Cross-section Microscopy Report

Exterior Paint Research -- C100 Automotive Museum Building
Balboa State Park, San Diego, California

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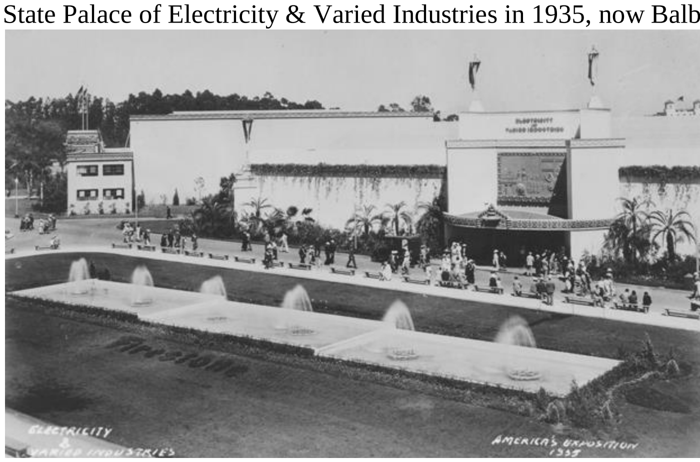
Date: May 24, 2020

C.P.I.E. California State Building in 1935, now San Diego Automotive Building

C.P.I. E. California State Palace of Electricity & Varied Industries in 1935, now Balboa Park Gymnasium



Purpose:

The goal of this project is to use optical microscopy analysis techniques to identify and compare the paint on three different areas of the exterior cement walls of the 1935 California State Palace of Electricity & Varied Industries and on one area of the 1935 Federal Building to identify the original 1935 paint color(s). It is hoped that this analysis will help guide the color selection for repainting the 1935 California State Building, now the Automotive Museum, to its original 1935 palette. Investigations conducted there by Will Chandler suggested that no early paint coatings had survived several aggressive restorations and repainting campaigns. The original color(s) found on the other two buildings will be measured and matched with the help of a Minolta colorimeter-microscope.

Procedures:

Four bags of samples containing sandy cementitious substrates and paints were provided by Will Chandler, Chandler Art Consulting Services, to Susan Buck for analysis. Chandler has been conducting ongoing research into the exterior paints for these three 1935 buildings. Three samples were from different areas of intact 1935 walls of the Municipal Gymnasium, which was originally the Palace of Electricity and Varied Industries Building during the California Pacific International Exposition held May - November 1935 and February - September 1936. Samples of peeled paint were also supplied from an area of an original 1935 wall of the California Federal Building from the California Pacific International Exposition, which is now the Comic-Con Museum. All the samples included either coarse cement substrates or sand particles from the substrate to ensure that the complete coating stratigraphies remained intact.

The samples were first examined at 30X magnification and then portions were cast into polyester resin cubes for permanent mounting. The cubes were ground and polished for cross-section microscopy analysis and photography. The sample preparation methods and analytical procedures are described in the reference section of this report.

The cast samples were analyzed and photographed using a Nikon Eclipse 80i epi-fluorescence microscope equipped with an EXFO X-Cite 120 Fluorescence Illumination System fiberoptic halogen light source and a polarizing light base using SPOT Advanced software (v. 5.1) for digital image capture and Adobe Photoshop CS for digital image management. Digital images of the best representative cross-sections are included in this report. Please note that the colors in the digital images are affected by the variability of color capture and printing.

Cross-section Microscopy Results:

Dated black and white photographs from the exposition suggest that the body colors of the buildings were light, while the pediments and applied ornaments appeared to be slightly darker. It is difficult to precisely assess tonalities in these black and white images, but in bright sun surfaces that are light colors (like the walls) could appear as white in the photographs, when they may actually have been lighter tans, yellows, pinks or beiges.

Automotive Museum[1]

Gymnasium[2]

Sample Locations
1. C100 Gymnasium. 1935 east Gymnasium wall, far right front corner.
2. C100 Gymnasium. South Gymnasium wall, 1935 wall to right of later pair of exit doors.
3. C100 Gymnasium. South Gymnasium wall, intact 1935 wall above handrail.
4. C100 Federal Building. Peeling late 20th-century paint next to left-hand door reveals what appears to be the original brushed 1935 paint layer.

Comparisons between the coatings on the two buildings is complicated by the fact that there are variations in the coatings histories in different areas. However, it is ultimately possible to determine what seem to be the earliest wall colors for both buildings. The three samples from different areas of the Gymnasium building can be related based on the nature of the cementitious substrates and the sandy stucco or sanded paint coatings, as well as on later finely ground, smooth, relatively clean, oil-based paints that appear on top of the substrates. All of the more recent oil-bound paints in these three cross-sections are consistent with post-1950s paints which have not weathered substantially or collected dirt on their surfaces.

By contrast, the paints in the samples collected from one wall of the Federal Building, where the later paints have peeled off the substrate, are coarsely ground and have eroded

[1] sandiego.gov/digital-archives-photos/1935-36-california-pacific-exposition-california-state-building.
[2] sandiego.gov/digital-archives-photos/1935-36-california-pacific-exposition-palace-electricity.

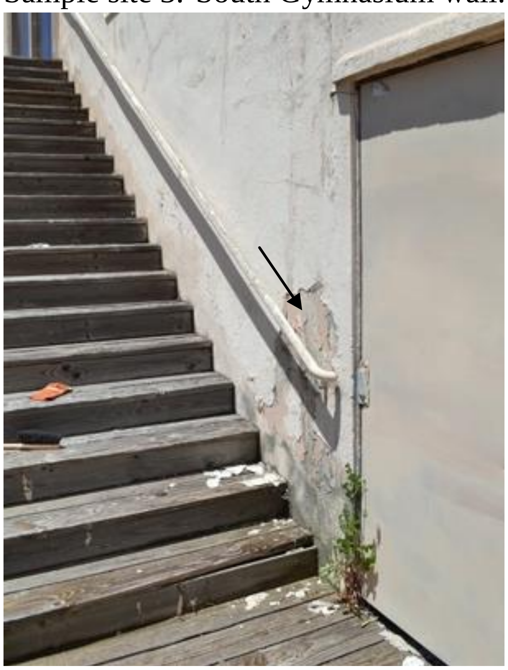
weathered surfaces. The remnants of the first chalky, tannish-yellow paint remain at the bottom of the cross-section for sample 4, and it is the only paint in the coating sequence that did not react strongly positively for the presence of oils with the biological fluorochrome DCF (a marker for oils). It could be leanly bound emulsion paint, or perhaps some form of modified pigmented limewash.

The paint sequences found in samples 1 through 3 from the Gymnasium and sample 4 from the Federal Building are discussed and illustrated in this section of the report. Many of the paints are similar light-colored layers which can best be distinguished by comparing the reflected ultraviolet light images to the reflected visible light images in the cross-sections.

Sample site 1. East Gymnasium wall.

Sample site 2. South Gymnasium wall.

Sample site 3. South Gymnasium wall.



Sample site 4. Federal Building.

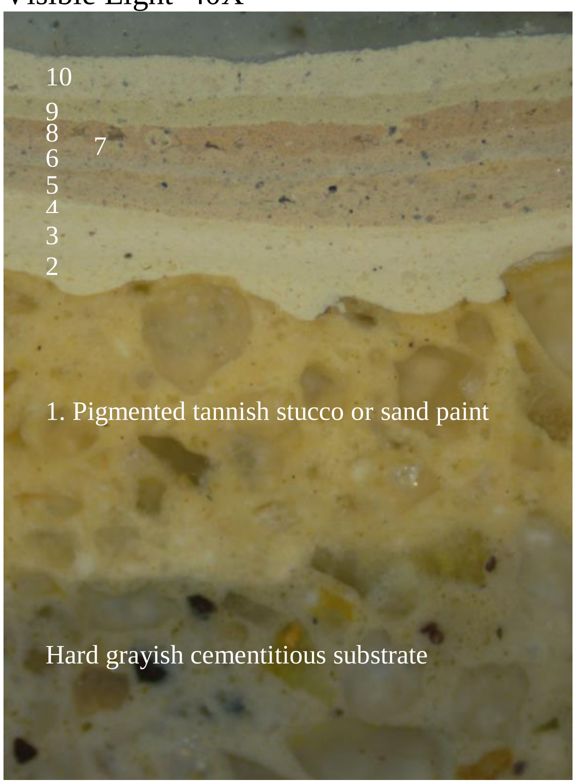
The comparative evidence in sample 1 suggests that the first presentation layer on the building was a light tannish sanded paint or stucco coating. This coating has a grimy, slightly eroded surface. It is followed by nine generations of finely ground, evenly mixed, clean and smoothly applied oil-bound paints. All of these paints are nonfluorescent in reflected ultraviolet light. The physical properties of these paints are more consistent with post-1950s commercially prepared paints.

There is a slight positive reaction for oils in the sanded stucco or paint at the bottom, which might be part of the binder, or oil that soaked into this porous coating from later paint applications. Binding media analysis with biological fluorochromes confirms the presence of oil in all the paints (with DCF), as well as carbohydrates in the binders which could be modern bulking agents and/or natural gum additives (with TTC). None of the paints have protein components in their binders.

The color matching and measurement process shows that the first sanded presentation layer is a good match to the Sherwin Williams SW 6114 “Bagel” identified by Will Chandler as part of his recent investigation.

1. C100 Gymnasium. 1935 east Gymnasium wall, far right front corner.

Visible Light 40X

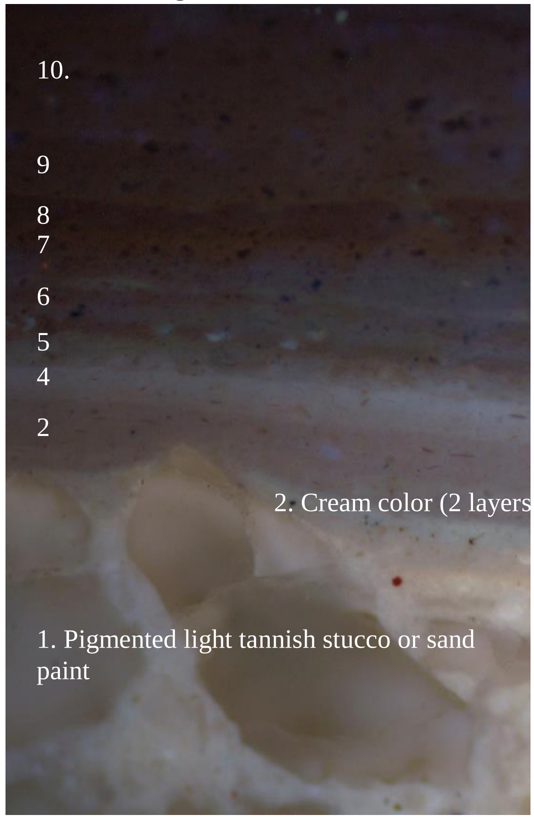


Ultraviolet Light 40X

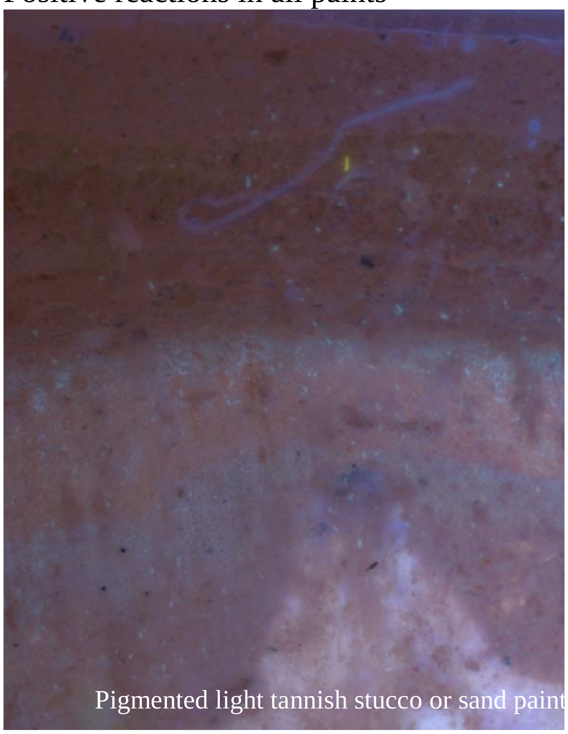
1. C100 Gymnasium. 1935 east Gymnasium wall, far right front corner.

Visible Light 100X

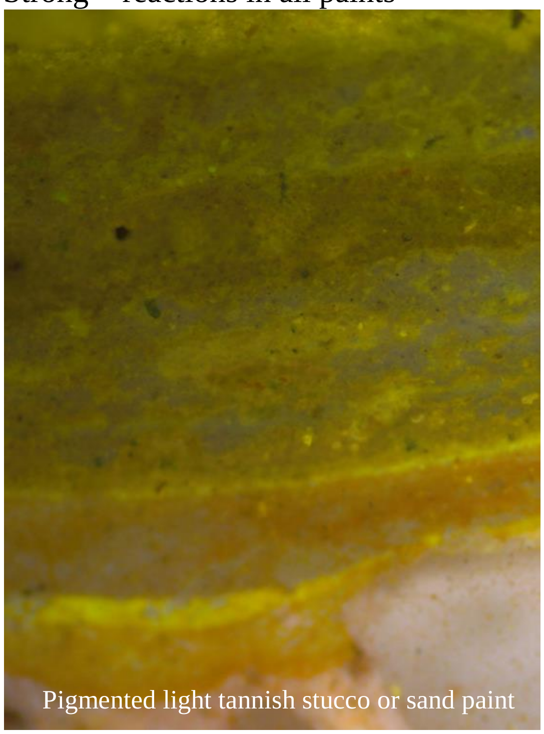
Ultraviolet Light 100X



UV Light & TTC for carbohydrates 100X
Positive reactions in all paints

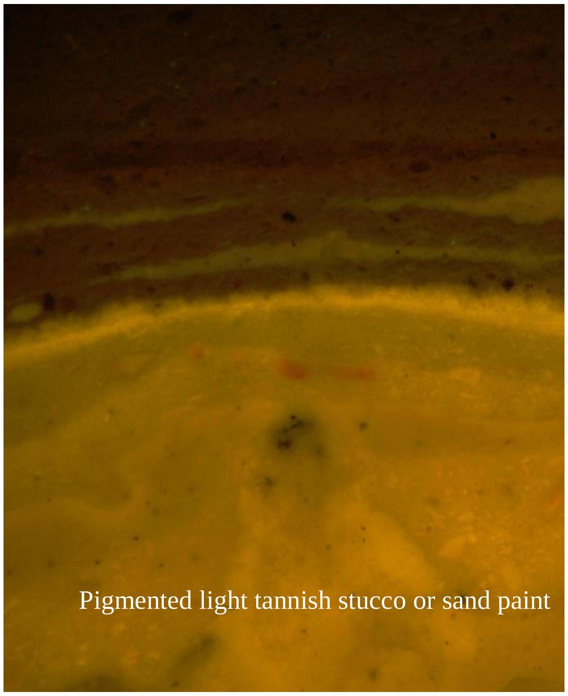


UV Light & DCF for oils 100X
Strong + reactions in all paints

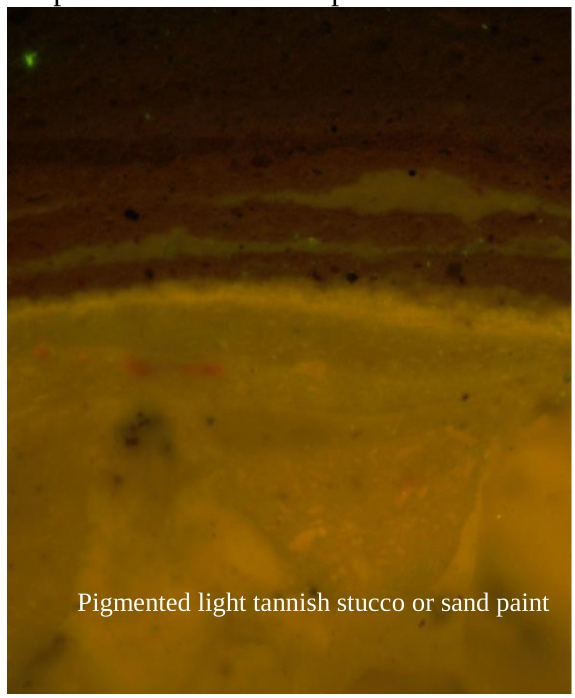


1. C100 Gymnasium. 1935 east Gymnasium wall, far right front corner.

B-2A filter 100X



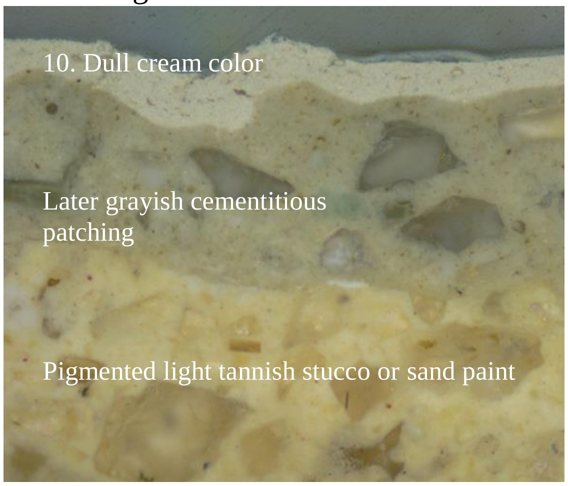
B-2A filter & FITC for proteins 100X
No positive reactions for proteins



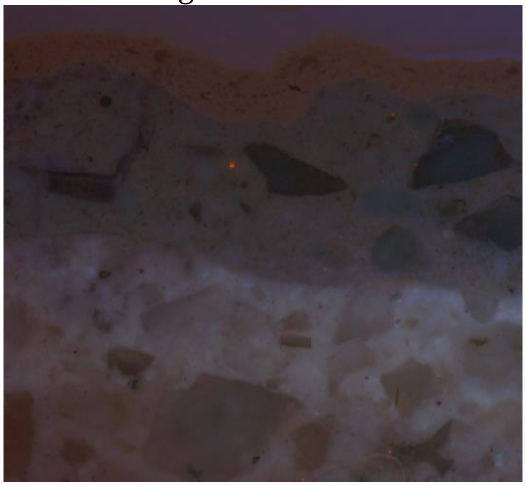
Analysis of sample 2 shows that the same light tannish stucco or sanded paint is present at the bottom of this cross-section, but it is covered over with a later grayish cementitious layer, which was possibly applied as patching. Only the most recent paint identified as generation 10 is present on top of this grayish repair layer.

2. C100 Gymnasium. South Gymnasium wall, 1935 wall to right of later pair of exit doors.

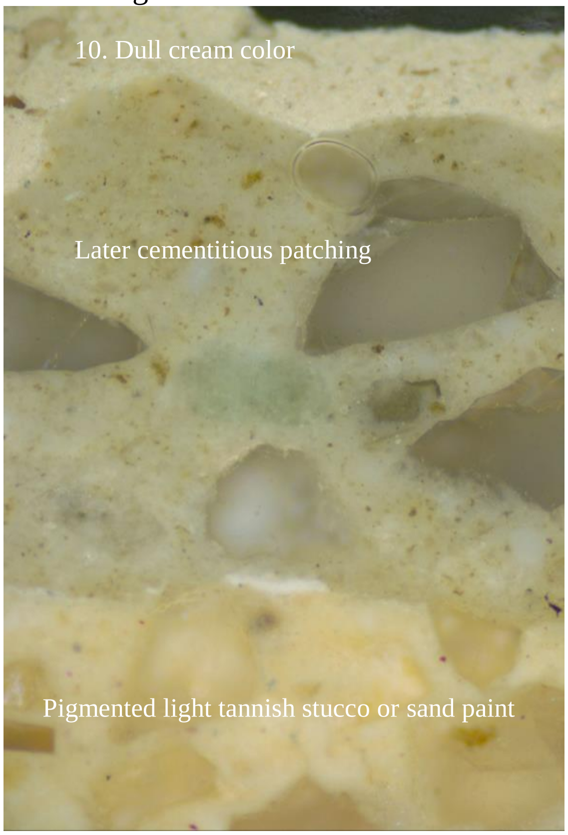
Visible Light 40X



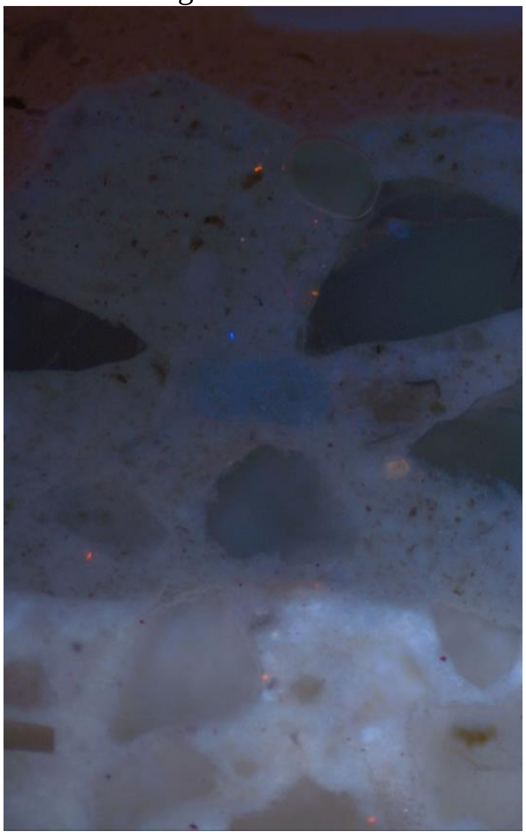
Ultraviolet Light 40X



Visible Light 100X



Ultraviolet Light 100X



Sample 3 is missing the earliest tannish sandy stucco or paint, but it retains most of the other oil-bound paints identified in sample 3.

3. C100 Gymnasium. South Gymnasium wall, intact 1935 wall above handrail.

Visible Light 100X

Ultraviolet Light 100X

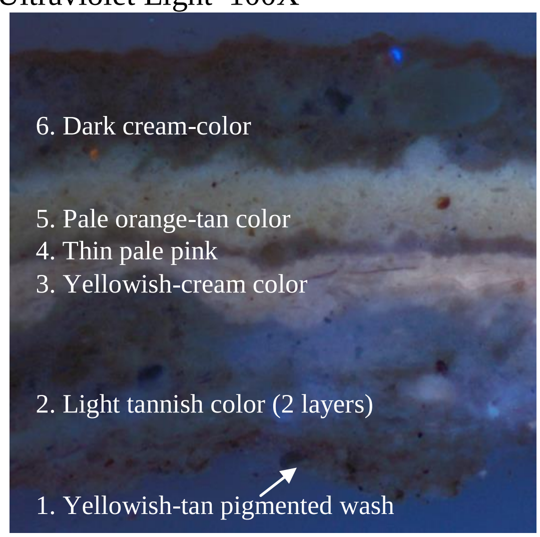
Sample 4 is the outlier of the group. The original paint appears to be a yellowish-tan pigmented wash that was thinly applied on the substrate. This coating was not found on the other building, but modified limewashes and leanly bound emulsion paints are compatible with cementitious substrates as they are more moisture-permeable than traditional and modern oil-bound paints. The second generation in this cross-section sample is a light tannish oil-based paint that is coarsely ground and has an eroded surface. This layer is very close in color to Sherwin-Williams SW 6114 identified by Chandler. Generations 3 through 6 are also coarsely ground and unevenly mixed, and have eroded, weathered surfaces. The physical properties of these paints are more consistent with early 20th-century coatings which were each allowed to weather and collect dirt before repainting.

Binding media analysis show that all the paints contain oil components and carbohydrates, but the earliest tannish-yellow paint at the bottom of the cross-section is far more leanly bound than the subsequent layers.

4. C100 Federal Building. Peeling late 20th-century paint next to left-hand door reveals what appears to be the original brushed 1935 paint layer.

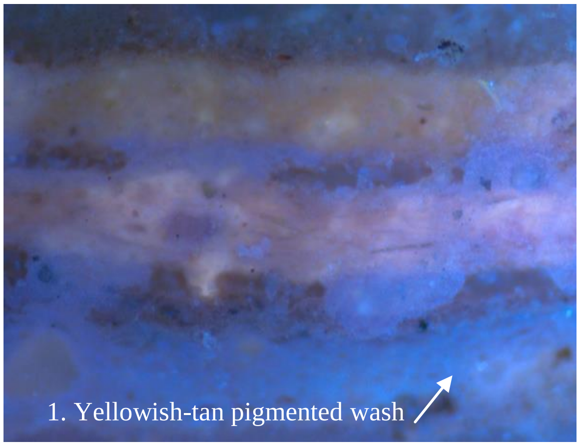
Visible Light 100X

Ultraviolet Light 100X

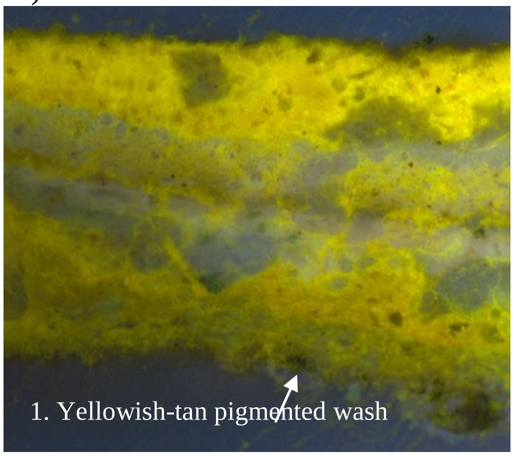


4. C100 Federal Building. Peeling late 20th-century paint next to left-hand door reveals what appears to be the original brushed 1935 paint layer.

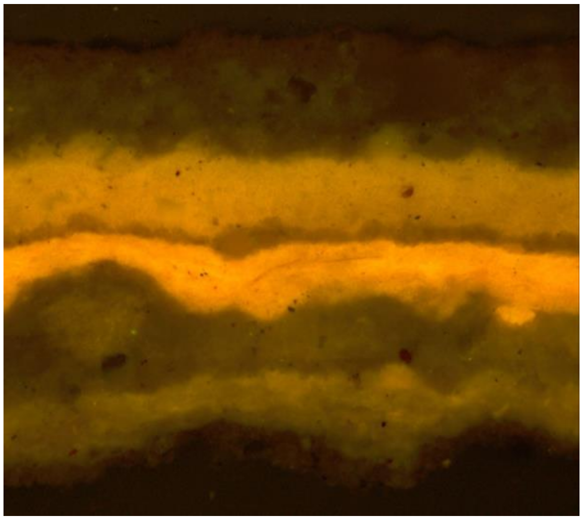
UV Light & TTC for carbohydrates 100X
+ reactions in all paints
(paints partially softened on exposure to ethanol)



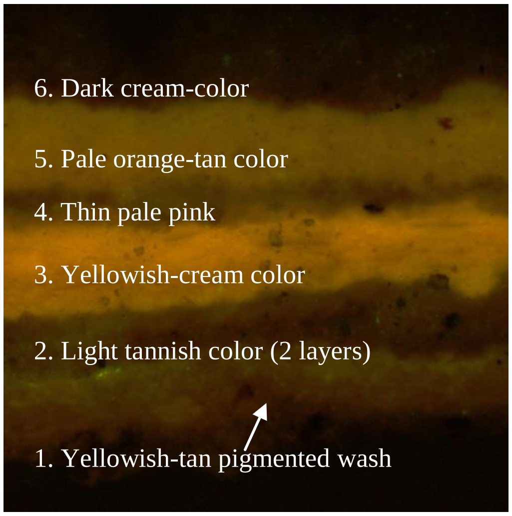
UV Light & DCF for oils 100X
+ reactions in all paints but generation 1



B-2A filter 100X



B-2A filter & FITC for proteins
No reactions for proteins



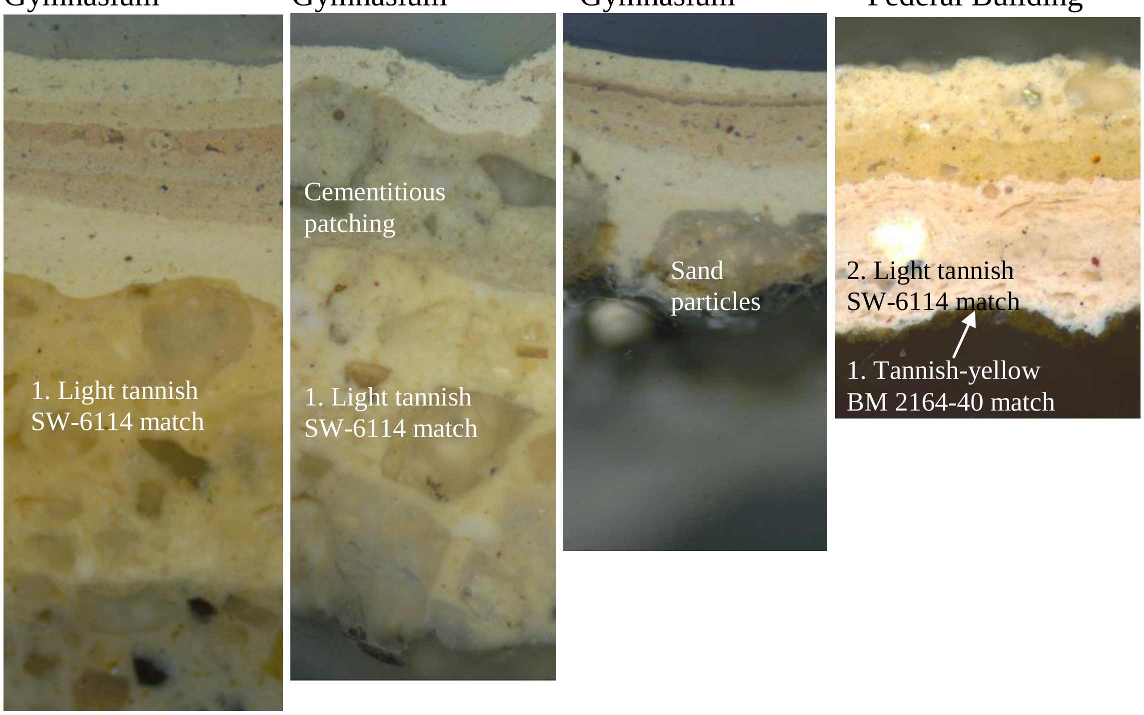
Conclusion:

Comparative cross-section microscopy analysis suggests that the earliest coating on the current Gymnasium is a light tannish sanded stucco or paint that collected some dirt and became eroded from weathering before being painted over (samples 1 and 3) or patched with a grayish cementitious coating (sample 2). All of the smooth, finely ground paints in generations 2 through 10 in these three cross-sections are more consistent with commercial paints dated to the 1950s or after.

The surprising finding is the first leanly bound tannish-yellow wash at the bottom of cross-sample 4. It survives now only as a chalky, thin layer in sample 4. The second generation of paint in sample 4 is a light tannish paint which is very similar in color to the sandy presentation coating in samples 1 and 2 (although the color rendering is slightly different in the photomicrographs). The results of the color matching follow in the next section, and confirm that the color match provided by Chandler of SW 6114 "Bagel" is appropriate for the sanded coating on the Gymnasium Building, and for the second generation paint coating on the Comic-Con Museum Building (formerly the Federal Building). Perhaps the Federal Building was painted first in 1935, but then repainted soon after with a lighter color to match the California State Palace of Electricity & Varied Industries when it was completed.

Comparative Coating Sequences

1. Gymnasium | 2. Gymnasium | 3. Gymnasium | 4. Federal Building



Color Measurement and Matching

Uncast portions of the most intact samples taken from the walls of the Gymnasium (sample 1) and the Federal Building (sample 4) were used for matching with the Minolta Chroma Meter CR-241, a tristimulus color analyzer/microscope with color measurement area of 0.3mm. This instrument has an internal, 360-degree pulsed xenon arc lamp and provides an accurate color measurement in a choice of five different three-coordinate color systems.

The original paints were first identified using cross-section microscopy paint analysis to identify the paint stratigraphies, and then uncast portions of the samples were used for matching. The target layers were exposed with a scalpel at 30X magnification to provide clean areas for color matching. The exposed layers were measured three times in three different areas of the target layers to establish the color coordinates. The measurements were first generated in the Munsell color system (a color standard used in the Architectural Preservation field), and after the measurements were taken the closest Munsell color swatches from a standard Munsell Book of Color (gloss paint standards) was compared under 30X magnification to the actual samples. The measurements were also generated in the CIE L*a*b* color space system, which is currently one of the most widely accepted industry color space measuring systems.

When the target paints were too degraded or transparent to allow accurate color measurement, a second round of color matching was done by eye comparing the Munsell swatches to the samples under 30-45X magnifications and a color-corrected light source. The best visual matches for the Munsell swatches were then used to generate close commercial paint matches.

Original Matte Tannish-yellow Paint

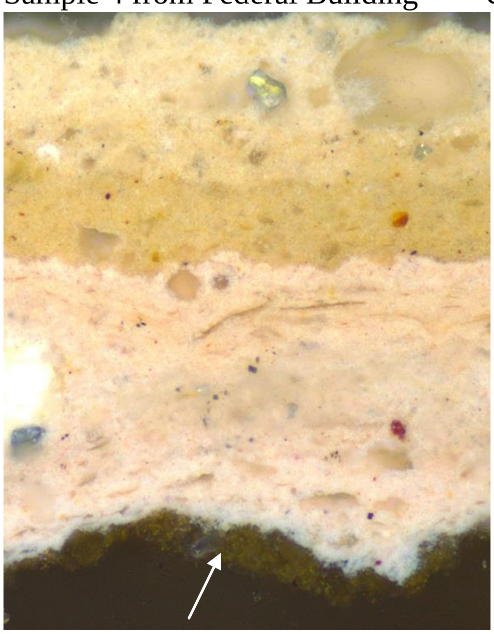
4. C100 Federal Building. Peeling late 20th-century paint next to left-hand door reveals what appears to be the original brushed 1935 paint layer.

Color-matched May 24, 2020

Benjamin Moore 2161-40 "Acorn"

Color System*		Coordinates	
Munsell	Hue	Value	Chroma
	0.7Y	6.8	4.3
CIE L*a*b*	Black to White	Green to Red	Blue to Yellow
	L69.14	a+3.36	b+28.57

Sample 4 from Federal Building   Underside of detached paint flake at 20X



Cross-section analysis shows that the original paint is a thinly applied, tannish-yellow washy layer. The commercial match #2161-40 is an excellent visual match to the most intact areas of the earliest tannish-yellow exterior wall paint when the uncast samples and the cross-sections are examined by eye at 30X magnification under a color-corrected light source. Binding media analysis indicates that the original paint may be some early form of mineral emulsion paint. This paint should be replicated in a flat gloss level to match the original matte appearance of the leanly bound paint.

Earliest Light Tannish Sandy Wall Coating

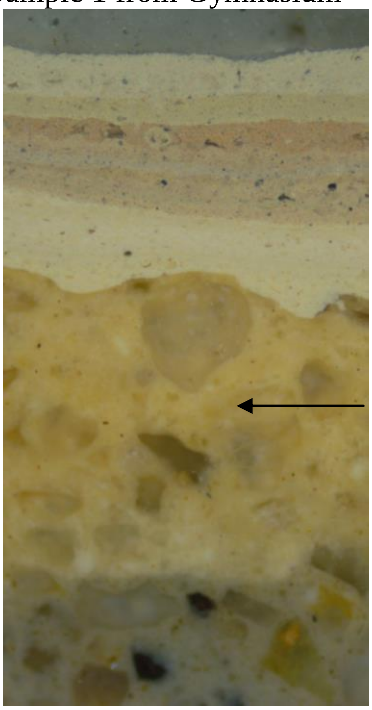
1. C100 Gymnasium. 1935 east Gymnasium wall, far right front corner.

Color-matched May 24, 2020

Sherwin-Williams SW 6114 "Bagel"

Color System*	Coordinates		
Munsell	Hue	Value	Chroma
	2.5Y	7.4	3.6
CIE L*a*b*	Black to White	Green to Red	Blue to Yellow
	L74.97	a+0.39	b+24.77

Sample 1 from Gymnasium



Cross-section analysis shows that the original coating on the Gymnasium is a sandy light tannish layer that appears to be some sort of pigmented stucco or sand paint. The commercial match #SW 6114 is an excellent visual match to the most intact areas of the sandy wall coating when the uncast samples and the cross-sections are examined by eye at 30X magnification under a color-corrected light source. It is also a very good match to the second generation of light tannish paint on the Federal Building (sample 4). Binding media analysis indicates that there is some oil in the binder of this coating. It should be replicated in a flat gloss level to match the original matte appearance of the leanly bound sandy coating.

*** COLOR SYSTEMS** Derived from the Minolta CR-241 Instruction Manual and Minolta Precise Color Communication

Chroma Meter CR-241 offers five different color systems for measuring absolute chromaticity: CIE Yxy (1931), L*a*b* (1976), and L*C*H* (1976) colorimetric densities DxDyDz; Munsell notation and four systems for measuring color differences.

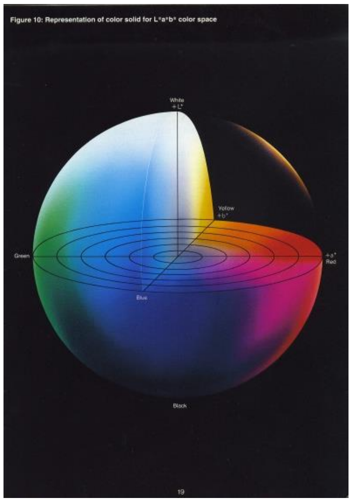
For two colors to match, three quantities defining color must be identical. These three quantities are called tristimulus values X, Y, and Z as determined by CIE (Commission Internationale de l'Eclairage) in 1931.

Color as perceived has three dimensions: hue, chroma and lightness. Chromaticity includes hue and chroma (saturation), specified by two chromaticity coordinates. Since these two coordinates cannot describe a color completely, a lightness factor must also be included to identify a specimen color precisely.

Munsell Color System: The Munsell color system consists of a series of color charts which are intended to be used for visual comparison with the specimen. Colors are defined in terms of the Munsell Hues (H; indicates hue), Munsell Value (V; indicates lightness), and Munsell Chroma (C; indicates saturation) and written as H V/C.

CIE Yxy (CIE 1931): In the Yxy (CIE 1931) color system, Y is a lightness factor expressed as a percentage based on a perfect reflectance of 100%, x and y are the chromaticity coordinates of the CIE x, y Chromaticity Diagram.

CIE L*a*b*: Equal distances in the CIE x,y Chromaticity Diagram do not represent equal differences in color as perceived. The CIE L*a*b* color system, however, more closely represents human sensitivity to color. Equal distances in this system approximately equal perceived color differences. L* is the lightness variable; a* and b* are the chromaticity coordinates.



ΔE: ΔE (Delta E) is the industry measure used to determine how closely two colors match in the CIE L*a*b*. The symbol Δ means "the change in". It is based on calculating the sum of the differences between each measure. The calculation is: $\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$, or, the color difference equals the square root of the squared sums of the differences between each of the three L* a* b* tristimulus values. Industry color standards indicate a ΔE of 1 is barely perceptible to the human eye, and ΔE of 6 to 7 is acceptable for color matches in the printing industry.

Cross-section Preparation Procedures:

The samples were cast in mini-cubes of polyester resin (Excel Technologies, Inc., Enfield, CT). The resin was allowed to cure for 24 hours at room temperature and under ambient light. The cubes were then ground to expose the cross-sections, and dry polished with 400 and 600 grit wet-dry papers and Micro-Mesh polishing cloths, with grits from 1500 to 12,000.

The cast samples were analyzed and photographed using a Nikon Eclipse 80i epi-fluorescence microscope equipped with an EXFO X-Cite 120 Fluorescence Illumination System fiberoptic halogen light source and a polarizing light base using SPOT Advanced software (v. 4.6) for digital image capture and Adobe Photoshop CS for digital image management. The samples were photographed in reflected visible and ultraviolet light using a UV-2A filter with 330-380 nm excitation, 400 nm dichroic mirror and a 420 nm barrier filter and a BV-2A filter with 400-450 nm excitation, 455 nm dichroic mirror and a 470 nm barrier filter. Photographs were taken at 200X and 400X magnifications.

The samples were also stained with three fluorescent stains to characterize the binding media in the various layers and to provide a better comparison between the different materials present in the layers.

The following fluorescent stains were used for examination of the samples:

> Triphenyl tetrazolium chloride (TTC) 4.0% in ethanol to identify the presence of carbohydrates (starches, gums, sugars). Positive reaction color is dark red or brown.
>
> 2, 7 Dichlorofluorescein (DCF) 0.2% in ethanol to identify the presence of saturated and unsaturated lipids (oils). Positive reaction for saturated lipids is pink and unsaturated lipids is yellow.
>
> Rhodamine B (RHOB) 0.06% in ethanol to identify the presence of oils. Positive reaction color is bright orange.

Information Provided by Ultraviolet Light Microscopy:

When viewed under visible light, cross-sections which contain ground, paint and varnish may often be difficult to interpret, particularly because clear finish layers look uniformly brown or tan. It may be impossible using only visible light to distinguish between multiple varnish layers. Illumination with ultraviolet light provides considerably more information about the layers present in a sample because different organic, and some inorganic, materials autofluoresce (or glow) with characteristic colors.

There are certain fluorescence colors which indicate the presence of specific types of materials. For example: shellac fluoresces orange (or yellow-orange) when exposed to ultraviolet light, while plant resin varnishes (typically amber, copal, sandarac and mastic) fluoresce bright white. Wax does not usually fluoresce; in fact, in the ultraviolet it tends to appear almost the same color as the polyester casting resin. In visible light wax appears as a somewhat translucent white layer. Paints and glaze layers which contain resins as part of the binding medium will also fluoresce under ultraviolet light at high magnifications. Other materials such as lead white, titanium white and hide glue also have a whitish autofluorescence.

There are other indicators which show that a surface has aged, such as cracks which extend through finish layers, accumulations of dirt between layers, and sometimes diminished fluorescence intensity, especially along the top edge of a surface which has been exposed to light and air for a long period of time.