed oil without grinding in a paint mill and was imperfectly dispersed. Unlike most of the other paints the unexposed backs of the specimens at the end of the test were lacking in gloss. It seems probable that reaction between the litharge and linseed oil continued long after the paint dried and left a distinctly porous coating. The measured effectiveness of the coating after 36 months was 19; if that of the back was 26 the effectiveness of the face was 12. The data of Table 2, however, justify the assumption that the coatings of the practical exterior paints retained about the same effectiveness against moisture movement on the unexposed backs of the specimens throughout the test and that the changes in effectiveness of the coatings on the exposed faces were in general twice the changes recorded in Table 1.

Visual Inspections of the Exposed Paints

At each interval of 6 months during the exposure tests the coatings were inspected for chalking, checking, cracking, and integrity by the methods used by the Forest Products Laboratory (3) for ordinary exposure tests. The results are summarized in abbreviated form in Table 1. The term chalking has its usual significance. Checking refers to readily visible checking, the earlier stages in which a magnifying glass was necessary to see checking clearly are not recorded in Table 1. Cracking refers only to sigmoid cracking, which is not followed immediately by curling or flaking. Cracking followed immediately by curling and flaking is reflected promptly in the rating for integrity. The integrity of coatings is rated on a scale of good, good-, fair+, fair, fair-, poor+, poor, poor-, bad+, bad, and bad-. When the rating reaches poor the coating is considered in need of repainting and durability is therefore defined as the age at which integrity is first rated poor. If between inspections the rating falls from one better than poor to one worse than poor the age at which poor was attained is calculated by linear interpolation. In Table 1 the data for integrity are summarized by recording either the durability or, if the integrity remained better than poor at the end of 36 months, the rating for integrity at age 36 months. Specimens removed from test before the last cycle though still rated better than poor in integrity are left blank under the integrity heading.

Chalking, checking, and sigmoid cracking depend on the nature of the coating, not on the nature of the wood, and therefore occurred simultaneously on the four woods.

Table 2.--Average effectiveness of unexposed backs of certain specimens determined at the conclusion of the weathering tests

Key to Symbols: E_0, initial effectiveness rating, which was the same for face and back. E^F_{A1}, effectiveness of aluminum paint applied to face at conclusion of exposure test, assumed to be 90. E^B_{36}, effectiveness of back of specimens at age 36 months.

Reference No.	E_0	$(E^B_{36} + E^F_{A1})/2$ determined	E^B_{36} calculated
202B	68	77	64
203B	79	85	80
204B	69	78	66
205B	72	80	70
206B	72	80	70
207B	73	80	70
208B	68	79	68
209B	68	78	66
210B	68	77	64
211B	68	77	64
212B	67	78	66
213B	72	78	66
214B	69	79	68
215B	70	79	68
216B	70	79	68
302C	69	80	70
315C	67	81	72
316C	60	58	26
602C	66	74	58
604C	62	71	52
605C	63	73	56
606C	63	74	58
607C	64	72	54
608C	67	71	52
611C	67	76	62
612C	66	72	54
613C	66	67	44
614C	87	89	88
615C	87	80	70
616C	85	63	36

Crumbling, curling, and flaking, however, usually develop much more rapidly on southern yellow pine and Douglas fir than on northern white pine and redwood. For that reason it is necessary to record the durabilities or final ratings in integrity separately for the four woods.

Changes in Effectiveness of Paints with Age

In general the effectiveness of paints against moisture movement increases during the first few months of exposure to the weather. Nearly all of the coatings tested were more effective at age 6 months than they were before exposure. Previous tests likewise reveal that tendency (2). Some paints remain near their maximum effectiveness for many months while others soon pass through the maximum and decrease steadily in effectiveness thereafter. The two control paints, white lead in linseed oil (X02) and white lead in Bakelite paint oil (X03), illustrate the two types. White lead in linseed oil declined steadily in effectiveness after its maximum at 6 months while white lead in Bakelite paint oil was almost as effective after 36 months as it was at the beginning. Chalking, checking, and cracking of paint coatings clearly determine which of these two types of behavior shall prevail but the significant feature of chalking and checking in this connection is not the age at which they first appear but the rate at which they penetrate through the coating.

Series 100 -- Aluminum Paints

As priming coats under white lead paint in place of conventional priming (group B) all of the aluminum paints improved both the initial and the maximum effectiveness during subsequent exposure that is characteristic of white lead paint when used for all three coats. From the point of view of protection this long maintenance of effectiveness is more important than increased initial effectiveness (12).

Aluminum in the paste form proved as effective as dry aluminum powder of standard varnish grade when substituted pound for pound in the same vehicles (compare 104 with 106 and 105 with 108). The paste aluminum, however, contained 40 percent mineral spirits and made paint equivalent in composition to a mixture of 1.07 lbs. (0.485 kg.) of dry aluminum per gal. (3.79 l.) of varnish of slightly lower content of non-volatile. Such mixtures made with dry aluminum (107 and 109) proved less effective than the paints made with 2 lbs. of dry powder or 2 lbs. of paste aluminum per gal. For equal effectiveness, therefore, less aluminum is required in the form of aluminum paste than in the form of dry powder of standard varnish grade. Subsequent tests not reported here indicate that dry powder of standard lining grade is likewise effective with lower proportions of aluminum than the coarser standard varnish grade.

Two vehicles, shellac plasticized with castor oil and a nitrocellulose lacquer, proved lacking in durability either as primers for white lead paint (group B) or as complete paints (group C). All the other vehicles tested made aluminum primers that greatly improved the maintenance of effectiveness throughout the life of white lead paint. From this point of view there was little basis for preference among the satisfactory vehicles; all left coatings that were more effective after 36 months than were many good paints initially (series 300, group C, for example). Among the satisfactory aluminum primers, however, some proved more successful than others in prolonging the life of the coating on southern yellow pine and Douglas fir. No. 111B, for example, made with ester gum varnish of 33-gal. length, was not entirely satisfactory in improving durability on southern yellow pine and Douglas fir although it was satisfactory in maintaining effectiveness. Nos. 114 and 115, made with linseed oil without resin, were very satisfactory from the point of view of durability but were not correspondingly superior to the other satisfactory aluminum primers in effectiveness against moisture movement. Raw linseed oil, of course, does not make an aluminum primer of proper consistency for good working properties but kettle bodied linseed oil makes a very satisfactory one.

As complete paint coatings (group C) all of the satisfactory aluminum paints proved outstandingly durable both in maintenance of integrity of the coatings on all woods and in maintenance of effectiveness against moisture movement.

Series 200 -- White Pigments in Linseed Oil

Except where otherwise indicated all paints made with granular pigments only throughout this study were mixed in such proportions that the priming-coat paint contained 19 percent total pigment, 58 percent nonvolatile vehicle, and 23 percent volatile thinner by volume; second-coat paint 29 percent total pigment, 45 percent nonvolatile vehicle, and 26 percent volatile thinner; and third-coat paint 27 percent total pigment, 69 percent nonvolatile vehicle, and 4 percent volatile thinner. Second-coat white lead paint for group B was mixed with 29 percent pigment, 41 percent linseed oil, and 30 percent volatile thinner.

As priming coats under white lead paint the white paints of series 200 did not alter significantly the initial or maximum effectiveness against moisture movement or the changes in effectiveness with age. All primers that contained zinc oxide, namely Nos. 205, 206, 207, 213, 214, 215, and 216, gave rise to conspicuous alligatoring of the top coats of white lead paint in place of the usual finely reticulated and inconspicuous checking normal for white lead paint. Similar alligatoring occurred throughout the tests wherever there was zinc oxide in a primer under white lead, for example, 412B, 413B, 705B, and 706B, and was severe enough to reduce the durability of the coatings to 24 months or less even on white pine and redwood. Over primers made with antimony oxide, titanium dioxide, titanium barium pigment, zinc sulfide, and lithopone (208 to 212, incl.) white lead paint checked in the normal inconspicuous manner and the coatings proved fully as durable as the control specimens with white lead paint for primer and top coats. Specimen 204 on which the primer was basic sulfate white lead developed alligatoring of the white lead top coats on group B and sigmoid cracking of the basic sulfate white lead paint on group C. It was therefore inferred that the pigment manufacturer, through an error, had supplied a basic sulfate white lead containing some zinc oxide. Analysis of a sample of the original supply of dry pigment revealed 6.8 percent zinc oxide by weight.

The effectiveness at 36 months was slightly higher than that at 30 months for most of the specimens of group B that survived until the 36 months period. This is an experimental error resulting from the fact that the 36 month period ended when the exposed specimens were at an unusually high moisture content because of a thaw following a heavy fall of snow. Two weeks in 65 percent relative humidity failed to establish equilibrium moisture content sufficiently closely and reduced the subsequent absorption in 97 percent relative humidity. The uncoated control panels, of course, were not subject to that error, which therefore operated to make the effectiveness seem higher than it actually was. All of the values for the 36 month period throughout the study are probably slightly too high but the error is greater for coatings of low effectiveness than for those of high effectiveness.

In group C of the 200 series where the same pigments were used in all three coats of paint the paints represent three different types of disintegration with age: (1) rapid chalking leading to early failure by erosion, (2) moderately rapid chalking followed by checking and eventually by crumbling, (3) slow chalking, sometimes followed by checking, but always followed eventually by cracking, curling, and flaking (8), though the type of cracking is not always sigmoid. The distinction between rapid and slow chalking refers to the rate at which chalking penetrates through the coating, not to the age at which it is first observable, which with most of the white paints was about age 6 months. To the first type belong paints 209 to 212, made respectively with titanium dioxide, titanium-barium pigment, zinc sulfide, and lithopone. These paints showed very material loss of effectiveness as early as age 12 months and within two years the coatings became too thin to hide the surface of the wood, failure taking place about as rapidly on white pine and redwood as on southern pine and Douglas fir. To the second type belongs paint 202, made with basic carbonate white lead. The effectiveness declined from the maximum at 6 months at first slowly, then more rapidly and crumbling developed more rapidly on southern pine and Douglas fir than on white pine and redwood. Pure basic sulfate white lead probably belongs in this class but the presence of zinc oxide in the sample for paint 204 caused it to develop sigmoid cracking instead of checking. To the third type belong paints 205, 207, and 213 to 216, which contain zinc oxide alone or in admixture with other pigments. The effectiveness of these paints varied with age between the course exhibited by basic carbonate white lead and the course exhibited by paint 214, which changed little if at all in effectiveness between ages 6 and 24 months and was still high in effectiveness and intact on all woods after 36 months. The facts that chalking, though clearly evident at 6 months, penetrated the coating very slowly, checking remained entirely absent, and sigmoid cracking was delayed to the 30th month account for the long retention of effectiveness by this paint. Paint 208, made with antimony oxide, did not proceed far enough in deterioration during the 36 months for definite classification. It probably resembles white lead paint but chalking and checking proceed less rapidly. Microscopic checking appeared at age 30 months and was not yet visible without magnification at 36 months.

In initial and maximum effectiveness all of the paints that contained either white lead or zinc oxide were superior to any of the paints that contained neither white lead nor zinc oxide. The difference is too small to be significant as far as protection of wood is concerned but is of interest in connection with the theory of the action of pigments in paints.

Series 300 -- Colored Pigments in Linseed Oil

As primers under white lead paint the colored pigment paints except red lead and litharge proved slightly superior to any of the white priming paints of series 200 but inferior to the satisfactory aluminum primers of series 100 in their effect on maintenance of effectiveness against moisture movement. The iron oxide pigments, lemon chrome yellow, Prussian blue, and graphite likewise improved the integrity of the coatings on southern yellow pine and Douglas fir but they were not quite so satisfactory in that respect as the summarized data of Table 1 indicate because in most cases the checking pattern of the coating was coarser and more conspicuous by reason of the color showing through it although it was not coarse enough to be classified as alligatoring.

As complete paint coatings the colored pigment paints except red lead proved lower in initial and maximum effectiveness than the paints of series 200 that contained white lead or zinc oxide and approximately equal to the white paints containing neither white lead nor zinc oxide. Red lead increased in effectiveness up to the 18th month, after which its effectiveness decreased rapidly. The litharge paint rapidly lost effectiveness after age 6 months; as already pointed out the unexposed backs as well as the faces became ineffective by the end of the test. The two chrome yellow paints remained as effective after 36 months as they were initially. The other colored pigment paints followed a course of change in effectiveness similar to that of white lead paint but at somewhat slower rates so that, while less effective than white lead paint at the beginning they were as effective or a little more effective at the end of 36 months. In maintenance of the integrity of the coatings all of the colored pigment paints except red lead paint were more durable than any of the white paints of series 200 except Nos. 208 and 214, neither of which had yet reached the end of its life. On the whole the colored pigment paints took longer to develop chalking than did the white paints. The colored pigment paints, except red lead and litharge paints, developed neither checking nor sigmoid cracking during the test.

Series 400 -- Transparent Pigments in Linseed Oil

As primers under white lead paint the transparent pigment paints, Nos. 404 to 409, part B, proved very similar to each other and to the white paints of series 200 that contained no zinc oxide, such as Nos. 208 to 212. Checking of the white lead paint over the transparent pigment primers followed the normal inconspicuous pattern. Up to age 30 months, when these specimens were removed from test, the coatings maintained their integrity about as well as the coatings based on white primers free from zinc oxide.

The complete paint coatings with transparent pigments, group C, looked more like varnishes than paints when freshly applied but chalking set in within 6 months and penetrated rapidly, after which the coatings turned white and had fairly good hiding power. No. 409, made with English chalk, developed checking within 18 months. None of the others developed checking and none sigmoid cracking. The course of the changes in effectiveness and the durability were very similar to those of the rapidly chalking white paints, Nos. 209 to 212, part C.

Series 400 -- Aluminum and Granular Pigments in Linseed Oil

As primers under white lead paint, No. 411, which contained red lead, and Nos. 412 and 413, which contained zinc oxide, led to early failure both in integrity and in effectiveness. The other primers of this group, in which aluminum powder was mixed with white lead, iron oxide, or asbestine, proved very satisfactory in maintenance of both effectiveness and integrity of the coatings. In each case the addition of aluminum powder made the primer more satisfactory than the corresponding primers made with the granular pigments without the aluminum. In group C where the paints were used for all three coats the admixture of aluminum improved the effectiveness, the maintenance of effectiveness, and the durability.

Series 500 -- Vehicles

As primers under white lead paint none of the clear vehicles, Nos. 512 to 516, exhibited any advantage either in effectiveness or in durability. As complete coatings they were all much less durable than good paints. Linseed oil and 75-gal. ester gum varnish were low in effectiveness from the beginning. The 33-gal. ester gum varnish, Bakelite resin paint oil, and Bakelite resin varnish were fairly effective initially, increasingly so in the order named, but they all lost effectiveness much more rapidly than good paints.

As vehicles for white lead pigment either for the priming coat only or for all three coats, neither of the ester gum varnishes proved as satisfactory as linseed oil. The Bakelite resin paint oil with white lead, however, made a priming paint that compared favorably with good aluminum priming paints (series 100B) and a three-coat paint of high initial effectiveness, excellent maintenance of effectiveness, and good durability. Both chalking and checking were retarded by substituting the Bakelite paint oil for linseed oil but the paint failed by cracking and flaking rather than by crumbling.

The Bakelite paint oil was a poorer vehicle than the ester gum varnishes for iron oxide primers to be used under white lead paint, at least from the point of view of maintaining effectiveness. With iron oxide for pigment the ester gum varnishes made distinctly better primers than they did with either white lead or asbestine for pigment but with Bakelite paint oil iron oxide made a less satisfactory primer than was obtained with either white lead or asbestine.

As vehicles for all three coats of paint the Bakelite paint oil was superior on the whole to either of the ester gum varnishes when pigmented with white lead, iron oxide, or asbestine. The 75-gal. ester gum varnish was more satisfactory than the 33-gal. varnish when pigmented with white lead or iron oxide but not when pigmented with asbestine. Although all three paints made with asbestine were comparatively short-lived (and were transparent), in each case they were more effective and more durable than the corresponding clear vehicles without pigmentation.

Series 600 -- Varying Pigment Volume

In the 600 series the paints in both group B and group C have the same kind of pigment in all three coats but on group B the second and third coats have pigment volumes of 38.8 and 28.0 percent, respectively, while in group C they have the same pigment volumes as the priming coats. Pigment volume is defined as the proportion of pigment by volume in the nonvolatile part of the paint. The experiments cover the range from moderate to high pigment volumes for gloss paints. Commercial paints often have lower pigment volumes than any of the paints tested.

The experiments on pigment volume are not extensive enough to justify too detailed discussion. It appears, however, that there is a fairly wide range of pigment volume within which the effectiveness and maintenance of effectiveness do not vary greatly but that the extremely high pigment volumes lead to earlier loss of effectiveness and reduced durability. Even the unexposed backs of the coatings of pigment volume 38.7 percent and higher lost effectiveness seriously by the end of 36 months, as shown in Table 2.

Series 700 -- Spray Application

Comparison of the results of application by spray gun with the results of brush application of similar paints in other series reveals no significant differences attributable to the method of application. Addition of extra volatile thinner to aluminum primer or paints before spraying seems to be detrimental to the maintenance of effectiveness. Such thinning has been common practice in spray application of aluminum primers but there seems to be no good reason for it inasmuch as aluminum paint without such thinning is particularly easy to apply with good spraying equipment. Forced drying is likewise frequently practiced in mill priming. In these tests the results with forced drying are not consistent enough to justify conclusions on the subject.

Comparison with Data of Edwards and Wray

Edwards and Wray (13) recently published data on changes with age in the permeability of paints to moisture. They used a different technic for measuring the movement of moisture (18) and expressed their results in terms of the moisture impedance of the coatings, which is the reciprocal of the permeability in milligrams of moisture per square centimeter per hour. The method of calculating the effectiveness rating from the impedance or vice versa was described by Edwards (10). Seven paints tested by Edwards and Wray at New Kensington, Pa., resemble paints reported in this paper closely enough to permit comparisons.

In Table 3 the data reported by Edwards and Wray for 3 coats of paint on white pine are recalculated and expressed in terms of the effectiveness ratings. Below each paint selected, the writer's results with a similar paint are given, expressed in terms of the effectiveness of the exposed face only, assuming that the unexposed backs retained their initial effectiveness. For 5 of the 7 kinds of paint the results agree excellently. Paints usually deteriorate somewhat more rapidly at Madison, Wis., than at New Kensington, Pa. For two coatings, lithopone in linseed oil and unpigmented 50-gal. Bakelite varnish, the writer's results are lower than those of Edwards and Wray. Apparently the Bakelite varnish was much more durable at New Kensington than at Madison.

Maintenance of Effectiveness on Different Woods

The effectiveness recorded in Table 1 is the average of separate determinations on four woods. In general, paints behave in the same way on all woods during the early life of the coatings but once crumbling or flaking sets in the disintegration proceeds more rapidly on southern pine and Douglas fir than on white pine and redwood. Paints that fail rapidly by chalking, however, do so at nearly the same rate on all four woods.

In Table 4 the initial effectiveness and the calculated effectiveness of the exposed face of the specimens when last examined are given for each wood separately in the cases of sixteen coatings selected for illustration. Eight of the coatings exhibited little or no difference in behavior on the four woods as judged by visual inspection while eight failed in integrity much more rapidly on some woods than on others. Of the first group of eight coatings, six coatings were exceedingly durable and remained fair or good in integrity on all woods after 36 months

Table 3.--Comparison of certain paints with results reported by Edwards and Wray.

Key to Symbols: E_0, E_6^F, etc., effectiveness rating for the exposed face of the coatings at the age indicated by the subscript.

Description of paint	Effectiveness ratings E_0	E_6^F	E_{12}^F	E_{18}^F	E_{24}^F	E_{36}^F
Aluminum powder in 80-gal. ester gum varnish	95	97	96	96	--	--
No. 110 in Table 1	90	96	84	84	84	76
Aluminum powder in glyceryl-phthalate varnish	97	98	97	97	98	97
No. 112 in Table 1	93	97	85	85	89	79
Aluminum powder in 50-gal. Bakelite varnish	97	98	97	97	98	98
No. 108 in Table 1	95	97	87	87	89	85
White lead and zinc oxide in linseed oil	86	87	90	83	83	48
No. 213 in Table 1	74	90	86	82	66	28
Lithopone in linseed oil	83	89	82	65	--	--
No. 212 in Table 1	55	55	39	23	21	--
Gray Bakelite enamel	88	93	89	87	--	--
No. 203 in Table 1	89	97	95	95	93	86
Clear 50-gal. Bakelite varnish	91	90	87	87	87	85
No. 513 in Table 1	73	65	45	41	--	--

Table 4.--Effectiveness of certain coatings on different woods before and after exposure and integrity ratings after exposure

Key to Symbols: E_0^F, initial effectiveness rating; E_{end}^F, effectiveness of exposed face at end of exposure test; SP, southern pine; DF, Douglas fir; WP, white pine; RD, redwood.

Reference No.	E_0^F				E_{end}^F				Integrity at end of test				Age at last inspection, months
	SP	DF	WP	RD	SP	DF	WP	RD	SP	DF	WP	RD	
Coatings remaining approximately equal in integrity on all woods at last inspection:													
104C	94	92	93	88	86	72	81	86	Good	Good	Good	Good	36
105C	96	93	93	93	86	77	81	85	Fair-	Good	Good	Good	36
115C	93	87	89	81	79	65	85	57	Good	Good	Good	Good	36
208C	74	62	64	72	44	22	52	46	Good-	Good-	Good	Good	36
214C	73	64	66	74	59	58	40	64	Fair+	Fair+	Fair+	Fair+	36
304C	66	49	58	42	48	19	42	36	Good	Good	Good	Good	36
209C	66	57	56	68	18	17	-4	34	Bad	Bad	Poor	Poor-	24
213B	75	73	72	64	-3	3	6	22	Bad-	Bad	Poor	Poor	30
Av.	80	72	74	73	52	42	48	54					
Coatings showing marked differences in integrity on the four woods at last inspection:													
203C	91	86	89	90	75	90	91	90	Poor	Good-	Good	Good	36
202C	76	65	71	76	20	9	31	46	Bad	Bad+	Fair	Fair	36
207C	79	68	73	76	3	26	9	40	Bad-	Poor+	Poor+	Fair	36
213C	77	69	71	78	13	29	27	48	Bad	Fair	Poor	Fair	36
111B	92	90	90	90	16	44	82	60	Bad	Bad	Fair	Fair	36
216C	74	69	70	76	-4	17	20	34	Bad	Poor	Poor+	Fair-	36
315C	76	58	69	56	24	20	20	24	Bad	Poor	Fair-	Fair-	36
513C	81	60	72	70	23	46	70	40	Bad	Poor	Fair	Fair	18
Av.	81	71	76	76	21	35	42	48					

while two coatings failed rapidly on all woods, No. 209C by rapid chalking and No. 213B by conspicuous alligatoring. The second group of eight coatings includes six of average durability, one (No. 203C) of great durability but failing on southern pine within 36 months, and one (No. 513C) a durable varnish but low in durability as compared with paints.

The variations in initial effectiveness of coatings on the different woods are due principally to differences in the rate of absorption of moisture by the uncoated control specimens and to practical difficulties in applying the coatings in exactly the same thickness on all woods. All coatings except No. 203C were less effective at the end of the exposure test than they were initially and No. 203C had less than its initial effectiveness on southern pine. Among the coatings showing little difference in integrity on the four woods at the end of the test there is, as a rule, no striking contrast in final effectiveness on southern pine and Douglas fir as compared with white pine and redwood. For the group as a whole the average final effectiveness on southern pine and Douglas fir is 52 and 42 and on white pine and redwood 48 and 54, respectively. For coatings 209C and 213B, which failed early on all woods, the final effectiveness seems to be higher on redwood than on the other woods, but to all practical purposes it is as low on white pine as it is on southern pine or Douglas fir. Of coatings 304C and 104C, both of which retained good integrity at 36 months, 304C was relatively low in effectiveness and 104C relatively high in effectiveness throughout the life.

Among the coatings showing marked difference in integrity on the four woods at the end of the test there is a fairly good parallel between final effectiveness ratings and final integrity on the four woods. Coating 203C failed in integrity and showed loss of effectiveness only on southern pine. Coating 202C failed in integrity on southern pine and Douglas fir and had less effectiveness on those woods than on the others. Coating 207C remained intact for 36 months on redwood only and retained moderate effectiveness on redwood only. For the group as a whole the average final effectiveness on southern pine and Douglas fir was 21 and 35 and on white pine and redwood 42 and 48, respectively. Coating 315C, however, was about equally ineffective on all woods at 36 months although still rated fair- in integrity on white pine and redwood and considered a failure in integrity on southern pine as early as 21 months. On the other hand coating 203C was rated 75 in effectiveness at 36 months although rated poor in integrity on southern pine.

For closer comparison of the changes in effectiveness during the life of coatings with the changes in integrity judged by visual inspection Table 5 records average results obtained with the two control paints in group C. These paints were white lead in linseed oil, No. X02, and white lead in Bakelite paint oil, No. X03, the former a paint of fairly high initial effectiveness steadily decreasing after passing its maximum and the latter a paint of very high and long-maintained effectiveness. Each paint was applied to 7 specimens of each wood, one specimen in each of the 7 series of tests. The values recorded in Table 5 are averages for these 7 specimens in each case.

At age 12 months coatings of X02 on all woods were approximately equal in effectiveness and as effective as they had been initially. They were chalking markedly and were checking enough to be seen without a magnifying glass. At 18 months they appeared much the same to visual inspection but on southern pine and Douglas fir the effectiveness was slightly lower than its initial value. At 24 months, decrease in effectiveness on southern pine and Douglas fir was definitely more serious than on white pine and redwood, though to visual inspection the coatings remained intact on all four woods. At 30 months the effectiveness was very low on all four woods, though lowest on southern pine and Douglas fir, and failure in integrity was clearly visible on southern pine and Douglas fir though the coatings remained intact on white pine and redwood even at 36 months. It seems safe to conclude that paints of this type fail as protective coatings before they fail visibly in integrity. It is also clear that such paints on woods that hold paint well may remain intact to visual inspection for a long time after they have failed in protection, a conclusion drawn by the writer as early as 1926 from observations of wood checking and other signs of wood weathering in painted panels on which the coatings were still considered intact (1).

Paint X03 presents a different picture. Chalking was first observed at 12 months, microscopic checking at 18 months. The checking remained microscopic even after 36 months. On southern pine slight cracking and flaking on most specimens at 24 months led to a rating of fair in integrity which was not yet paralleled by any loss in effectiveness but did appear as loss of effectiveness at 30 and 36 months, by the end of which time the integrity was rated poor on most specimens. On Douglas fir slight flaking was evident in the integrity ratings at 30 and 36 months but the effectiveness remained practically as high as it was initially. On white pine and redwood the integrity remained good and the

Table 5.--Effectiveness and integrity ratings for two paints on four woods at each interval of 6 months during the tests.

Key to symbols: E_0, initial effectiveness rating; E_6^F, E_{12}^F etc., effectiveness of exposed face at 6, 12, etc. months; X02C, average of specimens numbered 102C, 202C, etc. to 702C; SP, southern pine; DF, Douglas fir; WP, white pine; RD, redwood.

Reference No.	E_0	E_6^F	E_{12}^F	E_{18}^F	E_{24}^F	E_{30}^F	E_{36}^F
X02C							
SP	76	86	76	66	42	-2	8
DF	63	85	71	61	47	9	17
WP	71	83	77	77	63	23	23
RD	65	83	75	65	59	21	35
X03C							
SP	91	95	91	87	93	59	65
DF	87	93	89	93	93	85	87
WP	89	93	91	93	95	85	87
RD	87	93	91	91	93	85	87

Reference No.	Integrity determined by visual inspection						
	0 months	6 months	12 months	18 months	24 months	30 months	36 months
X02C							
SP	Glossy	Chalking	Checking	Fair	Fair-	Poor-	Bad
DF				Fair	Fair	Poor	Bad
WP				Fair	Fair	Fair	Fair
RD				Fair	Fair	Fair	Fair
X03C							
SP	Glossy	Flat	Chalking	Micro-scopic checking	Fair	Fair-	Poor
DF					Good	Fair+	Fair
WP					Good	Good	Good
RD					Good	Good	Good

effectiveness retained its initial value at 36 months. Coatings of this type, therefore, do not exhibit loss of effectiveness until break-up of the coating is clearly evident to visual inspection.

Effectiveness as a Technical Measure of Paint Durability

Measurement of the changes in effectiveness against moisture movement during the aging of paint coatings might prove useful as a basis for an arbitrary definition of paint durability for strictly technical purposes. Durability might be defined, for example, as the age of the coating at which its effectiveness falls to 50 percent of its initial value. Such a definition would give signigicance to a term that is now a meaningless catchword unless carefully defined in accordance with a standardized system of visual inspections and evaluation such as that in use by the Forest Products Laboratory (3). Even in the latter event measurement of durability by visual inspection rests upon personal judgments and the uncertainties inherent in subjective methods. Measurement of durability in terms of effectiveness against moisture movement would eliminate personal judgments entirely, substituting readings of the balance instead.

On the other hand durability defined in terms of effectiveness is not identical with durability as the user of house paint understands it. Paints, like white lead in linseed oil, that the average user considers durable for at least 4 or 5 years on white pine and redwood would be rated as durable for less than 3 years while paints like white lead in Bakelite paint oil would have to reach a very advanced stage of disintegration at which successful repainting is impossible before reaching the end of the technical life. Present methods of evaluating durability, however, suffer more or less from the same disadvantage because the technologist is prone to set the point of failure much earlier than does the practical user of paint.

Most of the common white paints lie between the extremes represented by white lead in linseed oil and white lead in Bakelite paint oil, that is, they retain effectiveness somewhat longer than white lead in linseed oil but become practically ineffective long before the coatings disintegrate badly on woods like white pine and redwood. The assumption often made by paint technologists that protection is satisfactory as long as integrity is satisfactory is unsound.

The fallacious assumption has survived so long because little or no effort was made to measure protection and in the common uses of house paint protection is of minor consequence anyway.

For special uses where protection by paint is really necessary paints should be chosen in accordance with their ability to retain effectiveness against moisture movement for a long time, as revealed by tests of the kind described in this paper. Paints exhibiting the effectiveness history of white lead in Bakelite paint oil possess the necessary quality but are subject to the disadvantage that the form of ultimate failure is very unsatisfactory from the point of view of repainting. Much the same effectiveness history is attained when the white paint is applied over a good aluminum primer but in that case the white paint, if wisely chosen, gradually wears thin enough to show the color of the aluminum beneath, revealing the need for repainting, at a time when the effectiveness of the coating is still fairly high.

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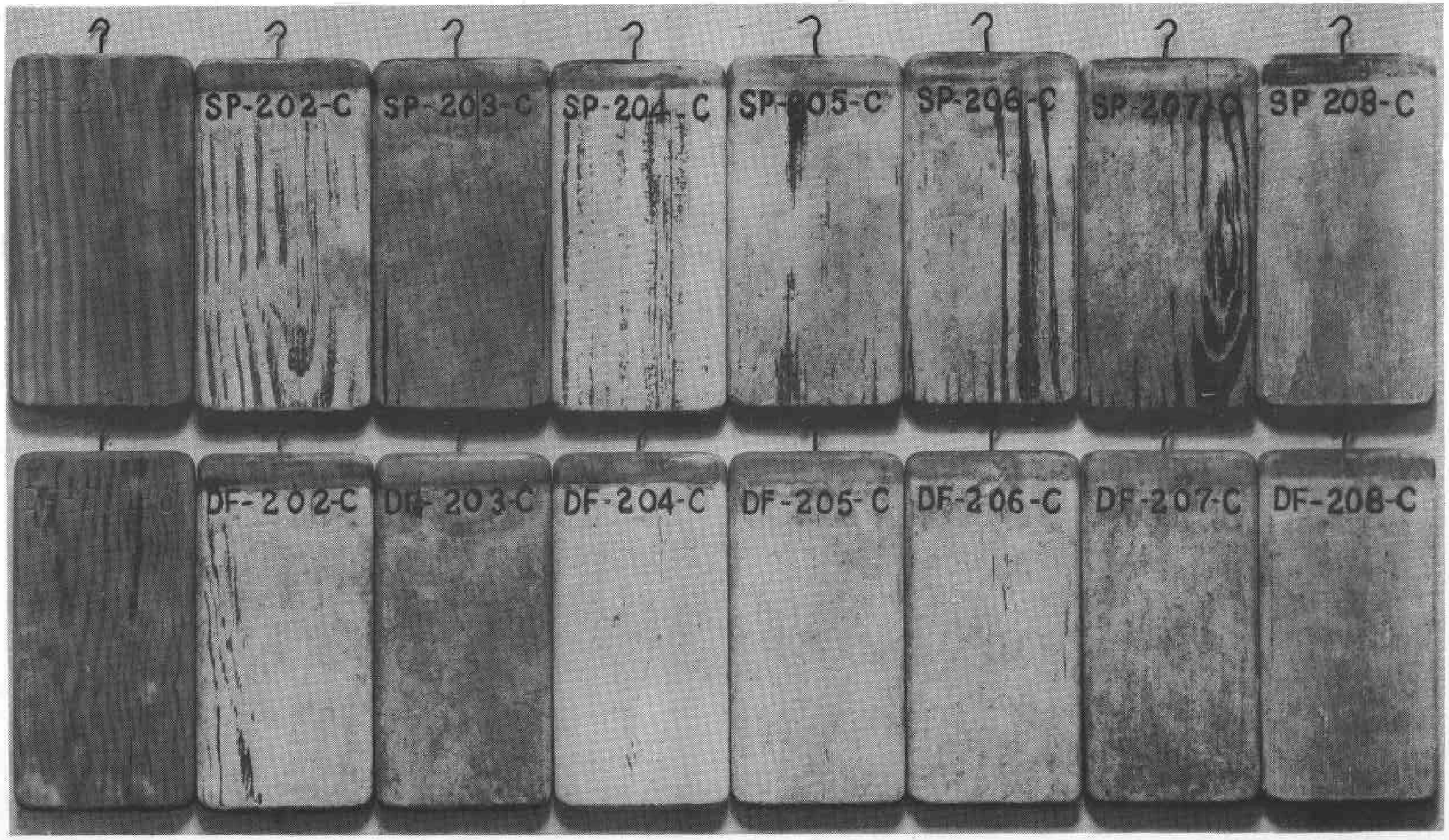
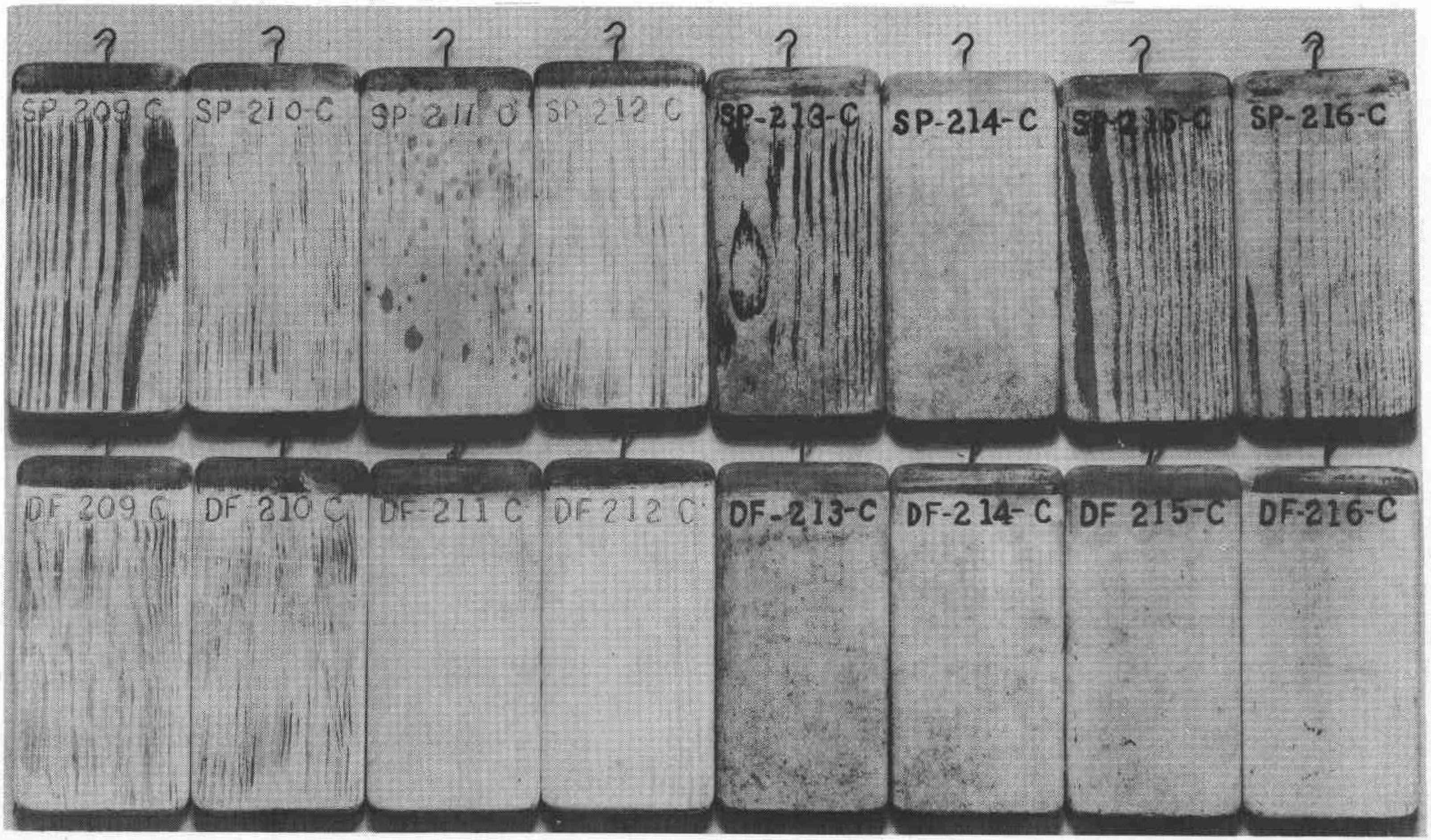


Series 200, group C, specimens 201 to 208 (in order left to right), after 36 months exposure. Top row southern yellow pine, bottom row Douglas fir. Specimens 201 at left are unpainted control specimens not exposed to weather.

Z M 27442 F



Series 200, group C, specimens 209 to 212 (in order left to right), after 24 months exposure, and specimens 213 to 216 after 36 months exposure. Top row southern yellow pine, bottom row Douglas fir.

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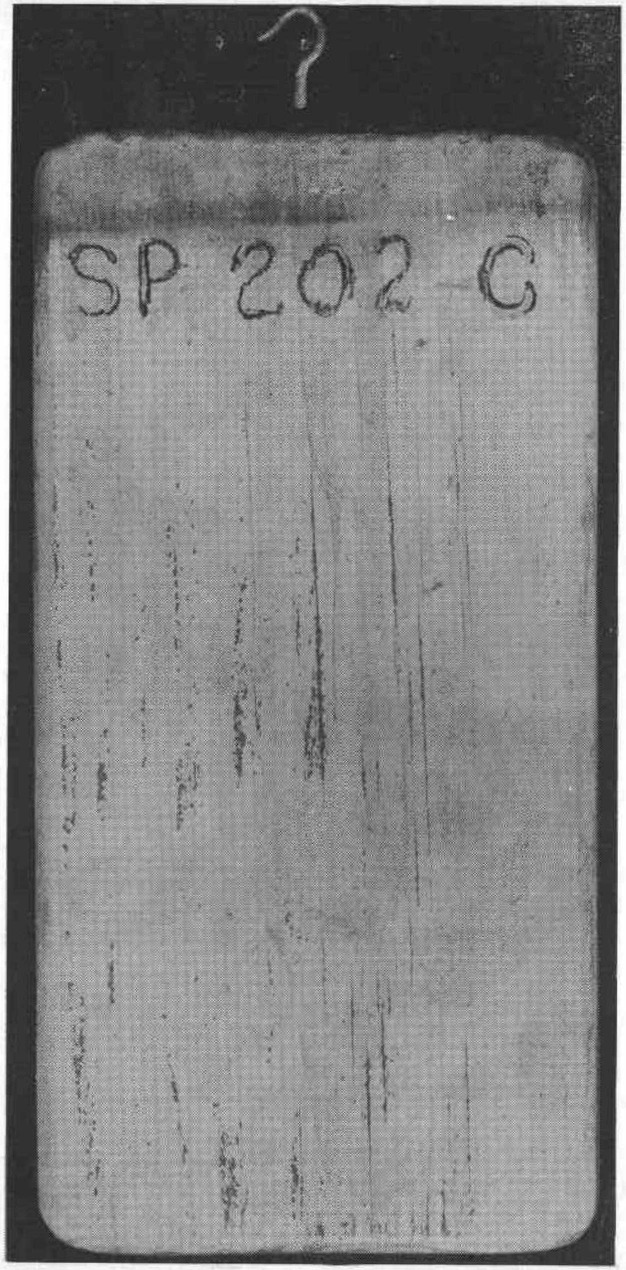
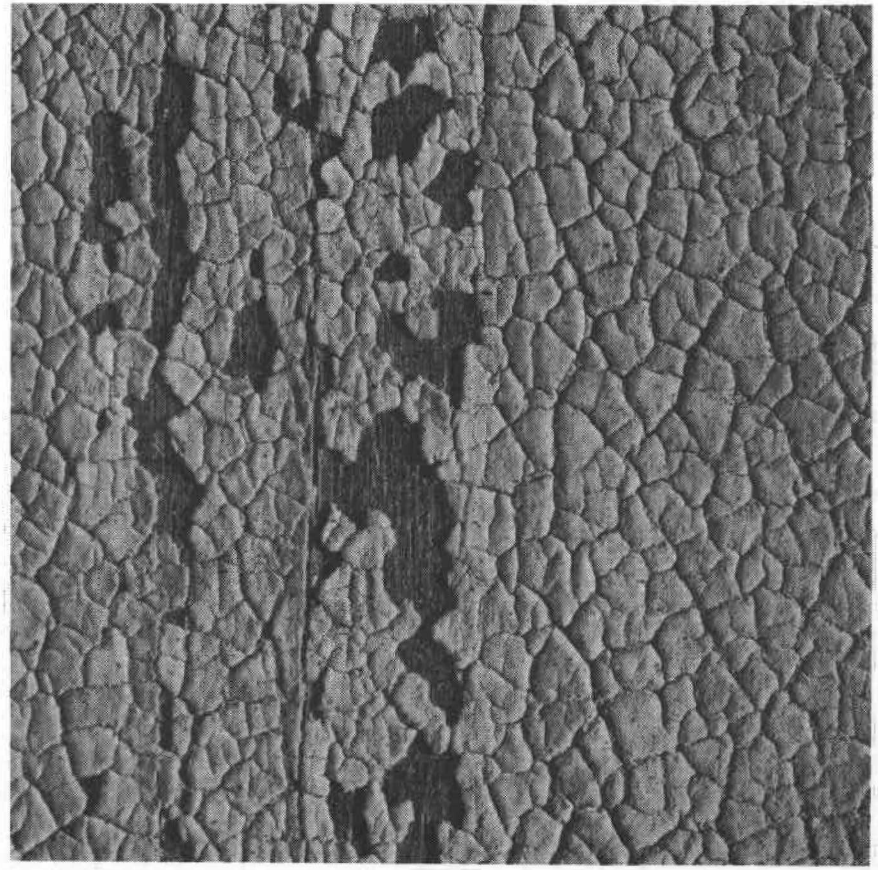
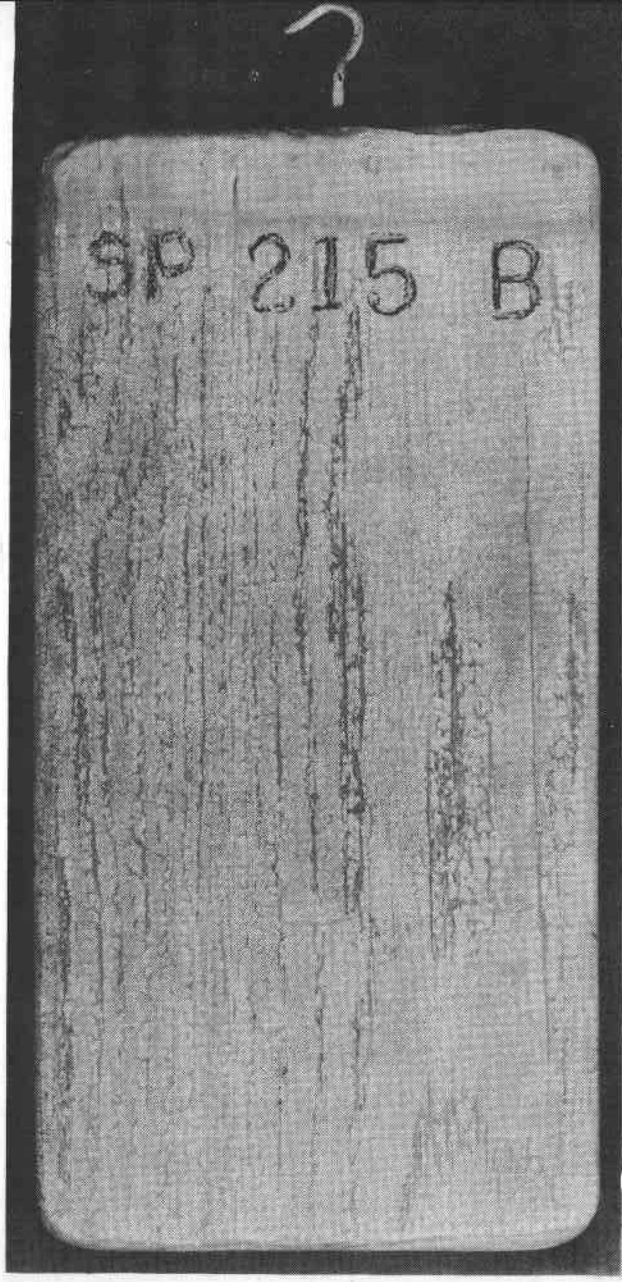
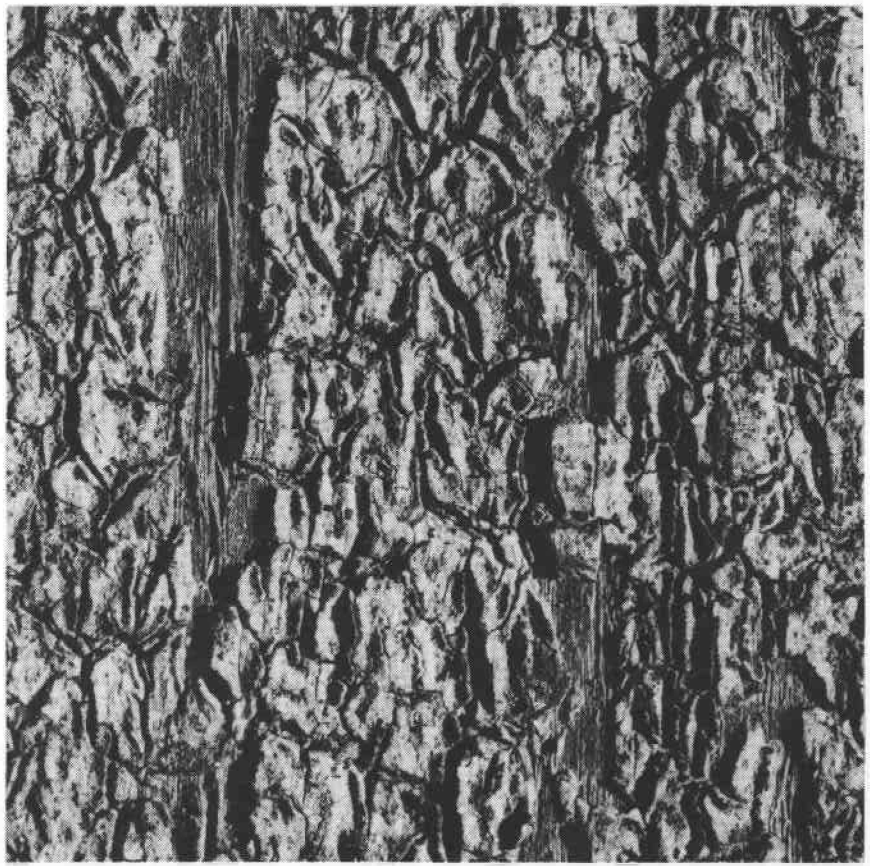




Specimen 202C, painted with 3 coats of white lead in linseed oil, after 24 months exposure. The specimen is 4 in. (10.1 cm.) wide. The magnified area is 3/8 in. (1 cm.) square, Typical of failure by checking and crumbling. Effectiveness 57.

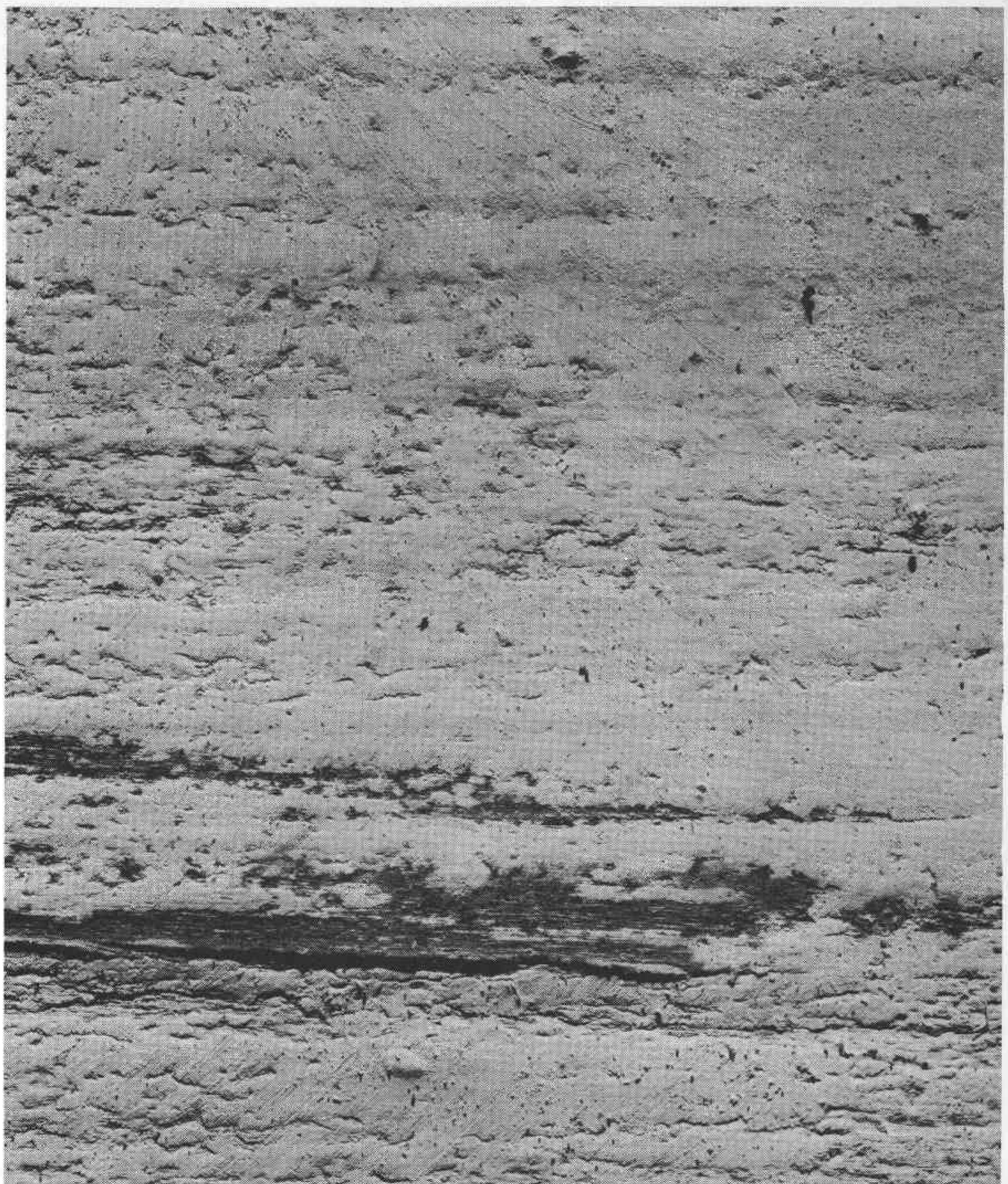
Z M 27797 F



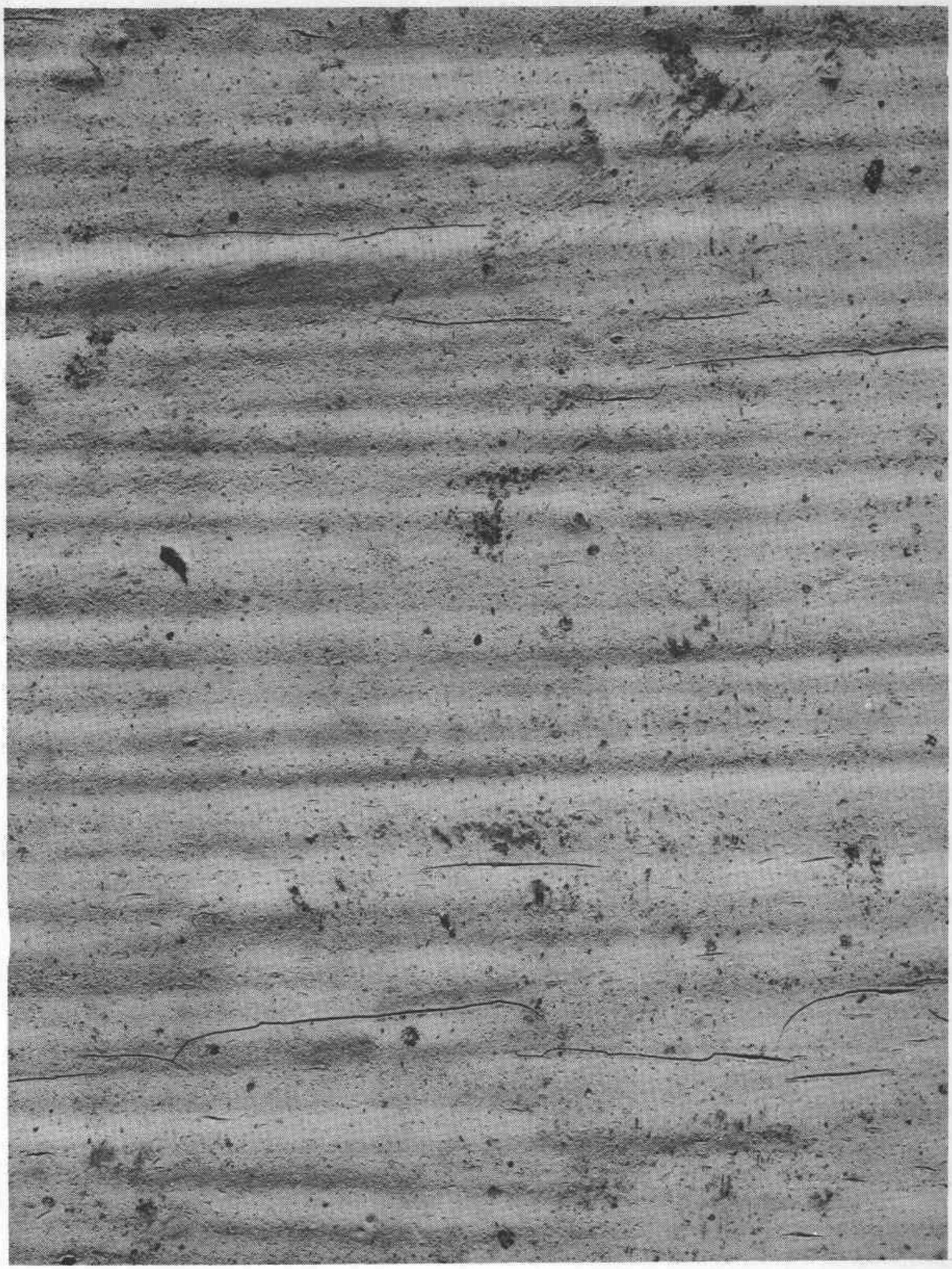


Specimen 215B, painted with a primer containing zinc oxide and lithopone followed by 2 coats of white lead paint, after 24 months exposure. The specimen is 4 in. (10.1 cm.) wide. The magnified area is 3/8 in. (1 cm.) square. Typical of failure by alligatoring. Effectiveness 34.

Z M 27798 F

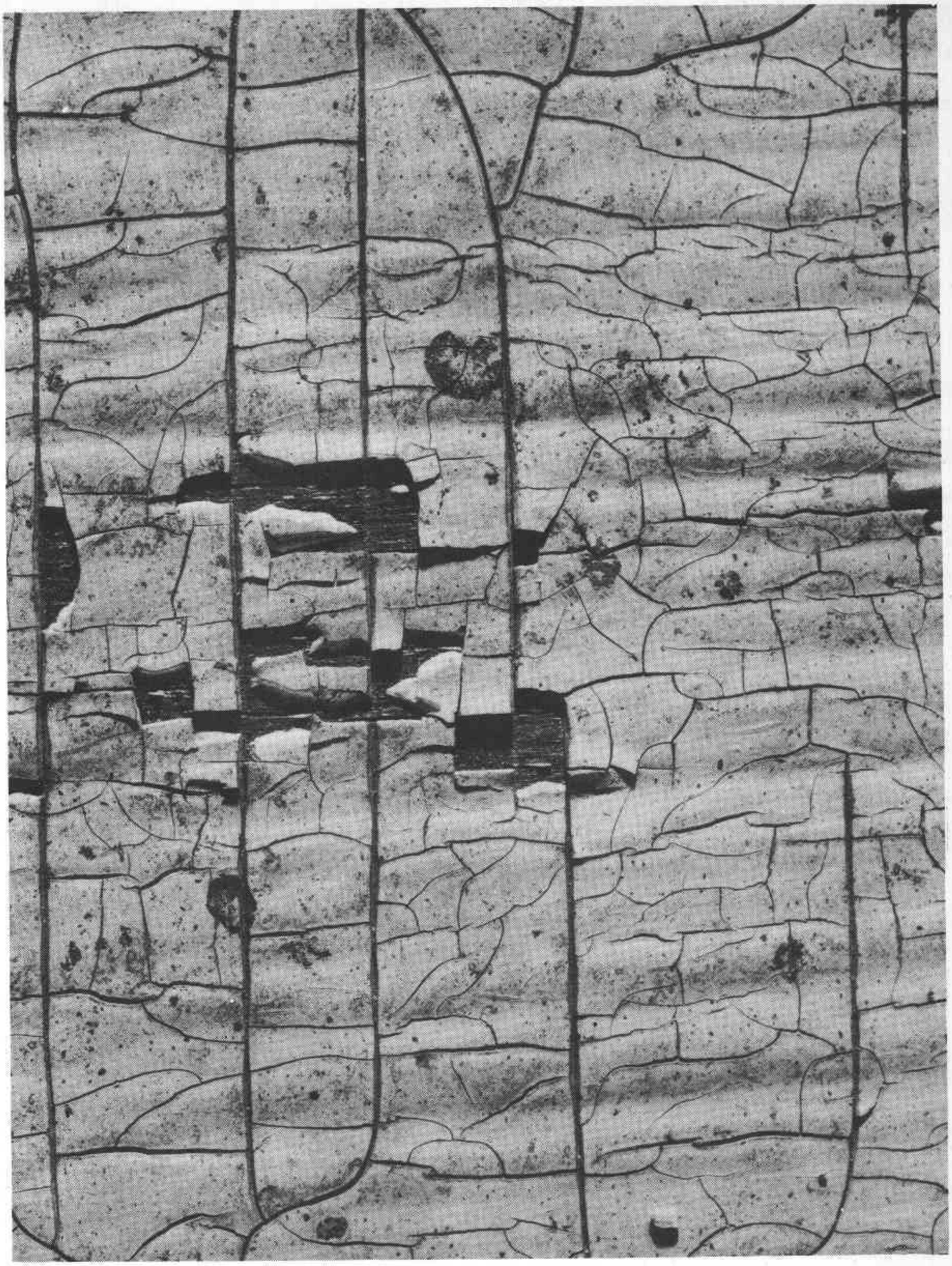


Specimen 210C, titanium-barium pigment in linseed oil, after 24 months exposure. Typical of failure by rapid chalking. Effectiveness 28.
Z M 26581 F



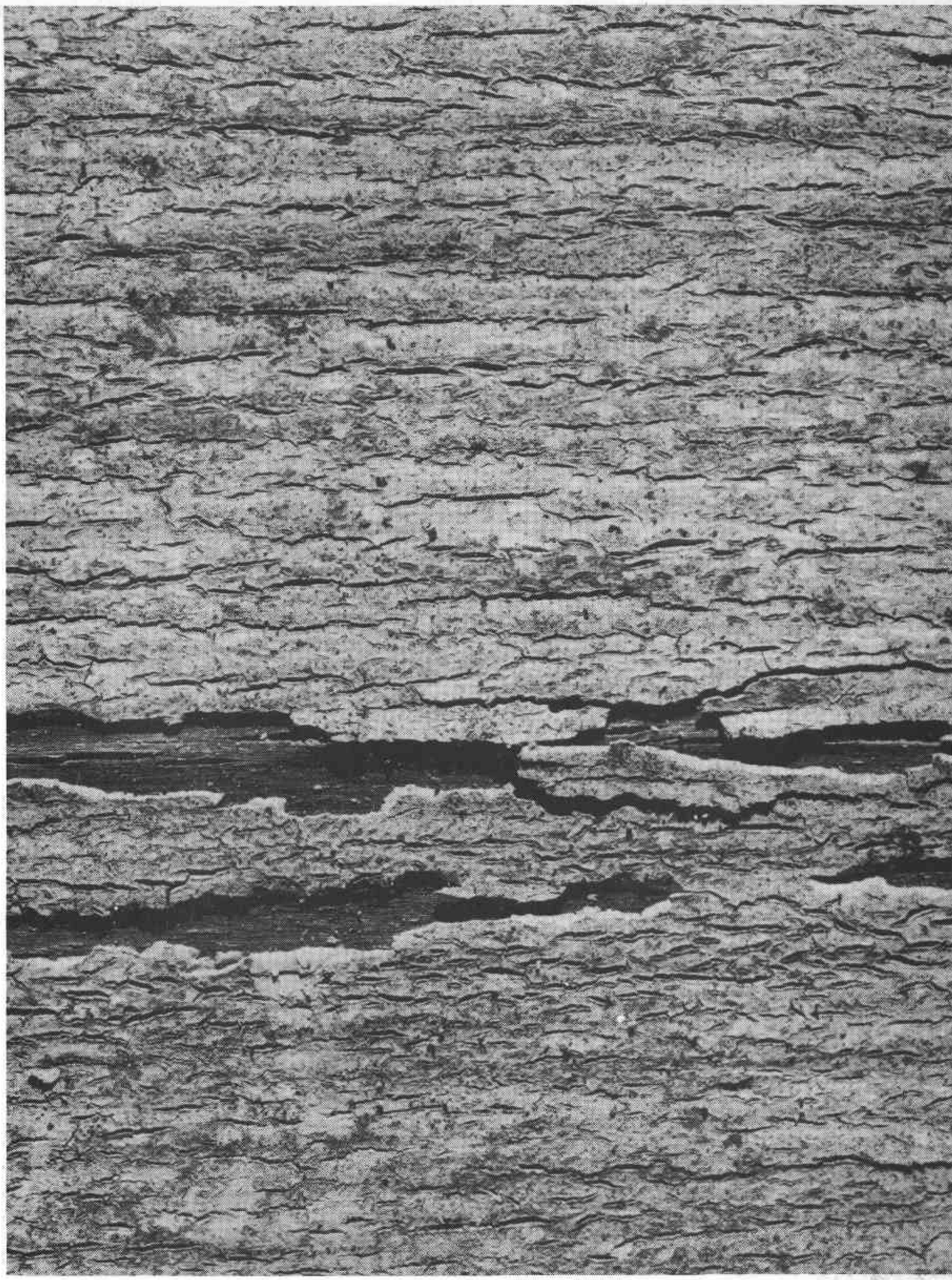
Specimen 214C, titanium-barium pigment, zinc oxide, and asbestine in linseed oil, after 24 months exposure. Typical of very durable white paint chalking slowly and with sigmoid cracking in early, still microscopic, stage. Effectiveness 92.

Z M 26585 F



Specimen 205C, leaded zinc oxide in linseed oil, after 24 months exposure. Typical of failure by conspicuous sigmoid cracking, curling and flaking. Effectiveness 60.

Z M 26576 F



Specimen 213C, white lead, zinc oxide, and asbestine in linseed oil, after 24 months exposure. Typical of failure by cracking, curling and flaking. Effectiveness 66.

Z M 26584 F