A STUDY OF HISTORIC PAINT COLORS AND THE EFFECTS OF ENVIRONMENTAL EXPOSURES ON THEIR COLORS AND THEIR PIGMENTS

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House paints differ from artist's paints in that they were often selected for their color popularity within a stylistic time frame as well as for their availability. Early reference to color names like "stone" or "pearl" have become obsolete and are difficult for the modern paint researcher to comprehend. Discoveries like an 1812 pamphlet published by Hezekiah Reynolds, a Connecticut house painter, and acquired by the American Antiquarian Society in 1977 provide "the earliest known American publication on house and ship painting compiled by a practicing New England craftsman and not based upon English printed sources."[1] The facsimile pamphlet entitled *Directions for House and Ship Painting* is accompanied by an introduction by Richard N. Candee which provides an interesting analysis of this unique find.[2] The pamphlet also puts forth one painter's perception of how historic colors like "stone" and "pearl" should be mixed.

Paint analysis has shown that pigments may vary in particle size, probably due to methods of mixing, and that they, along with their oil medium, may alter in color through years of different environmental exposures.[3] Unlike artist's pigments, house pigments may be exposed to a wider variety and intensity of environment.

With these factors in mind, the North Atlantic Historic Preservation Center, North Atlantic Region of the National Park Service, set up a project in which graduate students enrolled in Boston University's Preservation Studies Program could fulfill their summer internship requirements. The bulk of the study was conducted by two students during successive summers beginning in 1980, under the direction of E. Blaine Cliver, Chief of the North Atlantic Historic Preservation Center.

The two primary objectives of the study were: (1) to identify certain historic paint colors described in the pamphlet published by Hezekiah Reynolds in 1812, as well as other colors from historical recipes which postdate Reynolds' publication. The post-Reynolds recipes were chosen from a book by Arthur Seymour Jennings entitled *Paint and Colour Mixing*,[4] published in 1910; (2) to sample these paints and determine the effects of exposure to darkness over a long period of time (to which paint layers are frequently subjected by subsequent fresh paint); fading characteristics when exposed to near ultraviolet light; and resistance to exterior weathering. The data obtained from this study could yield a unique reference to historic paint color, texture, and hue, useful in the interpretation of the visual treatment of historic buildings, and also provide information concerning the changing characteristics of historic paint colors when exposed to different environments. These findings should be useful in providing a measuring stick for changes in historic house paints as well as identifying historic paints and determining the practicality of using similar paints in today's restorations.

Paint recipes were reviewed in both the Reynolds' and Jennings' publications and selected for color diversity and availability of stocked pigments in the Preservation Center's paint laboratory. It should be noted that although the paint lab is not as fully stocked as an historic paint shop might be, the supply still offers over fifty pigments and tints from which to choose.

Ten separate recipes were chosen from the Reynolds pamphlet, four of which were modified to produce variations of the original color. The end result was fourteen different samples originating from the 1812 publication, five exterior and nine interior samples. These will hereafter be referred to as follows:

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Reynolds' Exterior Color Descriptions	Code
Cream	RE 1
Straw	RE 2
Parrot Green — Ground in Oil	RE 3
Parrot Green — Ground Dry	RE 4
Pea Green — Ground in Oil	RE 5

Reynolds' Interior Color Descriptions	Code
Purple Color — Prussian Blue Color	RI 6
Purple Color — Prussian Blue Pigment	RI 7
Pearl Color	RI 8
Light Stone — Prussian Blue Hand Ground	RI 9
Light Stone — Prussian Blue Machine Ground	RI 10
Prussian Blue	RI 11
Navy Blue	RI 12
Dark Stone — Pigments Proportioned by Dry Measure	RI 13
Dark Stone — Pigments Proportioned in Liquid Measure	RI 14

Eighteen recipes were selected from the Jennings' book, one of which was modified to produce a single variation, therefore resulting in nineteen different samples from the 1910 publication. These will hereafter be referred to as follows:

Jennings' Color Descriptions	Code
Chocolate	J 15
Stone Blue — Over White Lead Base	J 16
Stone Blue — Minus White Lead Base	J 17
Cinnamon	J 18
Tan	J 19
Marine Blue	J 20
Stone	J 21
Brick	J 22
Red Terra Cotta	J 23
Terra Cotta	J 24
Buff	J 25
Chestnut	J 26
Bay	J 27
Coral Pink	J 28
Plum	J 29
Oriental Green	J 30
Olive Yellow	J 31
Persian Orange	J 32
Lemon	J 33

The paint machine employed by the Preservation Center was used to grind all pigments, regardless of the recipe origin. Its vintage coincides more directly to Jennings' publication, but as Reynolds' described method was more archaic and time-consuming, the decision was made to use the available equipment for Reynolds' recipes, even though they predate the machine.

Although the steps for paint mixing varied slightly from category to category, or among recipe modifications, a general procedure was followed. The individual pigments were first reduced to a proportion of the measure indicated by respective color recipes and placed in plastic containers. They were then placed on the glass plate of the paint machine, either individually or combined together according to the recipe, and finely ground. (In order to grind the pigments to a very fine consistency, it was necessary to remove one of the nuts attached to the screw protruding through the uppermost body of the paint machine. This allowed the screw to be tightened, creating greater pressure between the grinding wheel and the plate, yielding the necessary amount of friction to grind small quantities of pigments.) After grinding the pigments for approximately thirty seconds, they were removed from the machine, still sandwiched between the plate and grinding wheel. That portion of pigments which had escaped the grinding wheel on initial pressure of wheel to plate was collected and placed once again directly beneath the teeth of the wheel. The plate and wheel apparatus was then returned to the machine and the pigments ground again. If the second grinding did not produce uniformly ground pigments, the apparatus was returned to the machine for a third time to insure proper pigment dispersion.

Following the grinding process the pigments were once again placed in a plastic container. Boiled linseed oil was used as a vehicle for all color recipes and mixed with the pigments until a smooth, brushable consistency was obtained. The oil was not a controlled measure, but rather added gradually to produce a small quantity of paint with a good texture.

After a thorough mixing the paints were immediately sampled by brushing them onto wooden medical tongue depressors and index cards. Unless specifically stated in the color description, these applications were free from any undercoat or primer.

All pigments used to mix exterior paint colors from Reynolds' pamphlet were first dispensed in dry measure, combined in proportion, hand-stirred until a uniform mixture was obtained, ground dry, and then mixed with boiled linseed oil after the first sampling.

All interior colors from Reynolds' recipes contained pigments which were first proportioned dry, ground individually in their dry state, and then mixed with boiled linseed oil. After each pigment was mixed with oil it was combined in liquid proportions as indicated by the recipe, and the resulting color sampled. Variations of three of these colors were produced by three different methods: (1) two separate purple colors were mixed using the proportionate amount of Prussian Blue color in one, and Prussian blue pigment in the other; (2) the pigments in Light Stone were first ground by hand (in similar fashion to using a mortar and pestle), which produced a slightly lighter shade than when ground by machine; (3) Dark Stone was prepared by first combining and grinding its pigments in a dry state and then adding oil, which produced a lighter shade than the variation of combining and grinding the pigments in a liquid state.

Color recipes taken from Jennings' book were mixed by measuring proportioned dry pigments, placing them in plastic containers, and dispersing them dry through hand-stirring until a uniform mixture was obtained. The combined pigments were then ground dry, mixed with oil, and sampled.

Four sets of samples were compiled. An original set of thirty-three samples was matched to Munsell Color Notation System, and using a Bausch and Lomb Spectronic 20, spectrophotometric readings were taken of each sample to establish a permanent record for control

purposes. One set of samples, where the paint had been applied to index cards, was trimmed to one-inch squares and exposed to darkness for approximately eleven months. Another set of samples on tongue depressors was exposed to constant near ultraviolet light for approximately two months. The remaining sets of samples, also on tongue depressors, were exposed to weathering, one facing a northeast exposure, the other facing a southwest exposure, for approximately eleven months, attached to a building in the Charlestown Navy Yard, in Boston. Each altered set of samples was again color-matched to the Munsell Color Notation System as well as recorded spectrophotometrically to document changes in hue, value, and chroma. The spectrophotometric readings were computed on a Hewlett Packard 85 computer during the second summer of the study, and the coefficients then plotted on Munsell's color diagrams (prepared by: Color Research Laboratory, Agricultural Marketing Service, U.S.D.A., revised January 1964) to compare with color-matches for accuracy. Sections of Munsell color diagrams were extracted for individual color recipes in order to plot environmental color changes at a manageable presentation level. (Sets of full diagrams are available from Munsell Color, 2441 N. Calvert St., Baltimore, MD 21218.) Large differences in plotted colors from corresponding color-matches were rerun on the spectrophotometer.

The following section deals with the documentation of the Munsell Color Notations and spectrophotometric readings for each of the thirty-three colors sampled, and the changes which occurred in the individual colors when exposed to the four different environments. A clear understanding of the Munsell Color Notation System is required in order to comprehend the alterations in hue, value and chroma. The trichromatic coefficients derived from the spectrophotometer were plotted on the Munsell diagrams as a means of rechecking the accuracy of the spectrophotometer, and as a second reference for the color changes.

Since most spectrophotometric calculations will not exactly equal the value equivalent of an established diagram (Munsell provides nine diagrams each representing an established value ranging from whole numbers 1/ through 9/.), the nearest value diagram was selected to plot respective color coefficients in this study. When one color's value changed from one environmental exposure to another the dominant value of the color group, expressed in terms derived from the spectrophotometer readings, was selected for plotting so all of the color changes could be plotted on one diagram. This immediately may be construed as a flaw within the study, but it represents only one point of reference with the Munsell notations providing a second reference.

Another problem which developed was the inaccuracy of the spectrophotometric readings recorded from the control samples. These readings were not computed until the second summer of the study and were often found to be incorrect. Therefore, the plotting of the control samples on the sections of Munsell diagrams was derived from the Munsell notation rather than the spectrophotometric readings. The coordinates reflected on the following segments of Munsell diagrams are represented by: O for the original or control sample; D for the darkness sample; UV for the near ultraviolet light sample; NE for the weathered sample facing a northeast exposure; and SW for the weathered sample facing a southwest exposure.

It should also be noted that color perception is subjective according to the individual. Since two different people worked on the study, perception may have varied between the original control samples and those which were exposed to the different environments.

It is apparent from this study that some historic paint colors are more stable than others when exposed to darkness, near ultraviolet light, and weathering. By breaking down the changes in hue, value, and chroma within a color in all exposures, as measured by the Munsell notations, six groups of colors were established for stability-labeling purposes. These groups are, in descending order of stability:

1. Most Stable: Straw (RE 2), Dark Stone — Liquid Measure (RI 14), Marine Blue (J 20), Red Terra Cotta (J 23).

2. Very Stable: Cream (RE 1), Dark Stone — Dry Measure (RI 13), Terra Cotta (J 24), Bay (J 27).

3. Stable: Tan (J 19), Stone (J 21), Chestnut (J 26), Coral Pink (J 28), Olive Yellow (J 31), Persian Orange (J 32), Lemon (J 33).

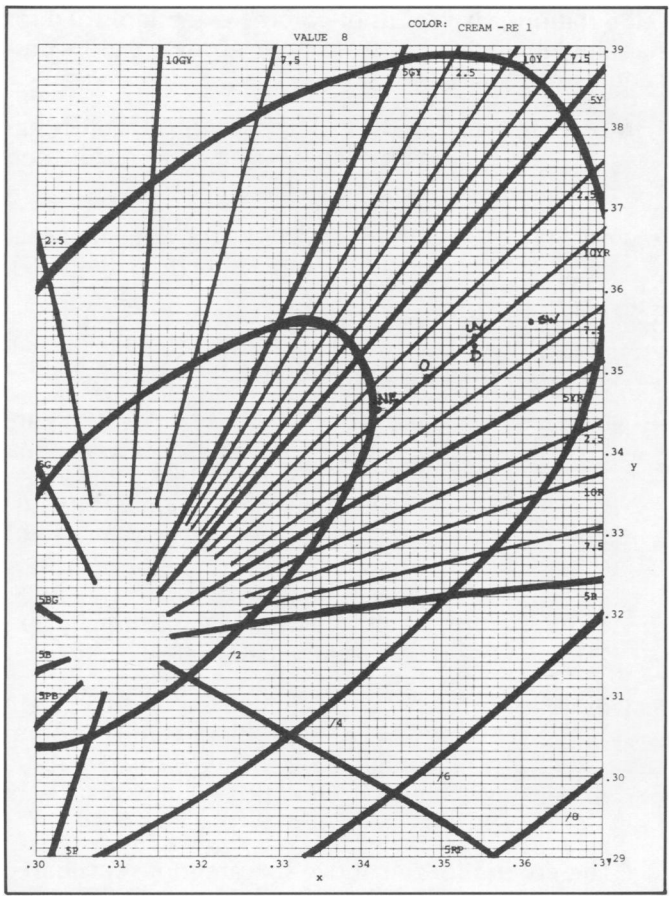
4. Moderately Stable: Parrot Green — Oil (RE 3), Parrot Green — Dry (RE 4), Pea Green — Oil (RE 5), Purple — Prussian Blue Pigment (RI 7), Stone Blue — Over White Lead Base (J 16), Stone Blue — Minus White Lead Base (J 17), Brick (J 22), Buff (J 25), Plum (J 29), Oriental Green (J 30).

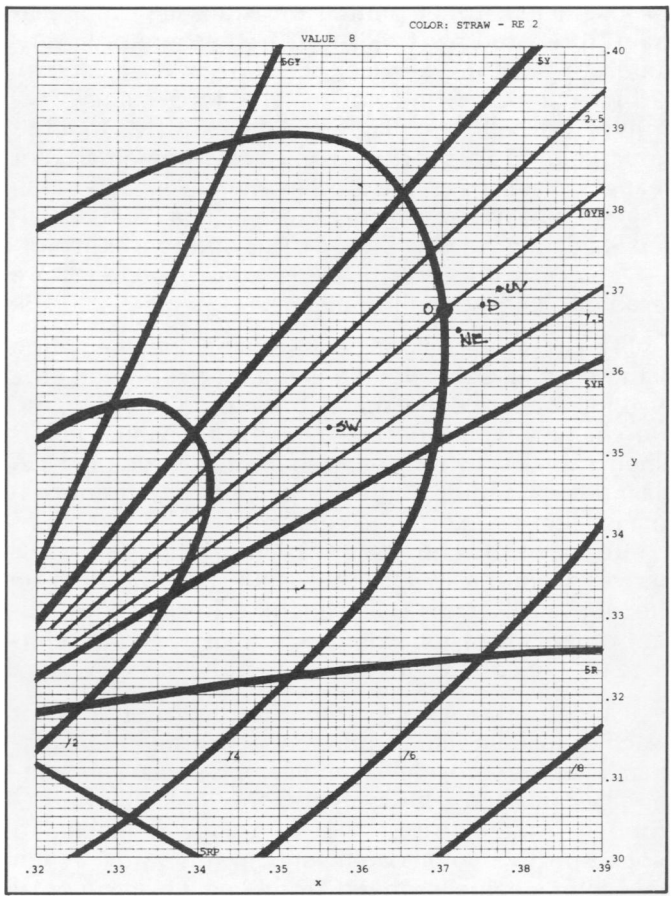
5. Unstable: Purple — Prussian Blue Color (RI 6), Light Stone — Prussian Blue Hand Ground (RI 9), Light Stone — Prussian Blue Machine Ground (RI 10), Prussian Blue (RI 11).

The criteria for the above six categories was based on the number of changes in hue, value, and chroma in all four exposures. (Refer to the individual data charts.) The most stable group had no changes or changes less than one step within all four exposures. The very stable group showed a combination of no or slight changes and no more than one step or slightly more than one step change. The third or stable group had no or slight changes and a combined total of two to slightly more than three step changes within a color. The fourth group exhibited no and slight changes, and a combined total of four to seven step changes, with no more than one two-step change in all four exposures. The fifth group, or moderately unstable group, had a combined total of seven to ten step changes. The least stable group, the only group to contain more than a two-step change within an individual category, had a total of 11 to more than 25 step changes.

CODE	COLOR	RECIPE
RE 1	Cream	1 Part Yellow Ochre 30 Parts White Lead

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Between 10YR 9/2 & 10YR 9/4	10 YR 8/2	Between 10YR 9/2 & 2.5Y 9/2	Slightly Darker Than 10YR 9/2	Slightly Lighter Than 10YR 8/4
TRICHROMATIC COEFFICIENTS		x = .354 y = .353 Y = 64.934	x = .354 y = .354 Y = 64.414	x = .342 y = .345 Y = 55.493	x = .361 y = .356 Y = 54.725



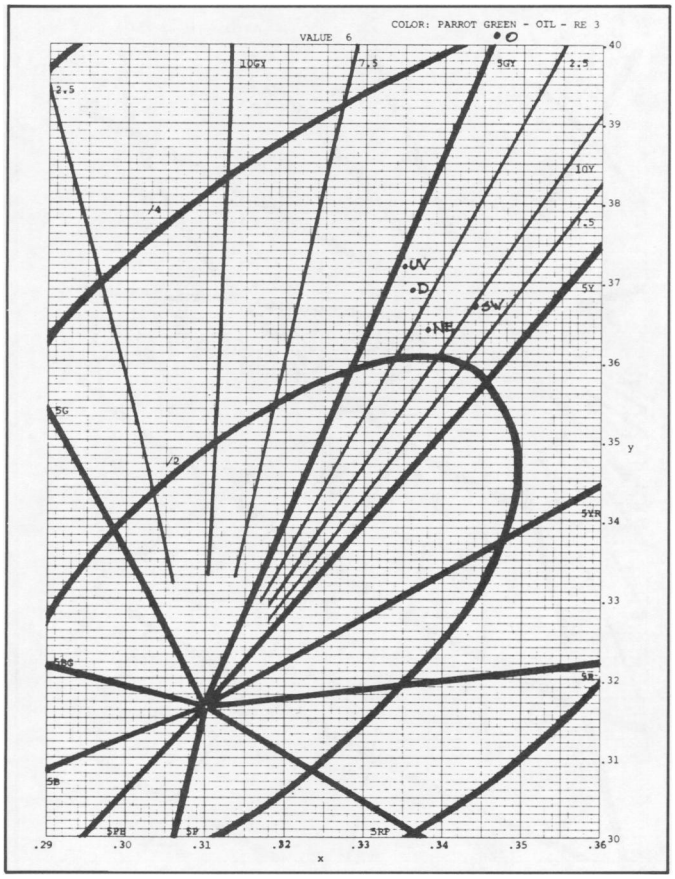


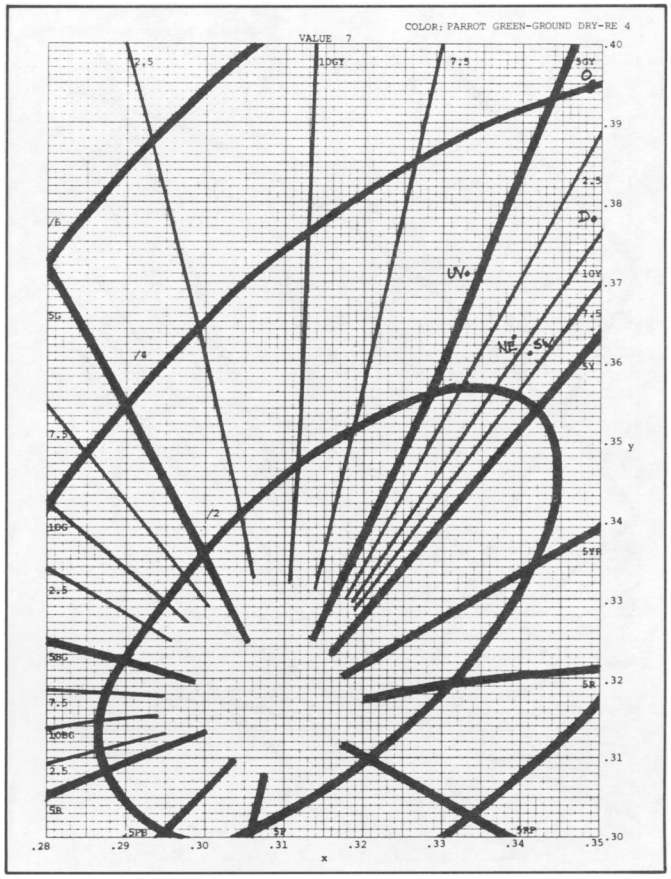
CODE	COLOR	RECIPE
RE 2	Straw	1 Part Yellow Ochre 10 Parts White Lead

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Slightly Darker Than 10YR 8/4	10 YR 8/4	10YR 8/4	10YR 8/4	Slightly Darker Than 10YR 8/4
TRICHROMATIC COEFFICIENTS		x = .375 y = .368 Y = 57.414	x = .377 y = .37 Y = 55.637	x = .372 y = .365 Y = 46.627	x = .356 y = .353 Y = 53.189

CODE	COLOR	RECIPE
RE 3	Parrot Green — Ground In Oil	5 Parts White Lead 1 Part Verdigris 1/4 Part Yellow Ochre

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Between 5GY 7/4 & 5GY 8/4	Between 7.5GY 7/4 & 7.5GY 6/4	Between 5GY 7/2 & 7.5GY 7/2	Slightly Darker Than 5GY 7/2	Between 2.5GY 7/2 & 2.5GY 6/2
TRICHROMATIC COEFFICIENTS		x = .336 y = .369 Y = 36.13	x = .335 y = .372 Y = 32.445	x = .338 y = .364 Y = 37.011	x = .344 y = .367 Y = 35.956



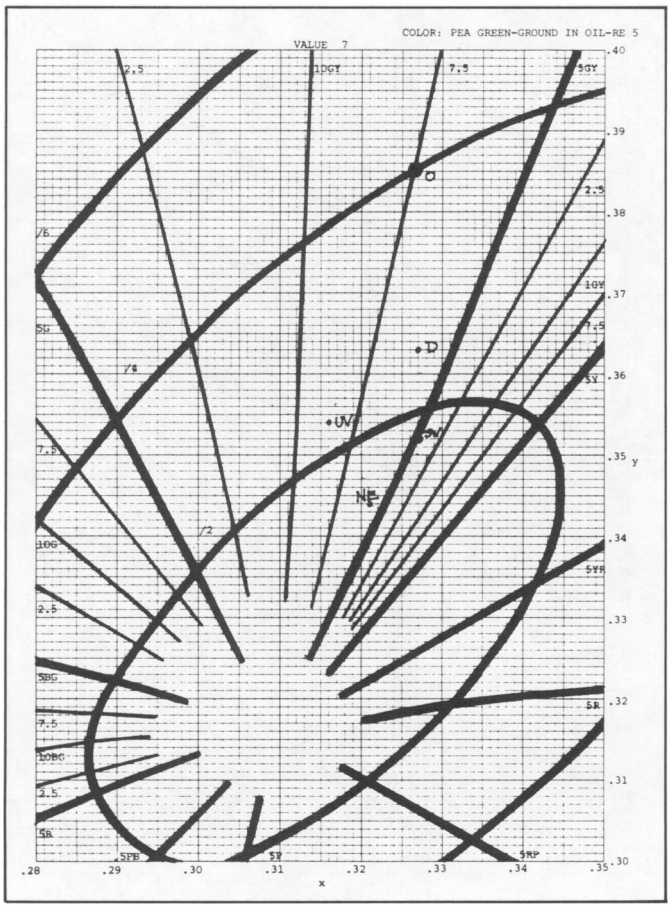


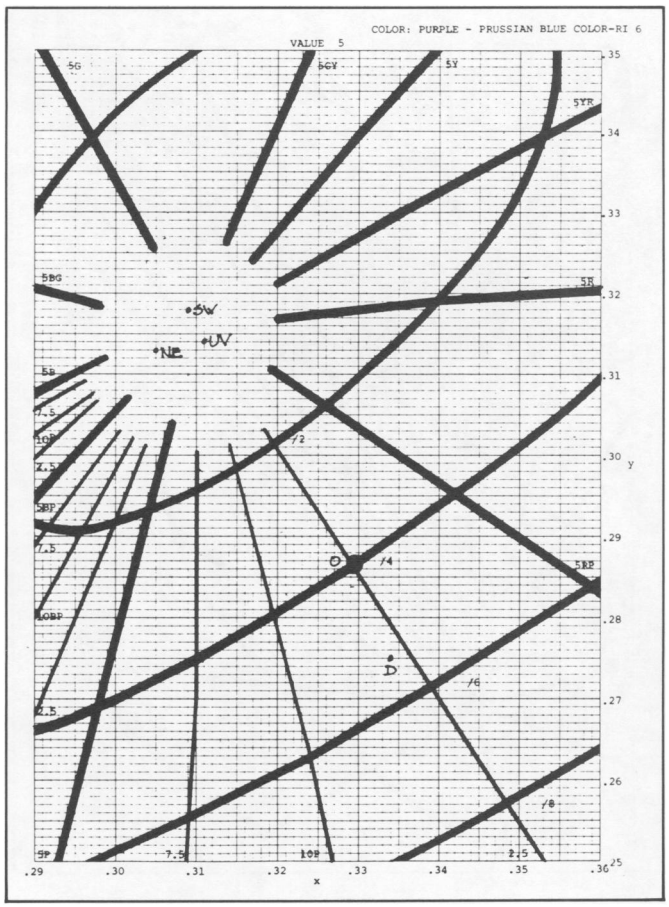
CODE	COLOR	RECIPE
RE 4	Parrot Green — Ground Dry	5 Parts White Lead 1 Part Verdigris 1/4 Part Yellow Ochre

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Between 2.5GY 8/4 & 5GY 9/4	2.5GY 7/4	5GY 7/2	2.5GY 7/4	2.5GY 7/4
TRICHROMATIC COEFFICIENTS		x = .349 y = .378 Y = 37.426	x = .333 y = .371 Y = 35.296	x = .339 y = .363 Y = 37.329	x = .341 y = .361 Y = 39.607

CODE	COLOR	RECIPE
RE 5	Pea Green — Ground in Oil	1 Part Verdigris 10 Parts White Lead

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Slightly Lighter Than 7.5GY 8/4	Between 7.5GY 8/4 & 7.5GY 7/4	10GY 8/2	Slightly Darker Than 7.5GY 8/2	5GY 7/2
TRICHROMATIC COEFFICIENTS		x = .327 y = .363 Y = 45.615	x = .316 y = .354 Y = 44.043	x = .321 y = .344 Y = 42.973	x = .327 y = .352 Y = 41.826



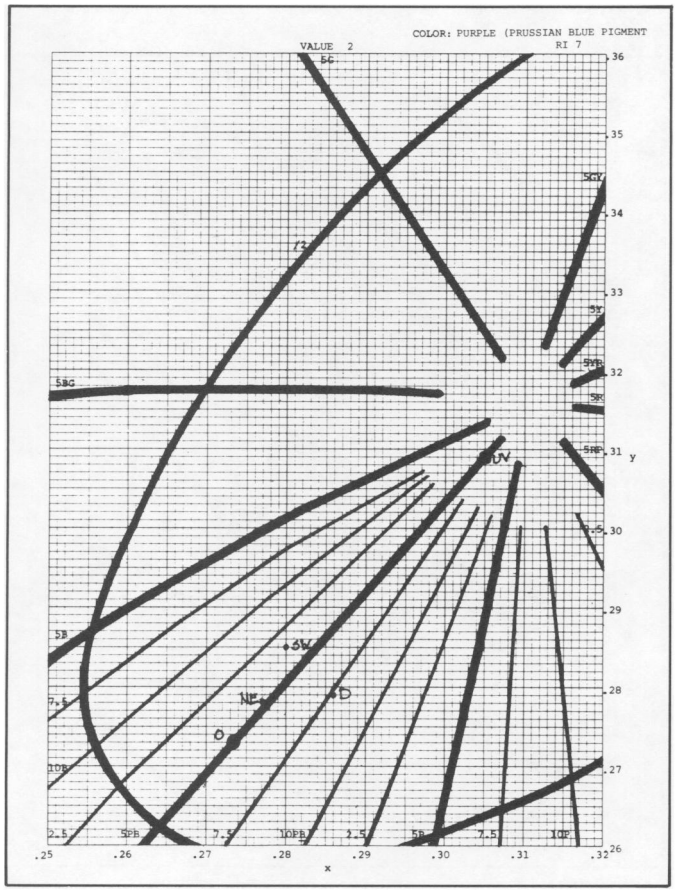


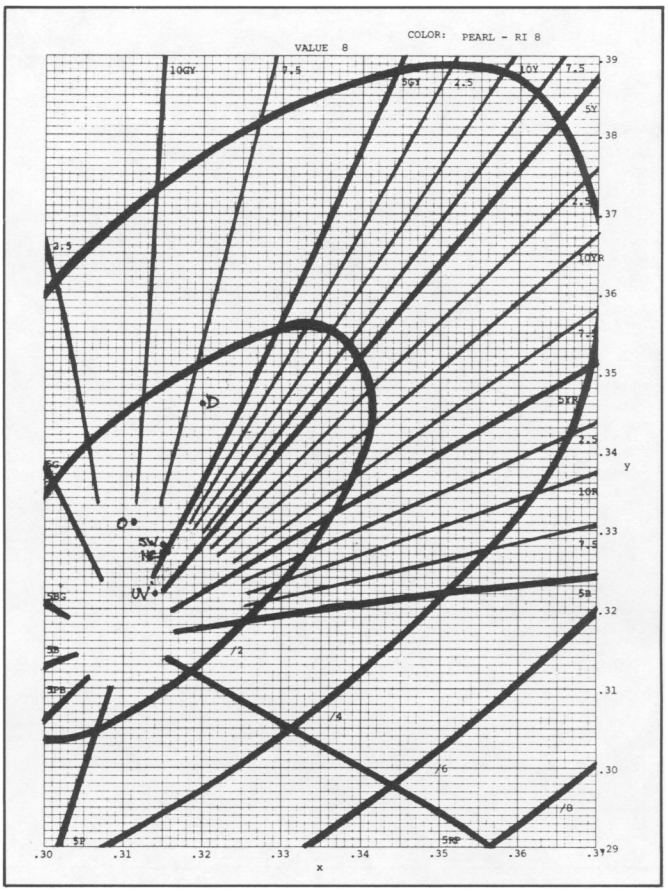
CODE	COLOR	RECIPE
RI 6	Purple (Prussian Blue Color)	1 Part Rose Pink 1 Part Prussian Blue

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	2.5RP 4/4	2.5RP 3/4	7.5P 7/2	10PB 7/1	10P 7/1
TRICHROMATIC COEFFICIENTS		x = .334 y = .275 Y = 7.849	x = .311 y = .314 Y = 38.306	x = .305 y = .313 Y = 38.797	x = .309 y = .318 Y = 35.39

CODE	COLOR	RECIPE
RI 7	Purple (Prussian Blue Pigment)	1 Part Rose Pink 1 Part Prussian Blue

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Between 5PB 2/1 & 5PB 2/2	Slightly Darker Than 7.5PB 2/2	10B 2/1	2.5PB 2/2	2.5PB 2/2
TRICHROMATIC COEFFICIENTS		x = .286 y = .279 Y = 2.684	x = .305 y = .309 Y = 3.71	x = .277 y = .278 Y = 3.555	x = .28 y = .285 Y = 3.572



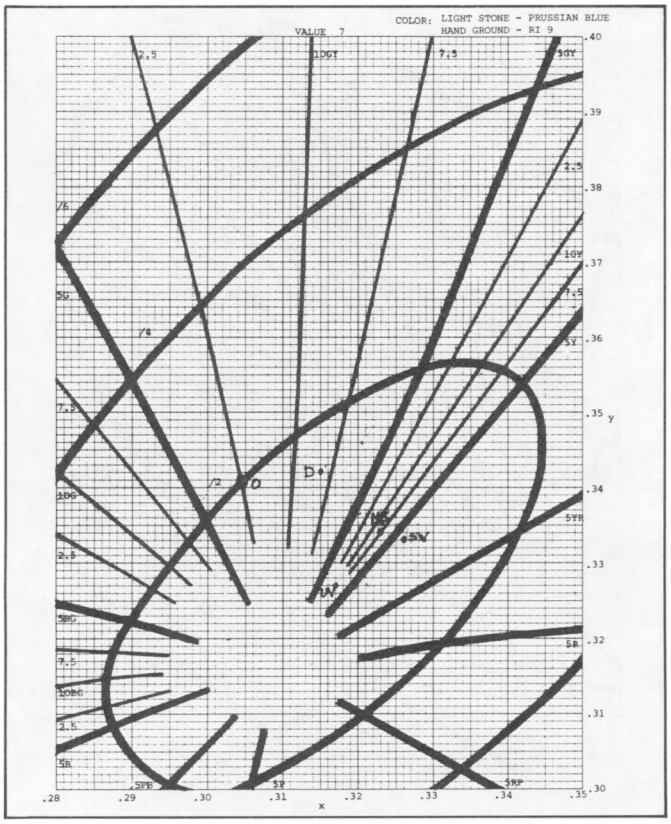


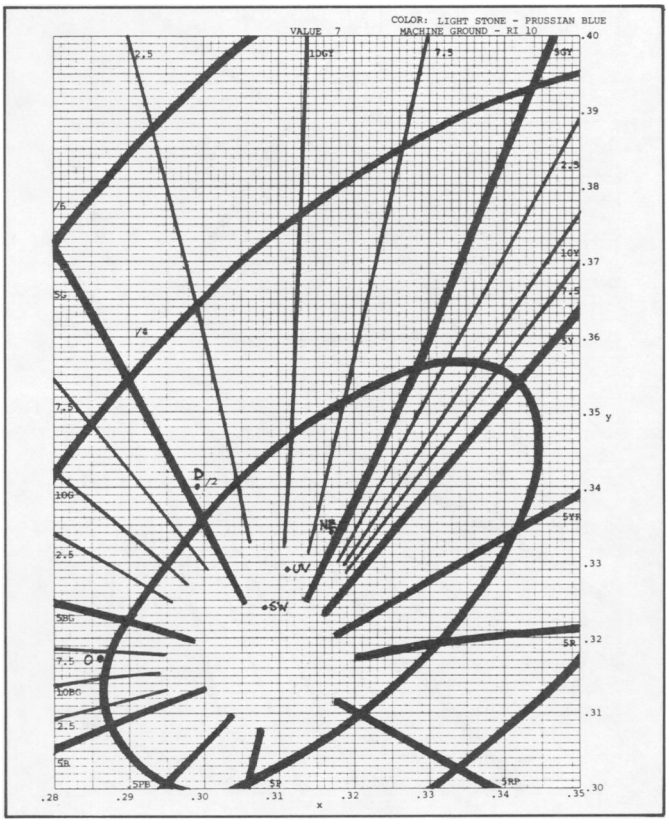
CODE	COLOR	RECIPE
RI 8	Pearl	1 Pint White Lead 1 tsp. Prussian Blue 1 tsp. Yellow Ochre

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	10GY 8/1	Between 7.5GY 7/2 & 7.5GY 8/2	Between N 8.5/ & N 9.0/	5GY 8/1	5GY 8/1
TRICHROMATIC COEFFICIENTS		x = .32 y = .346 Y = 52.437	x = .314 y = .322 Y = 67.842	x = .315 y = .327 Y = 51.921	x = .315 y = .328 Y = 52.6

CODE	COLOR	RECIPE
RI 9	Light Stone — Prussian Blue Hand Ground	1 Pint White Lead 2 tsp. Prussian Blue 4 tsp. Yellow Ochre 1 tsp. Umbre

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	2.5G 8/2	7.5GY 7/2	Between N 8.0/ & N 8.5	5GY 8/1	Slightly Lighter Than 7.5GY 7/2
TRICHROMATIC COEFFICIENTS		x = .315 y = .342 Y = 42.018	x = .317 y = .327 Y = 61.657	x = .323 y = .334 Y = 46.122	x = .326 y = .333 Y = 38.279



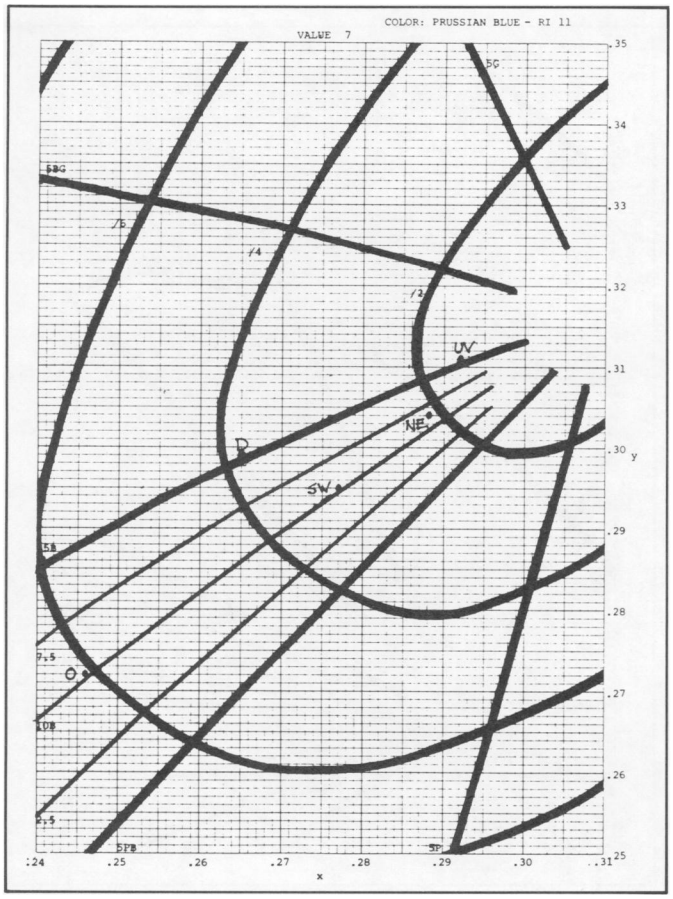


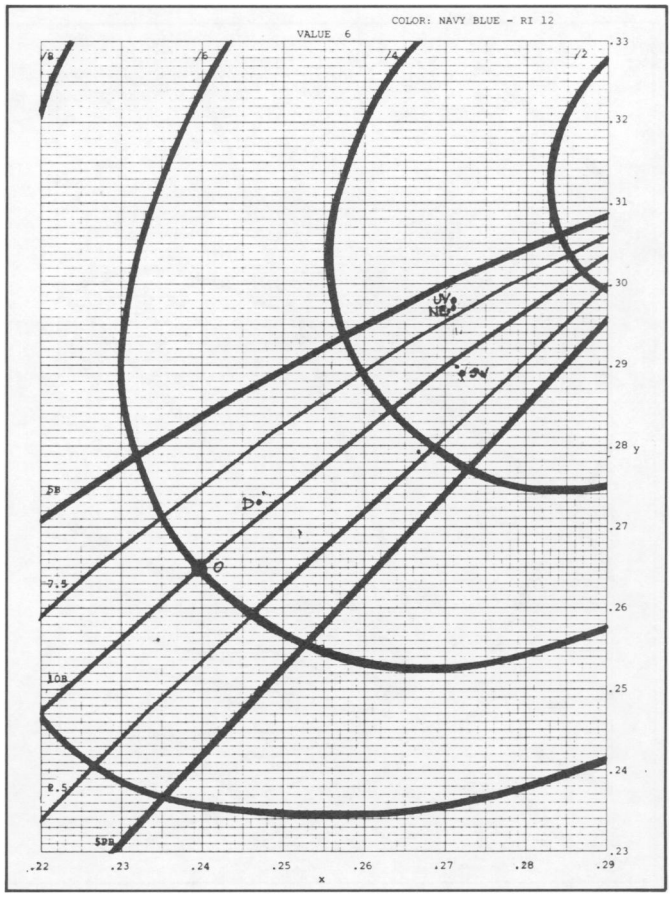
CODE	COLOR	RECIPE
RI 10	Light Stone — Prussian Blue Machine Ground	1 Pint White Lead 2 tsp. Prussian Blue 4 tsp. Yellow Ochre 1 tsp. Umbre

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	7.5BG 7/2	Between 7.5GY 7/2 & 7.5GY 6/2	Between N 8.0/ & N 8.5	5GY 7/1	10GY 7/1
TRICHROMATIC COEFFICIENTS		x = .299 y = .34 Y = 38.956	x = .311 y = .329 Y = 53.288	x = .317 y = .334 Y = 45.862	x = .308 y = .324 Y = 36.82

CODE	COLOR	RECIPE
RI 11	Prussian Blue	5 lbs. White Lead 1 oz. Prussian Blue

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	10B 7/6	5B 7/4	Slightly Lighter than 10B 8/2	5B 8/2	10B 7/4
TRICHROMATIC COEFFICIENTS		x = .265 y = .299 Y = 37.701	x = .292 y = .311 Y = 62.667	x = .288 y = .304 Y = 43.334	x = .277 y = .295 Y = 41.791



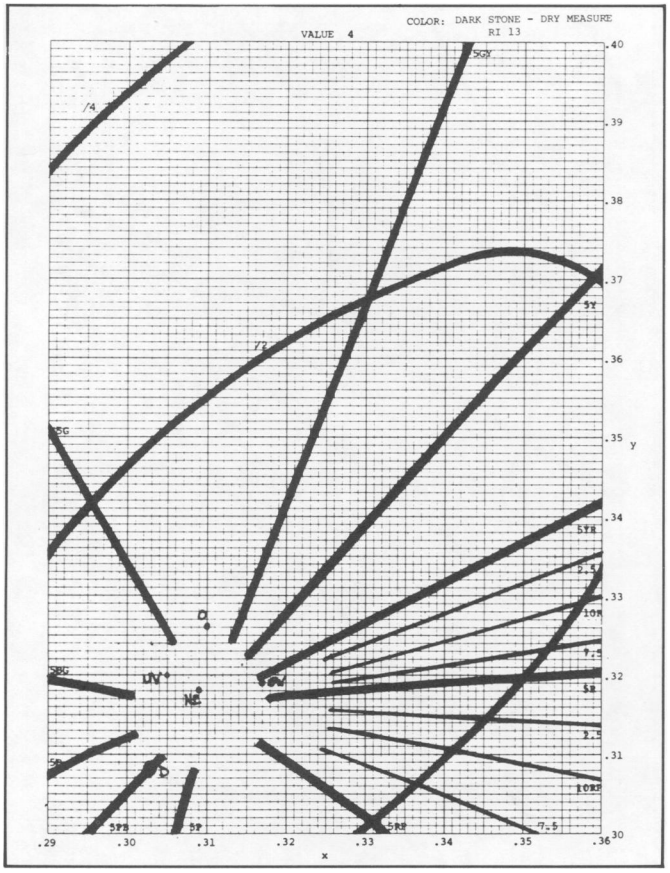


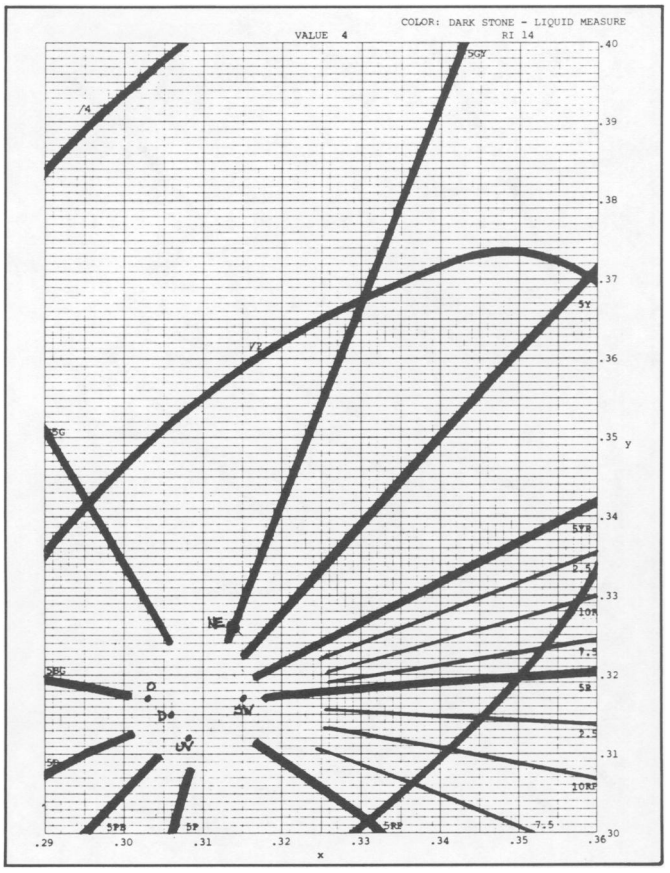
CODE	COLOR	RECIPE
RI 12	Navy Blue	5 lbs. White Lead 2 oz. Prussian Blue

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Slightly Lighter Than 10B 6/6	Between 7.5B 6/6 & 7.5B 6/4	Slightly Darker Than 10B 8/4	5B 7/2	10B 6/4
TRICHROMATIC COEFFICIENTS		x = .247 y = .273 Y = 29.11	x = .271 y = .298 Y = 38.927	x = .271 y = .297 Y = 32.371	x = .272 y = .289 Y = 27.616

CODE	COLOR	RECIPE
RI 13	Dark Stone — Dry Measure	6 lbs. White Lead 8 oz. Yellow Ochre 1/2 Gill Lampblack

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	N 4.0/	N 3.5/	N 3.0/	Between N 3.5/ & N 4.0	N 3.5
TRICHROMATIC COEFFICIENTS		x = .303 y = .308 Y = 10.033	x = .305 y = .32 Y = 10.377	x = .309 y = .318 Y = 9.256	x = .317 y = .319 Y = 9.851



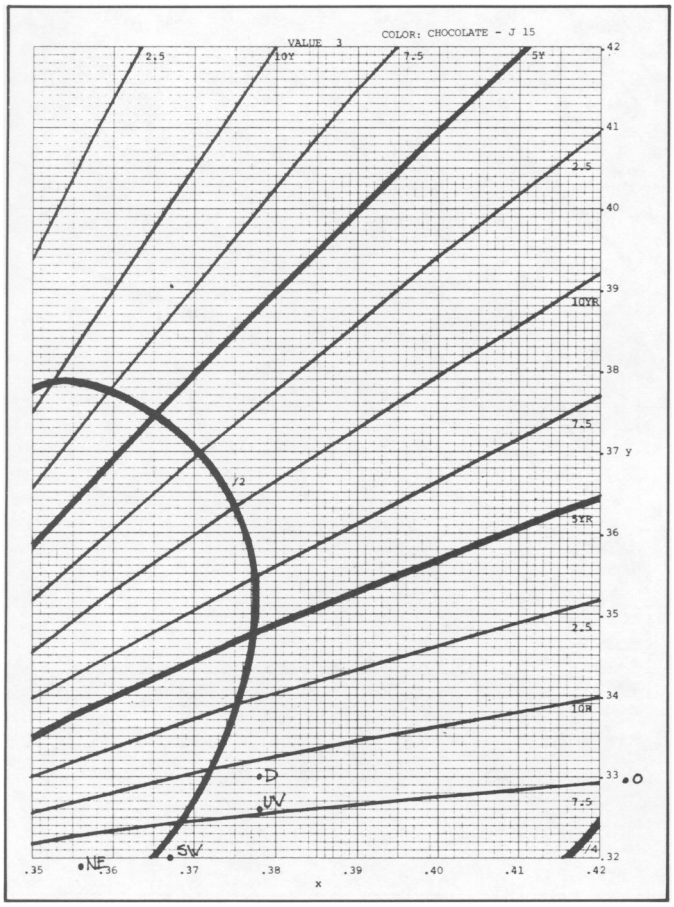


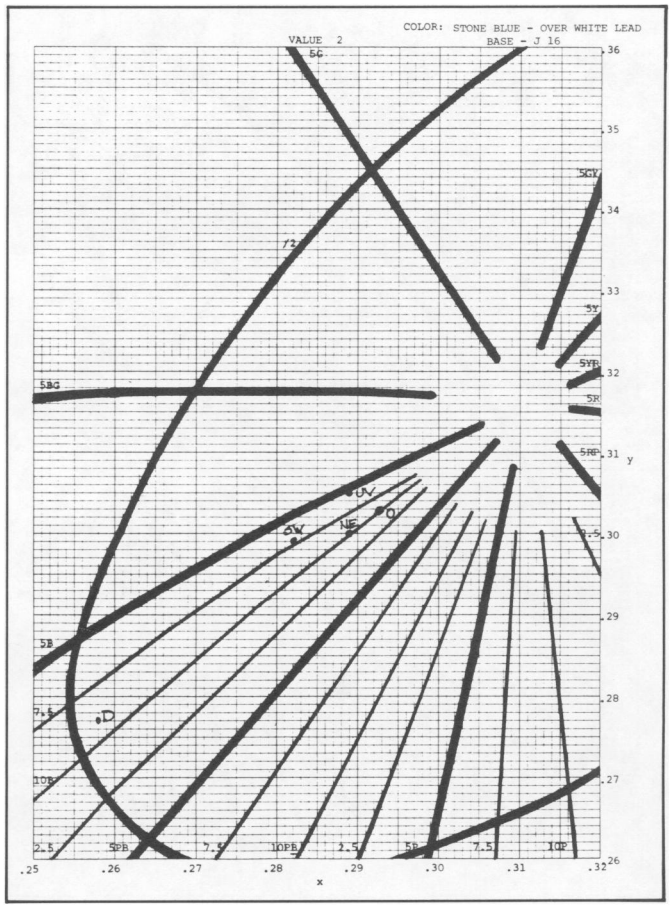
CODE	COLOR	RECIPE
RI 14	Dark Stone — Liquid Measure	6 lbs. White Lead 8 oz. Yellow Ochre 1/2 Gill Lampblack

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	N 4.5/	Slightly Lighter Than N 4.5/	N 4.5/	Slightly Lighter Than N 4.5/	Between N 4.5/ & N 5.0
TRICHROMATIC COEFFICIENTS		x = .306 y = .315 Y = 15.534	x = .308 y = .312 Y = 15.796	x = .314 y = .326 Y = 11.863	x = .315 y = .317 Y = 13.331

CODE	COLOR	RECIPE
J 15	Chocolate	5 Parts Burnt Sienna 1 Part Madder Lake

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	7.5R 2/4	2.5YR 2/4	10R 3/2	5R 3/2	7.5R 3/2
TRICHROMATIC COEFFICIENTS		x = .378 y = .33 Y = 5.376	x = .378 y = .326 Y = 5.963	x = .356 y = .319 Y = 6.533	x = .367 y = .32 Y = 5.82



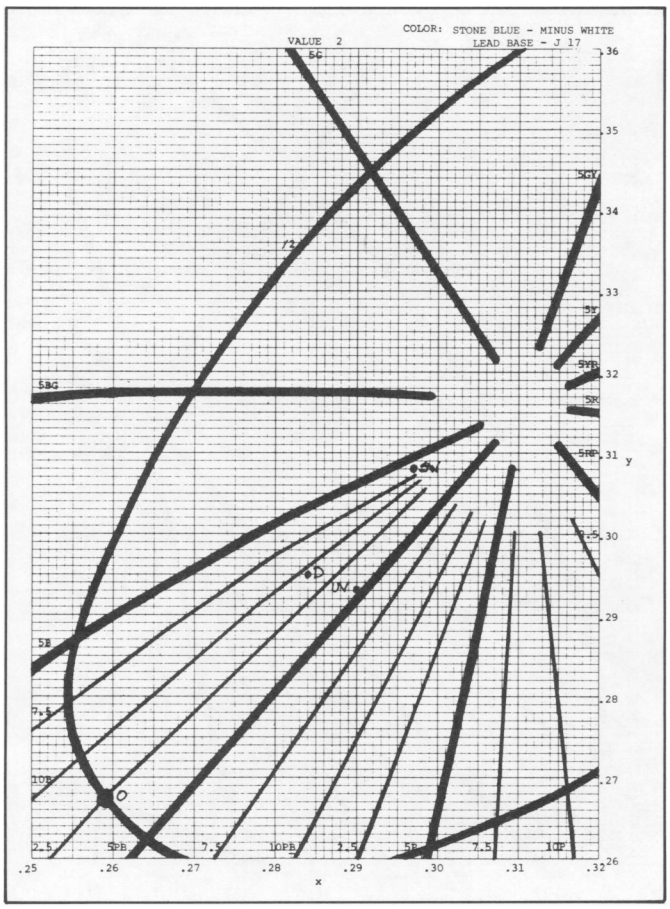


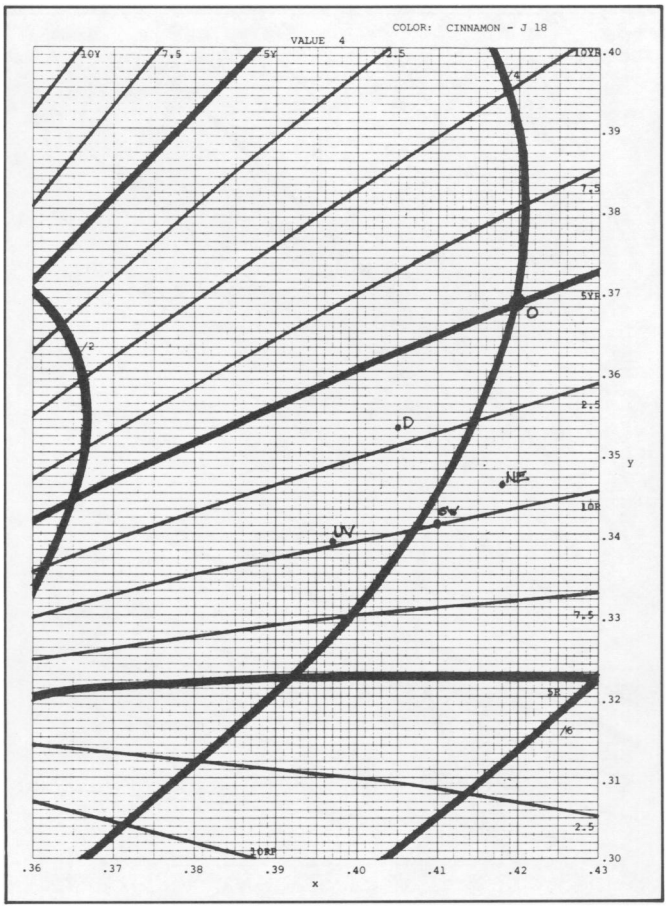
CODE	COLOR	RECIPE
J 16	Stone Blue — Over White Lead Base	1 Part Raw Umber 2 Parts Prussian Blue

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	10B 2/1	10B 2/4	10B 2/1	10B 2/2	Slightly Darker Than 2.5PB 2/2
TRICHROMATIC COEFFICIENTS		x = .258 y = .277 Y = 4.284	x = .289 y = .305 Y = 3.866	x = .289 y = .3 Y = 4.629	x = .282 y = .299 Y = 4.621

CODE	COLOR	RECIPE
J 17	Stone Blue — Minus White Lead Base	1 Part Raw Umber 2 Parts Prussian Blue

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Slightly Darker Than 2.5PB 2/2	Slightly Darker Than 10B 2/4	Slightly Darker Than 10B 2/1	No Sample	10B 2/1
TRICHROMATIC COEFFICIENTS		x = .284 y = .295 Y = 3.895	x = .29 y = .293 Y = 2.924	x = y = Y =	x = .297 y = .308 Y = 4.27



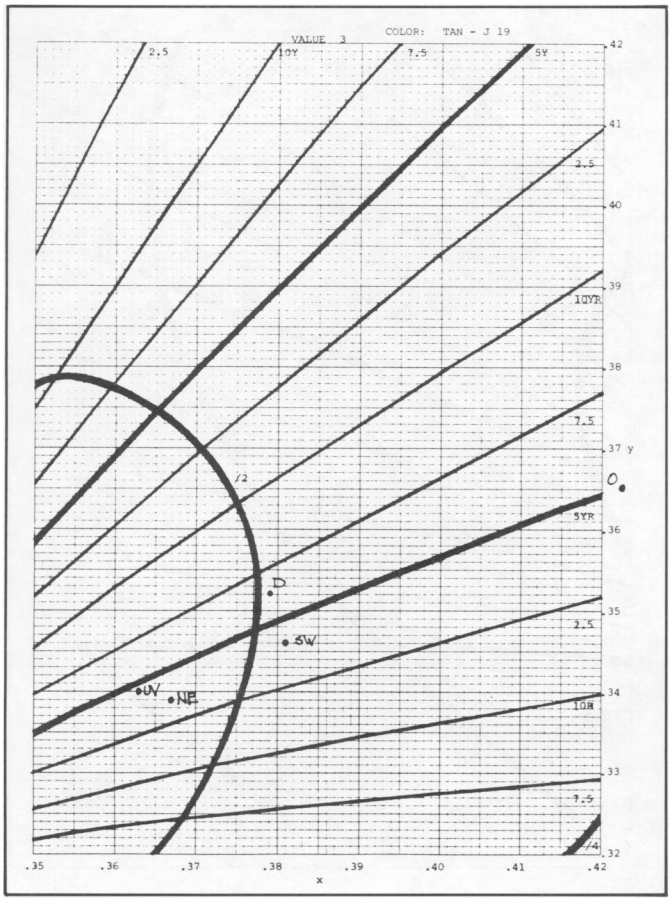


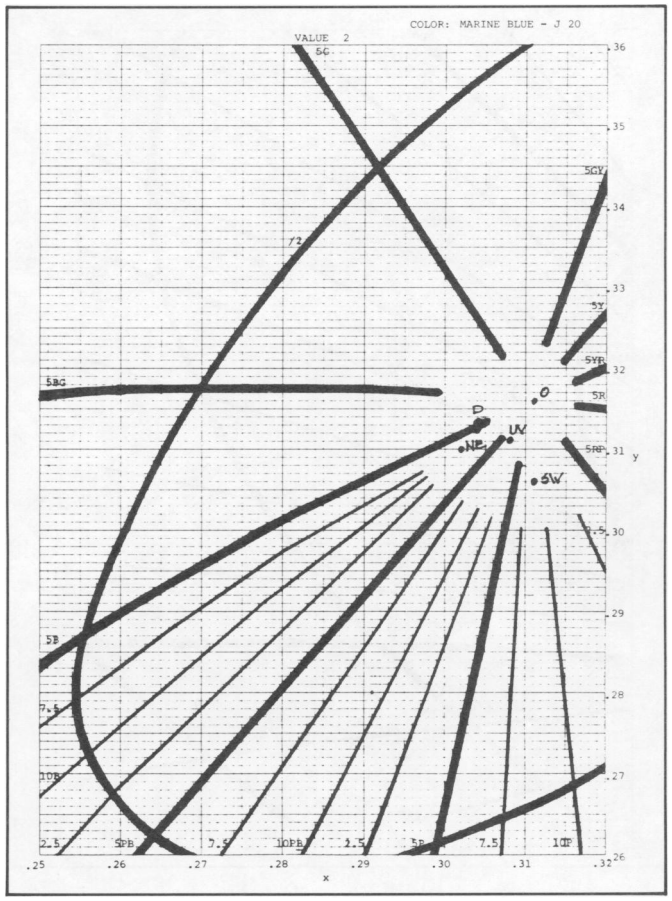
CODE	COLOR	RECIPE
J 18	Cinnamon	6 Parts White Lead 2 Parts Burnt Sienna 1 Part French Yellow Ochre

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	5YR 4/4	2.5YR 4/4	Between 2.5YR 4/6 & 2.5YR 5/6	10R 4/4	10R 4/4
TRICHROMATIC COEFFICIENTS		x = .405 y = .353 Y = 12.038	x = .397 y = .339 Y = 12.349	x = .418 y = .346 Y = 10.805	x = .41 y = .341 Y = 9.93

CODE	COLOR	RECIPE
J 19	Tan	10 Parts Burnt Sienna 4 Parts Medium Chrome Yellow 3 Parts Raw Umber

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Slightly Darker Than 5YR 3/4	5YR 3/4	Between 5YR 3/4 & 5YR 3/2	5YR 3/2	5YR 3/2
TRICHROMATIC COEFFICIENTS		x = .379 y = .352 Y = 8.663	x = .363 y = .34 Y = 10.347	x = .367 y = .339 Y = 7.755	x = .381 y = .346 Y = 7.622





CODE	COLOR	RECIPE
J 20	Marine Blue	1 Part Ultramarine Blue 9 Parts Ivory Black

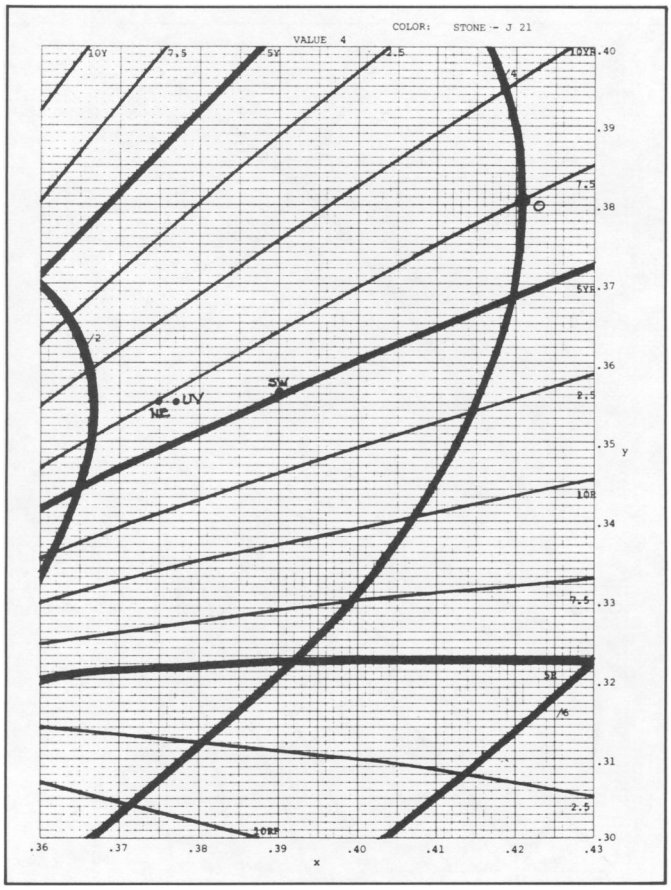
Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	N 2.0/	N 1.5/	N 1.5/	N 1.5/	N 2.0/
TRICHROMATIC COEFFICIENTS		x = .304 y = .313 Y = 2.947	x = .308 y = .311 Y = 3.148	x = .302 y = .31 Y = 3.56	x = .311 y = .306 Y = 3.485

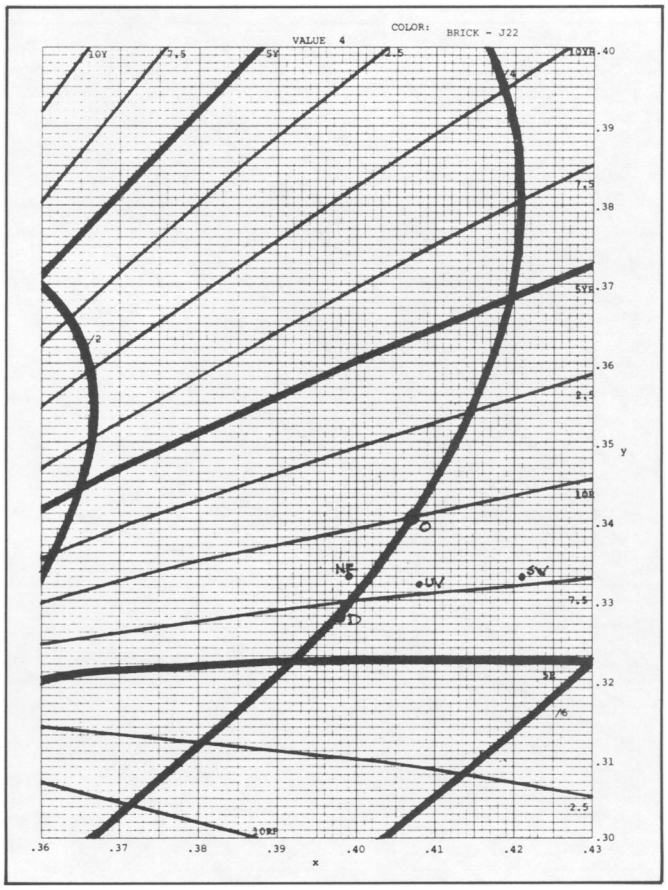
CODE	COLOR
J 21	Stone

RECIPE

5 Parts White Lead
2 Parts French Yellow Ochre
1 Part Burnt Umber

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	7.5YR 5/4	No Sample	Between 7.5YR 4/4 & 7.5YR 5/4	7.5YR 4/4	7.5YR 4/4
TRICHROMATIC COEFFICIENTS		x = y = Y =	x = .377 y = .355 Y = 14.408	x = .375 y = .355 Y = 13.041	x = .39 y = .356 Y = 11.371





CODE	COLOR
J 22	Brick

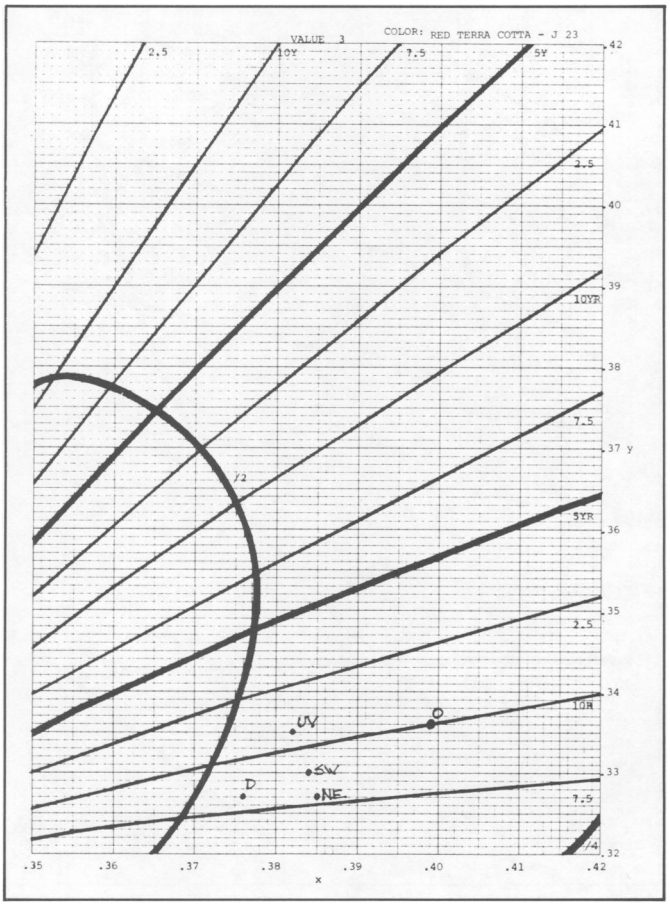
RECIPE

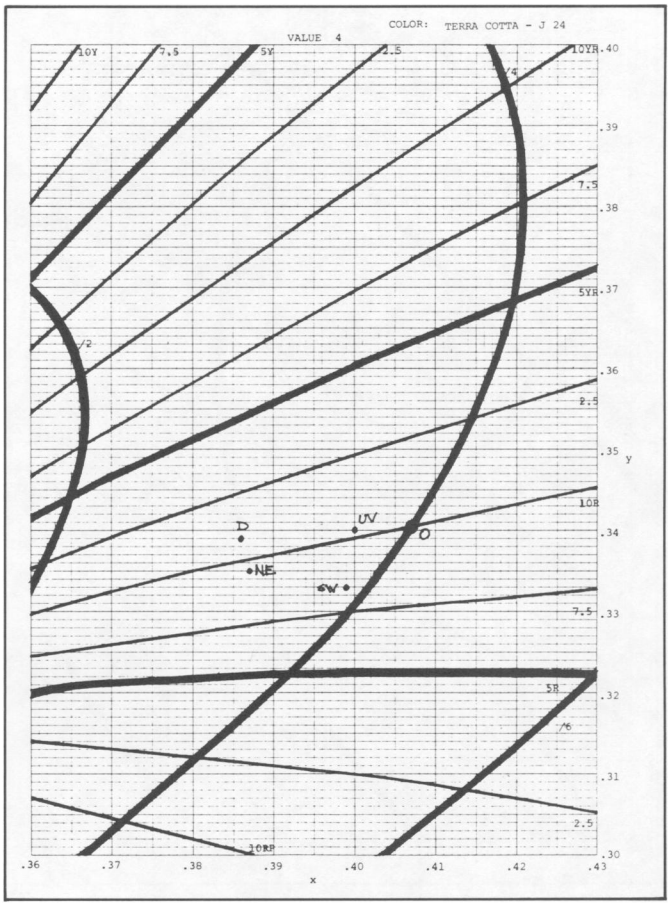
2 Parts French Yellow Ochre
1 Part Venetian Red
1 Part White Lead

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Slightly Lighter Than 10R 3/4	Between 7.5R 4/4 & 7.5R 3/4	7.5YR 4/6	10R 3/4	7.5YR 4/4
TRICHROMATIC COEFFICIENTS		x = .398 y = .328 Y = 10.667	x = .408 y = .332 Y = 9.82	x = .399 y = .333 Y = 9.073	x = .421 y = .333 Y = 8.492

CODE	COLOR	RECIPE
J 23	Red Terra Cotta	1 Part Burnt Sienna 1 Part White Lead

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Between 10R 3/2 & 10R 3/4	Between 10R 3/2 & 10R 3/4	10R 3/4	10R 3/4	10R 3/2
TRICHROMATIC COEFFICIENTS		x = .376 y = .327 Y = 8.208	x = .382 y = .335 Y = 8.329	x = .385 y = .327 Y = 7.031	x = .384 y = .33 Y = 6.691





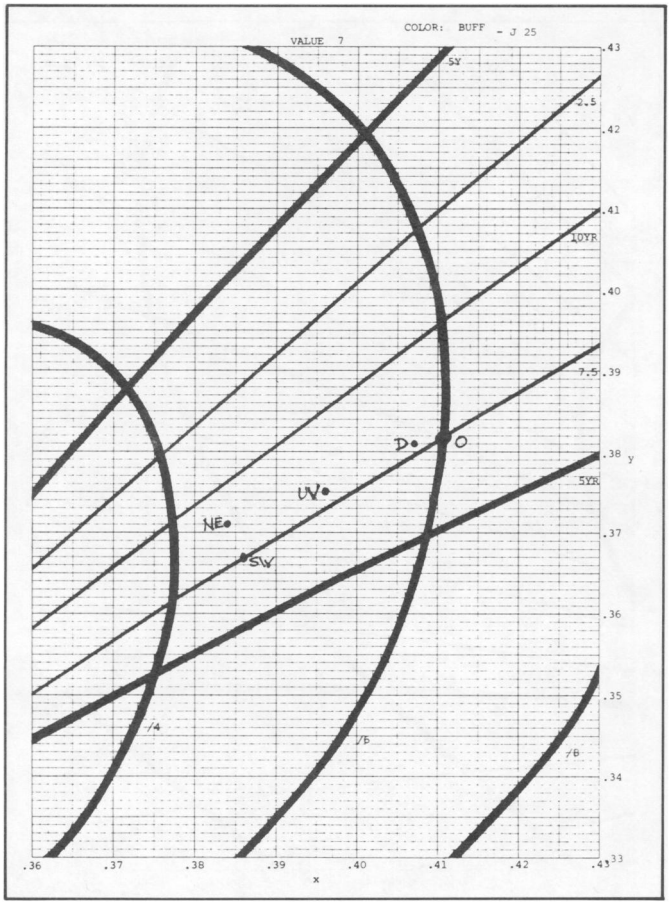
CODE	COLOR	RECIPE
J 24	Terra Cotta	2 Parts White Lead 1 Part Burnt Sienna

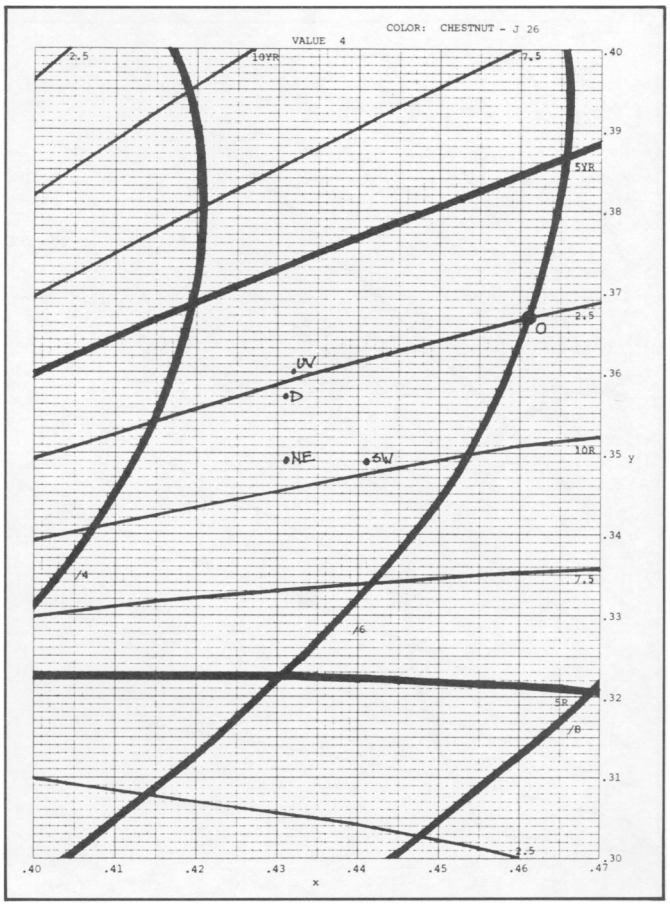
Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	10R 4/4	Between 10R 4/4 & 10R 3/4	10R 4/4	10R 4/4	10R 3/4
TRICHROMATIC COEFFICIENTS		x = .386 y = .339 Y = 11.512	x = .4 y = .34 Y = 10.573	x = .387 y = .335 Y = 9.5	x = .399 y = .333 Y = 9.114

CODE	COLOR
J 25	Buff

RECIPE
2 Parts White Lead
1 Part Yellow Ochre

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Slightly Darker Than 7.5YR 7/6	Between 10YR 7/6 & 10YR 7/8	7.5YR 7/6	10YR 7/4	10YR 7/4
TRICHROMATIC COEFFICIENTS		x = .407 y = .381 Y = 39.376	x = .396 y = .375 Y = 39.05	x = .384 y = .371 Y = 35.445	x = .386 y = .367 Y = 39.266





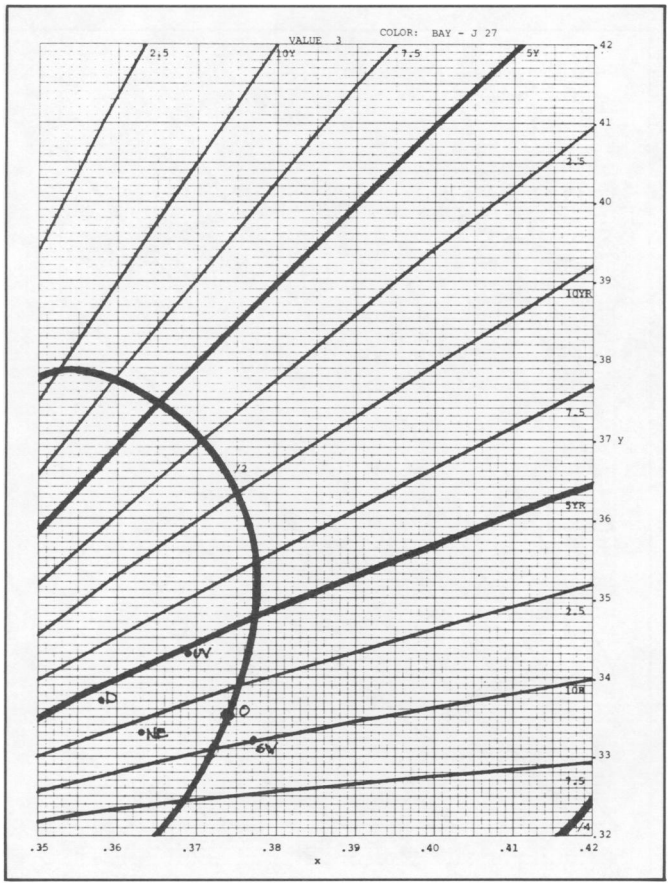
CODE	COLOR
J 26	Chestnut

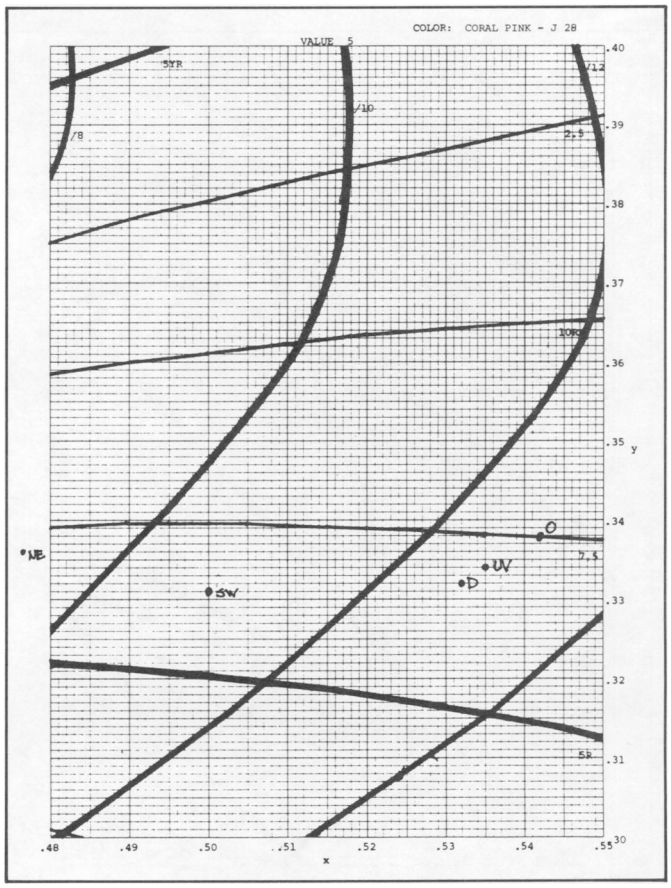
RECIPE
4 Parts Medium Chrome Yellow
2 Parts Venetian Red
1 Part Yellow Ochre

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Slightly Lighter Than 2.5YR 4/6	Between 2.5YR 4/6 & 2.5YR 3/6	2.5YR 4/6	Slightly Lighter Than 2.5YR 3/6	10R 4/6
TRICHROMATIC COEFFICIENTS		x = .431 y = .357 Y = 12.146	x = .432 y = .36 Y = 12.104	x = .431 y = .349 Y = 9.799	x = .441 y = .349 Y = 9.784

CODE	COLOR	RECIPE
J 27	Bay	3 Parts Black 3 Parts Venetian Red A little Orange Mineral

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Between 10R 3/2 & 2.5YR 3/2	5YR 3/2	10R 3/2	2.5YR 3/2	2.5YR 3/2
TRICHROMATIC COEFFICIENTS		x = .358 y = .337 Y = 8.296	x = .369 y = .343 Y = 7.951	x = .363 y = .333 Y = 6.649	x = .377 y = .332 Y = 6.021



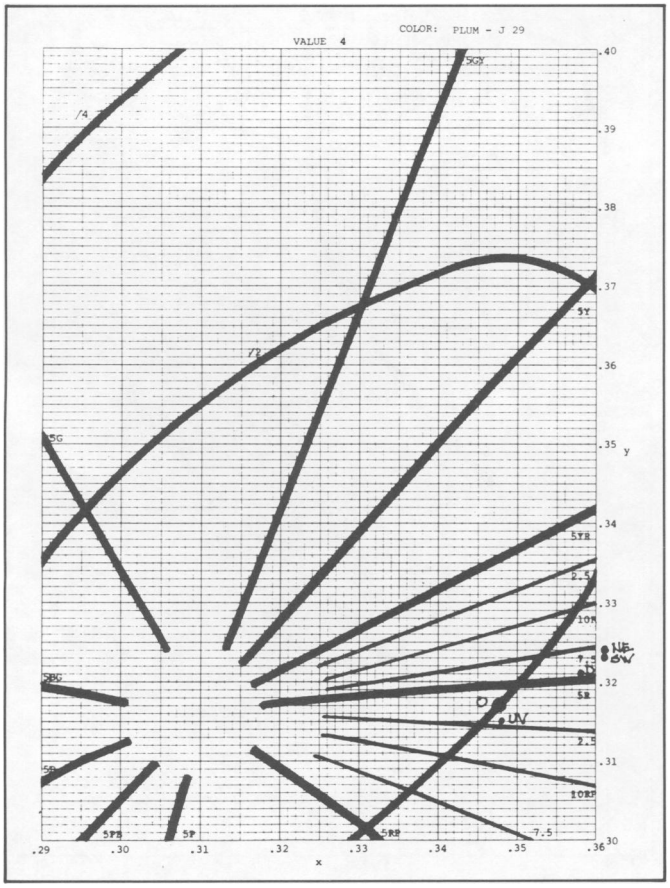


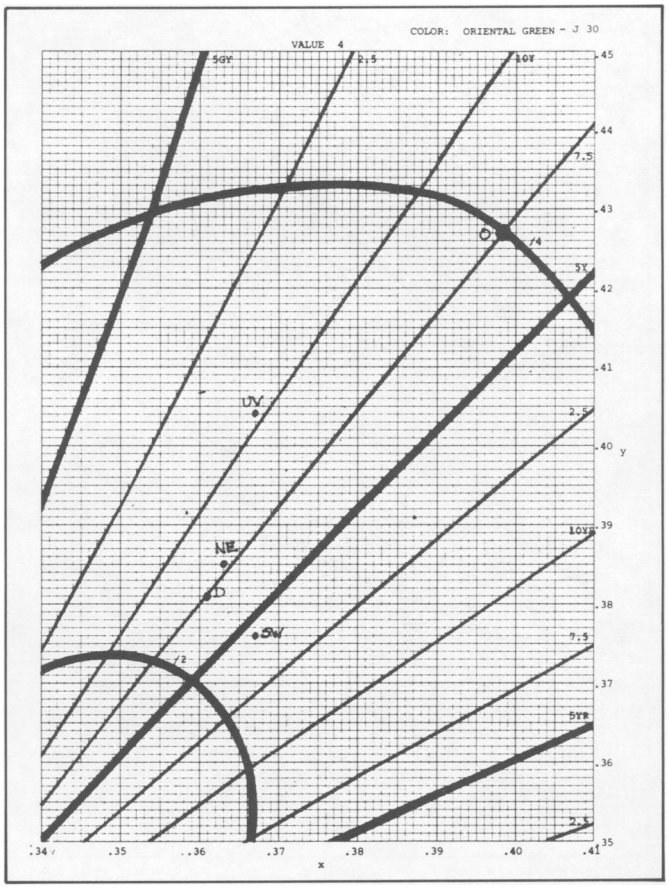
CODE	COLOR	RECIPE
J 28	Coral Pink	5 Parts Vermilion 2 Parts White Lead 1 Part Chrome Yellow

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Between 7.5R 5/12 & 7.5R 5/14	7.5R 5/14	7.5R 5/14	7.5R 4/12	7.5R 4/12
TRICHROMATIC COEFFICIENTS		x = .532 y = .332 Y = 18.424	x = .535 y = .334 Y = 17.741	x = .444 y = .334 Y = 9.795	x = .5 y = .331 Y = 11.165

CODE	COLOR	RECIPE
J 29	Plum	2 Parts White Lead 1 Part Indian Red 2 Parts White Lead 1 Part Ultramarine Blue

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Between 2.5R 4/2 & 5R 4/2	Between 7.5R 4/2 & 7.5R 3/2	5R 4/2	Between 7.5R 4/4 & 7.5R 4/2	7.5R 4/2
TRICHROMATIC COEFFICIENTS		x = .358 y = .321 Y = 9.702	x = .348 y = .315 Y = 9.992	x = .361 y = .324 Y = 12.462	x = .361 y = .323 Y = 12.792



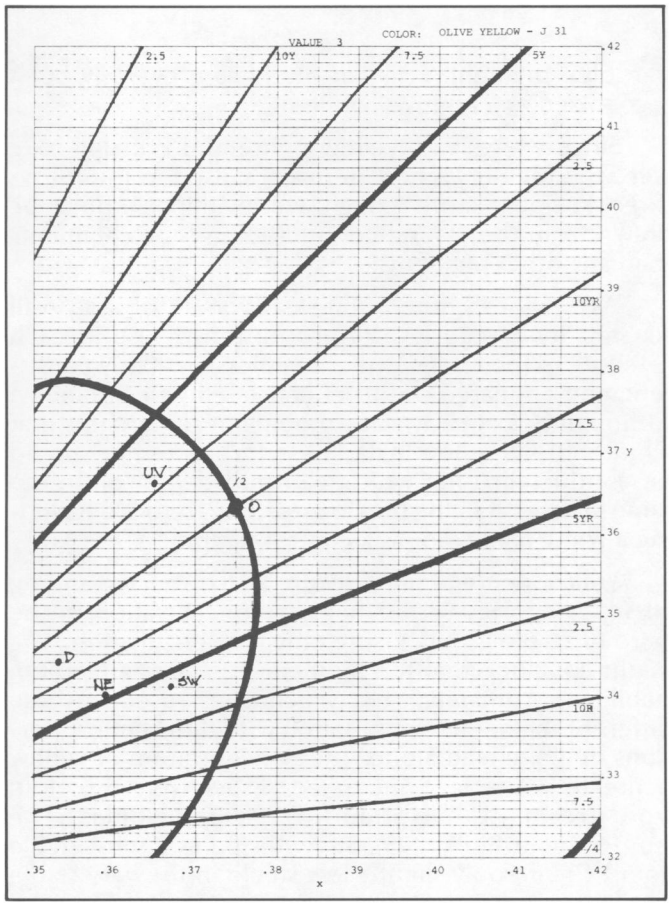


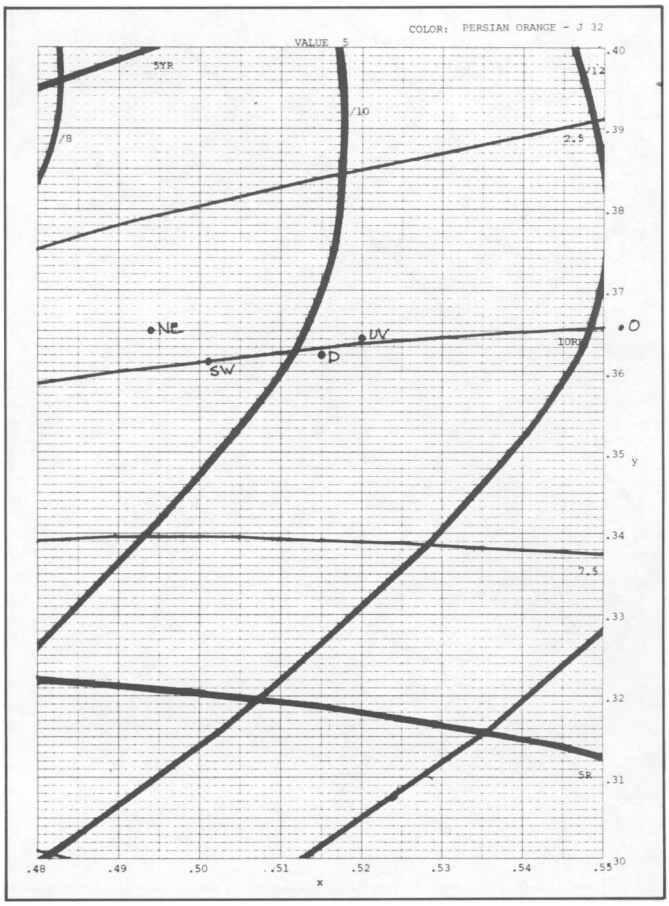
CODE	COLOR	RECIPE
J 30	Oriental Green	1 Part Raw Umber 1 Part Light Chrome Yellow

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Slightly Darker Than 7.5Y 4/4	Slightly Lighter Than 10Y 3/4	2.5GY 4/4	Between 10Y 3/2 & 10Y 3/4	Slightly Lighter Than 7.5Y 3/2
TRICHROMATIC COEFFICIENTS		x = .361 y = .381 Y = 10.802	x = .367 y = .404 Y = 11.76	x = .363 y = .385 Y = 8.927	x = .367 y = .376 Y = 9.15

CODE	COLOR	RECIPE
J 31	Olive Yellow	3 Parts Burnt Umber 1 Part Light Chrome Yellow

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	10YR 3/2	10YR 3/2	10YR 3/2	Between 7.5YR 3/2 & 5YR 3/2	5YR 3/2
TRICHROMATIC COEFFICIENTS		x = .353 y = .344 Y = 7.607	x = .365 y = .366 Y = 7.298	x = .359 y = .34 Y = 5.874	x = .367 y = .341 Y = 6.118



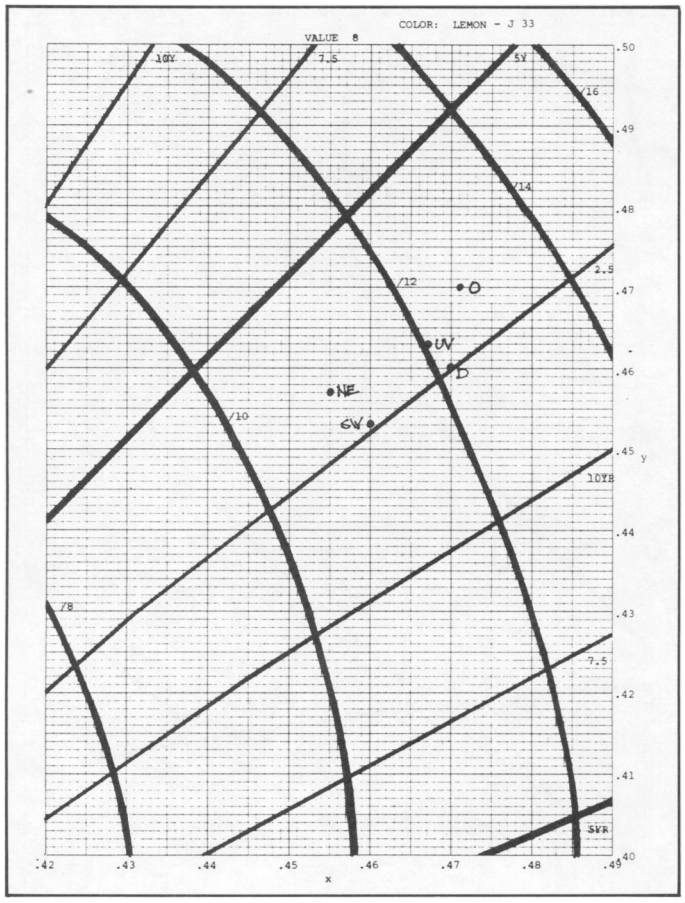


CODE	COLOR	RECIPE
J 32	Persian Orange	14 Parts Orange Mineral 5 Parts Yellow Ochre 1 Part White Lead

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Between 10R 5/12 & 10R 5/14	10R 5/12	10R 5/12	Between 10R 5/10 & 2/5YR 5/10	10R 5/10
TRICHROMATIC COEFFICIENTS		x = .515 y = .362 Y = 20.077	x = .52 y = .364 Y = 19.013	x = .494 y = .365 Y = 15.785	x = .501 y = .361 Y = 16.09

CODE	COLOR	RECIPE
J 33	Lemon	Light Chrome Yellow

Samples	CONTROL (Original)	DARKNESS	NEAR ULTRAVIOLET	WEATHERED NORTHEAST EXPOSURE	WEATHERED SOUTHWEST EXPOSURE
MUNSELL COLOR MATCH	Between 3.75Y 8/12 & 3.75Y 8.14	Between 2.5Y 8/14 & 2.5Y 8/12	3.75Y 8/14	5Y 7/12	2.5Y 7/10
TRICHROMATIC COEFFICIENTS		x = .47 y = .46 Y = 56.624	x = .467 y = .463 Y = 54.757	x = .455 y = .457 Y = 36.487	x = .46 y = .453 Y = 35.293



When the tested paints were itemized by the respective categories, it is interesting to note their pigment distribution. White lead was disbursed throughout all six categories and therefore cannot be considered as either a stabilizing or destabilizing factor. Yellow ochre appeared in all six categories with a heavier concentration in the stable and moderately stable groups. Perhaps the most striking concentration of a pigment was that of Prussian blue which was notably absent in all the paint recipes which fall within the most stable categories, and occurred only in the three least stable groups. It was also noteworthy to mention that of the four colors included in the most unstable group, every color contained Prussian blue pigment. Prussian blue has previously been recognized as a fugitive pigment.

Since white lead, yellow ochre and Prussian blue were the pigments most frequently used in the thirty-three recipes, more conclusive evidence could be drawn from the testing conducted on those pigments than any other pigments.

As previously noted white lead was distributed in all six stability categories. Its proportion of use in each category to the total number of colors was fairly consistent, and appeared not to effect stability or instability. Although it is already known by paint researchers that white lead will yellow in darkness, further testing should be conducted using white lead mixed with oil in the same manner as in the previous tests, therefore developing a white lead color as a control sample.

Yellow ochre pigments were also disbursed among all six categories with a heavier concentration in the third or stable group. Using only this information, one might conclude that the pigment possesses a medium stability. Fortunately, yellow ochre was used in three different recipes in combination with different proportions of white lead alone. The concentration of yellow ochre to white lead increased respectively threefold from Cream (RE 1) to Straw (RE 2) and five times more from Straw to Buff (J 25). Straw tested as a most stable color, Cream only slightly less stable in the very stable category, and Buff as only moderately stable. In its strongest concentration, yellow ochre was the least stable; in a medium concentration it was the most stable. When other pigments were introduced to the combination of yellow ochre and white lead in various proportions, the results of the testing broached the spectrum of stability. As represented in the following chart, a pattern of stability did not correlate to the proportion of yellow ochre to other pigments. (Table I.) It seems that the stability of yellow ochre depends on its combination with certain other pigments as well as proportion. Further testing should be conducted using only yellow ochre mixed with oil in the same manner as the original tests.

The test results showed that Prussian blue pigment did not lend stability to the paint colors, however, it appeared that heavier concentrations of the pigment

Table I
Ratio Parts/Volume of Pigments

Paint Colors	Yellow Ochre	White Lead	Lamp-black	Orange Mineral	Burnt Umber	Verdi-gris	Venetian Red	Burnt Sienna	Prussian Blue	Raw Umber	Stability Group
Straw (RE 2)	1	10									1
Dark Stone — Liq. (RI 14)	1	12	1/4								1
Dark Stone — Dry (RI 13)	1	12	1/4								2
Cream (RE 1)	1	20									2
Persian Orange (J 32)	1	1/4		2-4/5							3
Stone (J 21)	1	2-1/2			1/2						3
Buff (J 25)	1	2									4
Parrot Green — Oil (RE 3)	1	20				4					4
Parrot Green — Dry (RE 4)	1	20				4					4
Brick (J 22)	1	1/2					1/2				4
Cinnamon (J 18)	1	6						2			5
Pearl (RI 8)	1	96							1		5
Light Stone (RI 9)	1	24							1/2	1/4	6
Light Stone (RI 10)	1	24							1/2	1/4	6

rendered the color more stable. As shown in the table below, the decrease in stability did not necessarily correlate to the decreased concentration of Prussian blue pigment, but may have been influenced by the introduction of other pigments. (Table II.)

Although other pigments were used less frequently, limited conclusions could be drawn by comparing reactions of colors with similar pigments. Burnt sienna was incorporated in five of the historic paint colors. Composed of different proportions of burnt sienna and white lead, Red Terra Cotta (J 23) and Terra Cotta (J 24) proved to be two of the most stable colors in the whole study. The chart below showed that the heavier concentration of burnt sienna to white lead was most stable, but a heavier concentration of burnt sienna to madder lake was least stable. (Table III.) It appears that burnt sienna alone may be a stable pigment (it should be tested as its own color) but that when combined with certain other pigments, the combination renders it unstable. More testing must be completed for more definitive conclusions.

Chrome Yellows were used in six recipes and all tested to be stable except one which fell into the moderately stable category. Since the color Lemon (J 33) was composed only of chrome yellow pigment and oil, it seems conclusive that the pigment is stable, but, again, more testing should be conducted.

This experiment included five pairs of colors, each pair composed of the same pigments in like proportion, but using different methods of mixing each pair color.

The first pair included Parrot Green — Ground in Oil (RE 3), and Parrot Green — Ground Dry (RE 4). In this case, no appreciable difference in changes occurred within the exposures. Therefore the different mixing methods had no apparent effect except to produce slightly different original colors.

The second group included Purple Color — Prussian Blue Color (RI 6), and Purple Color — Prussian Blue Pigment (RI 7). Purple using Prussian Blue Color was very unstable except when exposed to darkness. In contrast

Table II
Ratio Parts/Volume of Pigments

Paint Colors	Prussian Blue	White Lead	Raw Umber	Rose Pink	Yellow Ochre	Stability Group
Stone Blue — White Lead (J 16)	1		1/2			4
Stone Blue (J 17)	1		1/2			4
Purple — Prus. Bl. Pig. (RI 7)	1			1		4
Navy (RI 12)	1	40				5
Pearl (RI 8)	1	96			1	5
Prussian Blue (RI 11)	1	80				6
Purple — Prus. Bl. Col. (RI 6)	1	80		81		6
Light Stone — PBHG (RI 9)	1	48	1/2		2	6
Light Stone — PBMG (RI 10)	1	48	1/2		2	6

the heavier concentration of Prussian Blue pigment in RI 7 proved to stabilize the color moderately and was only slightly less stable when exposed to near ultraviolet light.

The third pair included Light Stone — Prussian Blue Hand Ground (RI 9) and Light Stone — Prussian Blue Machine Ground (RI 10). Both colors were the most unstable of those tested, but Light Stone became radically more unstable when the Prussian blue pigment was machine ground and combined with the other component pigments, indicating that the finer particle size was less stable.

The fourth pair of colors consisted of Dark Stone — Dry Measure (RI 13) and Dark Stone — Liquid Measure (RI 14). The original color mixed dry was slightly darker than the original color mixed in liquid form. Since the colors were neutrals, change was noted only in values. The unexplainable phenomenon was that the dry measured color darkened slightly in all four exposures while the liquid-measured color lightened slightly (except when it was exposed to darkness it remained unaltered). Both colors tested as moderately stable.

The last pair included Stone Blue — Over White Lead Base (J 16) and Stone Blue — Minus White Lead Base (J 17). Stone Blue with the white lead base was very stable when exposed to near ultraviolet light; darkness and northeast weathering affected only its chroma; whereas hue, value, and chroma were affected by southwest weathering. Stone Blue without the white lead base was in general only moderately stable and its exposure to southwest weathering changed its hue, value, and chroma in exact opposite increments to its white lead base partner. Since the northeast weathered sample without the base was lost, no comparative explanation can be drawn from this apparent inconsistency.

Of the thirty-three colors tested, exposure to near ultraviolet light rendered three of them neutral. Pearl (RI 8) and both Light Stones (RI 9 and RI 10) turned grayish-white during their exposure. It is this type of change which may prove contemporary paint analysis inexact. All three colors shared white lead, Prussian blue and yellow ochre pigments, with the Light Stones also containing raw umber.

Other conclusions drawn from this experiment were:

1. Exposure to darkness resulted mostly in changes in hue, while changes in value and chroma occurred in less than half as many colors.
2. Exposure to near ultraviolet light caused primarily changes in chroma, with changes in hue following close behind.
3. In both weathered exposures, hues were most affected and changes in value the least. Overall weathering seemed to render most colors more unstable than exposure to darkness or near ultraviolet light. When combining all of the exposures, values of the tested paint colors were altered the least, hues the most.

In order to substantiate evidence of pigment changes in different environments, more recipes containing similar pigments to those already sampled should be mixed and tested in similar fashion. All individual pigments should be mixed only with oil and tested, and with oil and white lead and tested. As previously stated white lead should also be tested as an individual color. By conducting further tests, better control data could be established for comparison purposes. The most difficult deductions would lie in analyzing the

Table III
Ratio Parts/Volume of Pigments

Paint Colors	Burnt Sienna	White Lead	Chrome Yellow	Raw Umber	Yellow Ochre	Madder Lake	Stability Group
Red Terra Cotta (J 23)	1	1					1
Terra Cotta (J 24)	1	2					2
Tan (J 19)	1		2/5	3/10			3
Cinnamon (J 18)	1	3			1/2		5
Chocolate (J 15)	1					1/5	5

reactions of combinations of pigments, where stability would radically differ from the control data.

Certain problems were encountered in this study which should be recognized if future research is to be conducted. These included:

1. Exact proportioned measurements were not recorded for all recipes when the historic recipes called for unmanageable proportions.
2. Spectrophotometric readings for the original set of control samples were recorded but not calculated until one year later. Immediate calculations could have provided a system for comparing plotted coefficients on the diagrams to original Munsell color matches. Twenty of the thirty-three original colors' spectrophotometric readings were in error and could not be re-recorded on the equipment due to possible alterations in color over time.
3. Not all colors matched the available Munsell colors exactly, therefore leaving the researcher open to subjective application of terminology, such as "slightly lighter or darker than" and "between."
4. The human eye may tend to record variations of color within a sample differently from the spectrophotometer. This problem usually occurred in weathered samples, where the eye tended to exclude dirt; the spectrophotometer will include dirt as color.
5. More time may be required for darkness and weathered exposures to evaluate adequately the effects of said exposures to historic paints.
6. No equivalency has been established between near ultraviolet light exposure and exposure to the sun. How many years of sun exposure would be equal to the two months of near ultraviolet light exposure which this study employed? However, a trend can be utilized when dealing with similar pigments which have been exposed to direct sunlight.

The recorded observations included in this study can provide simple references for the specified historic paint colors exposed to the different environments. But this study can only begin to make a dent in trying to upgrade techniques for historic paint analysis. The researcher must be acutely aware that historic colors found when conducting analysis may have gone through slight or radical changes during their years when exposed to sunlight or weathering, or subsequent years when they lay in darkness under new coats of paint. Extensive testing and research should be continued on other historic paint colors and pigments in order to establish a solid reference for historic paint analysis.

Footnotes:

1. Hezekiah Reynolds, *Directions for House and Ship Painting*, ed. by Richard M. Candee, (Worcester, MA: American Antiquarian Society, 1978).
2. Reynolds, *Directions*.
3. Morgan W. Phillips, "Discoloration of Old House Paints: Restoration of Paint Colors at the Harrison Gray Otis House, Boston," *Bulletin of the Association for Preservation Technology*, III, No. 4 (1971), pp. 40-41.
4. Arthur Seymour Jennings, *Paint and Colour Mixing*, (4th ed.; London and New York: Spon & Chamberlain, 1910).