REVISITING A PAST TREATMENT OF THE PAINTED INTERIOR OF SAN JOSÉ DE TUMACÁCORI

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Section 1. Introduction

This thesis re-examines the conservation treatment performed by Rutherford Gettens and Charles (Charlie) Steen in 1949 on the interior painted plaster of the Mission Church of San José de Tumacácori near Nogales, Arizona. Rutherford Gettens of the Fogg Museum in Boston, and Charlie Steen, of the National Park Service, collaborated to analyze the materials and condition of the church's painted interior and make recommendations for its in-situ treatment. Their report addressed dry cleaning the plaster and painted areas, stabilizing the detached plaster with mortar edging, and consolidating or 'fixing' the fragile painted designs. This thesis focuses on the then novel polyvinyl acetate (PVAC) treatment performed on the painted plaster.

Gettens outlined the treatment proposal after a site visit in June, 1949 and Steen completed the treatment alone in October through November of the same year.[1] Gettens determined that the best method to consolidate Tumacácori's painted decoration was to apply a synthetic resin known as polyvinyl acetate or PVAC; a material he had pioneered for use in conservation and specifically murals. Since its introduction to conservation in 1932, PVAC has played a critical role in wall painting conservation; yet, there has not been extensive research done on its general use in the field.[2] This

[1] Charlie Steen and Rutherford Gettens, "Tumacacori Interior Decorations" (National Park Service, 1949), 13.

[2] For studies on PVAC in conservation, see Getten's "Polymerized Vinyl Acetate and Related Compounds in the Restoration of Objects of Art", Getten's *Painting materials: a Short Encyclopaedia*, Horie's *Materials for Conservation: Organic Consolidants, Adhesives, and* Coatings, and Hansen et al.'s "Consolidation of Porous Paint in a Vapor-Saturated Atmosphere: A Technique for Minimizing Changes in the Appearance of Powdering, Matte Paint".

thesis revisits that historic treatment and evaluates the surface changes produced by the PVAC application through limited physical examination and facsimile replication.

While PVAC has long been a commonly used consolidation method for wall paintings, there appears to be little scientific information on its long term effect when applied to wall paintings. The painted plaster treatment within the Church offers an opportunity to understand how PVAC impacted the matte painted decoration and wall plaster.

Initially, the methodology was to rely on in-situ examination; however, a site visit became impossible due to the COVID-19 Pandemic. Instead, facsimiles of the degraded painted plaster were used to perform physical testing to better understand the effects of the treatment when new and how the treatment may be affecting the overall performance of the plaster and its fragmentary decorative designs. This thesis is the first step in assisting the park in evaluating the current condition and conservation possibilities of Tumacácori's painted interiors.

Section 2. Site Analysis

The Mission Church of San José de Tumacácori exemplifies the traditional style and construction of frontier mission churches built in New Spain during Spanish colonial rule. While early National Park Service (NPS) staff commented on the remarkable survival of the decorated interiors of the ruined church, Gettens performed the first extensive scientific analysis of the interior decoration which greatly informed his treatment proposal.

2.1 Brief History of the Mission Church San José de Tumacácori

The Mission Church of San José de Tumacácori was established by Father Eusebio Francisco Kino, a Jesuit missionary, in 1691.[3] Father Kino had arrived earlier in New Spain in 1681.[4] He established missions in what was then called Pimería Alta, which is now modern-day northern Sonora and southern Arizona, beginning in 1687.[5] In total, Kino saw the development of over twenty missions in the Primería Alta region.[6] Missions were a critical part of the colonial effort to convert the indigenous people to Christianity. Tumacácori served as a site of conversion for the nearby O'odham and Apaches.

The primary Church found at Tumacácori today is the Franciscan Church that was built after the Jesuits were expelled from New Spain in 1767 (Appendix 1).[7] Construction of the Church began sometime between 1798 and 1802 (Appendix 2).[8] The Franciscan order was expelled in 1827 and maintenance of the site fell to Mexican priests until it was eventually abandoned in 1848.[9] During the abandonment period, the roof of the nave collapsed, leaving the interior painted plaster exposed to the elements. Only the

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[3] Anthony Crosby, "Historic Structure Report: Tumacácori National Monument, Arizona" (Arizona: U.S. Department of the Interior, National Park Service, September 1985), 2
[4] Eusebio Francisco Kino, *Kino's Historical Memoir of Pimería Alta : A Contemporary Account of the Beginnings of California, Sonora, and Arizona /* (Cleveland : Arthur H. Clark Company, 1919), 30.
[5] Ibid., 50.
[6] "Missions - Tumacácori National Historical Park (U.S. National Park Service)," accessed January 18, 2021, https://www.nps.gov/tuma/learn/historyculture/missions.htm.
[7] Crosby, "Historic Structures Report: Tumacácori National Monument, Arizona," 3.
[8] Ibid., 4.
[9] Ibid., 7-10.

masonry dome of the Sanctuary survived, protecting the decorative paintings on its walls and dome.

In 1908, Tumacácori became a National Monument, although preservation work did not begin until 1918 when NPS assumed responsibility.[10] In 1919, Frank Pinkley became the Superintendent of Tumacácori, and a new chapter of preservation began. Pinkley saw to the reconstruction of the missing timber roof as well as stabilization of the brick and adobe exterior (Appendix 3); however, it was not until 1949 that the interior plaster was studied and conserved.

2.2 Technical Description of the Interior Finishes of San José de Tumacácori

The Church at San José de Tumacácori is constructed of unfired adobe and low-fired bricks and lime plaster. Given that this thesis's focus is on the interior painted plaster, special attention will be given to the plaster substrate and its gypsum wash and decorative polychromy.

The walls are constructed of adobe and low fired brick and earthen and lime mortars (Appendix 2, pg. 52). The interior walls are finished with two coats of coarse lime plaster.[11] The plaster is gray in color and contains approximately 25 percent lime by weight."[12] The thickness of the two leveling preparatory coats varies, but it is one and a

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[10] Ibid., 11.

[11] Charlie Steen and Rutherford Gettens, "Tumacácori Interior Decorations," *Arizoniana: The Journal of Arizona History* 3, no. 3 (Fall 1962): 11.

[12] Jean Jang, "Performance Evaluation of Commercial Nanolime as a Consolidant for Friable Lime Based Plaster," *Theses (Historic Preservation)*, 2016, 35.

half inches thick on average. The original formulation was probably close to three parts sand to one part lime by volume. [13]

Finely ground gypsum was applied to the plaster as a white finish. Per Gettens and Steen, "The raw gypsum was heated, apparently, to form the hemihydrate (Plaster of Paris, $2CaSO_4 \bullet H_2O$) and rehydration occurred at time of wetting for purpose of application to the wall."[14] The gypsum was applied as a thin later, only 1-2 millimeters thick,[15] most likely to seal the lime surface, reflect the light, and provide a ground for the decorative polychromy.

Gettens and Steen performed the earliest technical description and analysis of the interior painting in 1949, later published in 1962.[16] Pigment analysis was performed again in 2001 by Tim Lewis and Matilde Rubio. The following table summarizes the findings of the color analysis:[17]

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[13] Ibid., 22.
[14] Steen and Gettens, "Tumacácori Interior Decorations," 1949, 35.
[15] Ibid., 36.
[16] Steen and Gettens, "Tumacácori Interior Decorations," *1962,* 7–21.
[17] Jocelyn Chan, "An Investigation of the Painted Finishes of Mission San José de Tumacácori's Façade: At the Interface of Materials Analysis, Conservation, and Cultural Confluence," *Theses (Historic Preservation)*, January 1, 2015, 65.

Table 1: Pigments Found in the Interior Decoration at Tumacácori			
Color	**Pigment**	**Formula**	**Source**
Bright Red	Cinnabar	HgS (mercury II sulfide)	R.J. Gettens, 1949, Lewis & Rubio, 2001
	Cadmium red (retouched areas?)	CdS and CdSe in varying proportions	Lewis & Rubio, 2001
Red, Orange-Red, Orange-Yellow, Pale Pink	Ocherous hematite	$FeO(OH)\bullet nH_2O$ (yellow ochre) Fe_2O_3 (red ochre)	R.J. Gettens, 1949
White	Gypsum	$CaS0_4\bullet 2H_2O$	R.J. Gettens, 1949, Lewis & Rubio, 2001
Black, Gray, Blue Gray	Charcoal	C	R.J. Gettens, 1949, Lewis & Rubio, 2001
Green	Copper chloride	$CuCl_2$	Lewis & Rubio, 2001
	Chromium green	Cr_2O_3	Lewis & Rubio, 2001
Blue	Indigo (stain)	$C_{16}H_{10}N_2O_2$	R.J. Gettens, 1949, Lewis & Rubio, 2001
	Prussian blue	$C_{18}Fe_7N_{18}$	Lewis & Rubio, 2001
Metallic Brown-Gray	Bronze gilt	Copper-zinc alloy	R.J. Gettens, 1949

2.3 1949 Site and Treatment Analysis

In June of 1949, Rutherford Gettens, chief of museum technical research at the Fogg Museum,[18] and Charlie Steen, NPS archaeologist, visited Tumacácori to analyze the Church's interior and make recommendations for treatments. Steen then later returned

[18] Francesca Bewer, *A Laboratory for Art: Harvard's Fogg Museum and the Emergence of Conservation in America, 1900-1950* (Cambridge, MA: Harvard Art Museum, 2010), 231.

that year to Tumacácori to complete the treatments as recommended by Gettens. Gettens and Steen submitted a report to the National Park Service with their findings and recommendations (Appendix 4).[19]

According to Gettens and Steen, the plaster in the Sanctuary was in fairly good condition at the time of their visit compared to the nave. The dome over the Sanctuary continued to protect the painted decorations. [20] The Sanctuary is primarily white with painted decoration. The authors state:

> To a height of about 15 feet the wall is white with the exception of a decorated band of red drapes and black conventional designs. The white finish coat here seems thinner than in the nave. In places, the finish coat is almost abraded away, showing the rough grayish plaster beneath.[21]

From the windows up to the molding, the plaster is "tinted, yellowish pink, except for the pendentives which are decorated."[22] Adobe dust covered the plaster. Before treating the decorations, Gettens and Steen recommended carefully dry cleaning the plain plaster surface.

Once the plaster was cleaned, they developed a treatment proposal for the decorative painting (Appendix 5). The applied decorations were identified as distemper with an aqueous medium[23] rather than a true fresco, and their condition was found to be “slightly chalky .”[24] A consolidant or ‘fixative’ was therefore needed to stabilize the

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[19] Steen and Gettens, “Tumacácori Interior Decorations,” 1949.
[20] Ibid., 18.
[21] Ibid.
[22] Ibid.
[23] Ibid., 28.
[24] Ibid., 24.

chalking paint to prevent loss. Gettens and Steen argued that an application of a fixative would:

1) Diminish lodgment of dust and aid in periodic cleaning;
2) Stabilize the decorative paint so it could be cleaned;
3) Enhance the brilliance of colors and make the designs more readable;
   In fixing the surface it will be necessary if possible, to avoid:
   1. Gloss;
   2. Accentuation of irremovable stains;
   3. Darkening of the scratch coat beneath, where it may be exposed.[25]

They determined that the best method for consolidating the painted decoration was to spray "a thin solution of a colorless or nearly colorless plastic solution. The fixative spray is to be followed immediately by a spray of pure thinner, same as that used to dissolve the plastic."[26] The conservators determined that polyvinyl acetate (PVAC) met these requirements. They used a specific PVAC manufactured by Union Carbide called Vinylite A™. The Vinylite™ series consisted of various forms of PVAC that varied based on viscosity. Gettens and Steen clarified that a Vinylite A™ with medium viscosity was to be used, likely being AYAF, based on the molecular weight of the PVAC. Vinylite A™ will be discussed in the following section.

The Vinylite A™ was added to a solvent mixture containing toluene, ethylene dichloride, cellosolve, cellosolve acetate, and dibutyl phthalate. The custom solution was prepared locally by Pioneer Paint and Varnish Company in Tucson. Correspondence between Gettens and the manager of Pioneer, Harry Bacal, indicates that for the

[25] Ibid.
[26] Ibid.

thinner, they used 50% toluene and 50% xylene, rather than only toluene.[27] The solutions were then sprayed onto the plaster.

The solution was 5% PVAC; the solvent ratio was 70% toluene, 20% ethylene dichloride, 4% cellosolve, 4% cellosolve acetate, and 2% dibutyl phthalate.[28] Toluene and ethylene dichloride were the primary solvents, cellosolve and cellosolve acetate reduced the rate of evaporation, and dibutyl phthalate acted as a plasticizer.[29]

Section 3. Technical History of Polyvinyl Acetate

Polyvinyl acetate, also known as PVAC, not to be confused with poly(vinyl) alcohol or PVAL, is a synthetic resin that has played a significant role in heritage conservation. PVA was first synthesized in 1912 by German scientist Fritz Klatte (U.S. patent number 1,241,738).[30] PVAC is formed by the free radical vinyl polymerization of vinyl acetate (U.S. patent number 1,710,825) (Figure 1).

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[27] Rutherford Gettens, "Letter in Regards to Polyvinyl Acetate," August 3, 1949, WACC.
[28] Steen and Gettens, "Tumacácori Interior Decorations," 1949, 25.
[29] Rutherford Gettens, "Polymerized Vinyl Acetate and Related Compounds in the Restoration of Objects of Art," *Technical Studies in the Field of the Fine Arts.* 4, no. 1 (1935): 20-21.
[30] Rutherford John Gettens, *Painting Materials; a Short Encyclopaedia,* (New York: Dover Publications, 1966), 74.

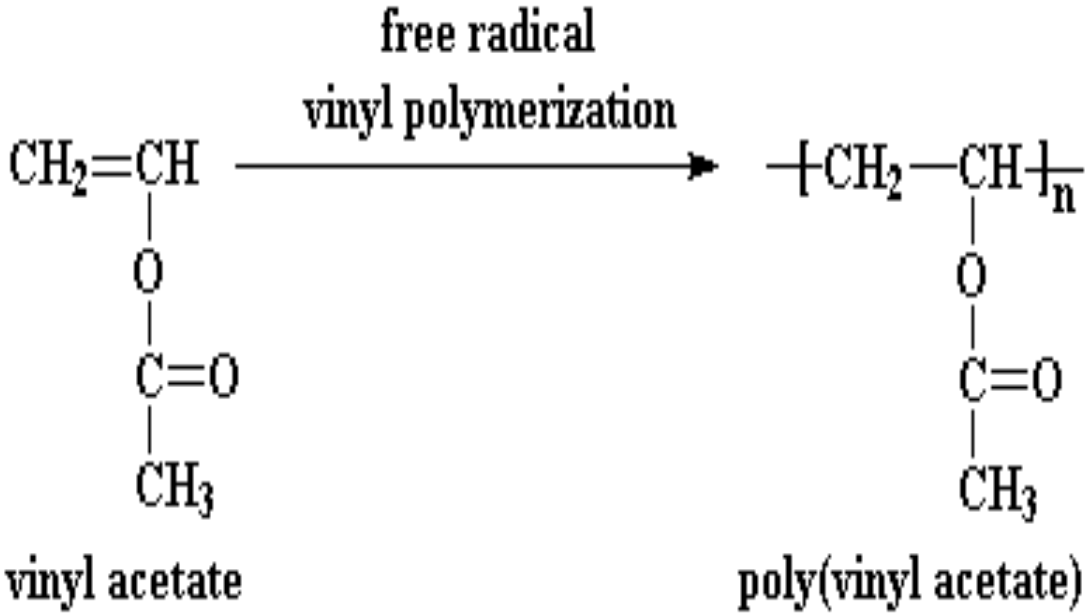

Figure 1- Free radical vinyl polymerization process of vinyl acetate

The resin is "colorless solid, horny, and a little rubbery, but not brittle."[31] PVAC has a wide range of commercial uses and applications. As an adhesive, it can be used on both porous and non-porous substrates, including paper, cloth, leather, glass and plastics.[32] As a solid, it can be molded into a wide variety of shapes with various functions. Vinylite™, the series of PVAC manufactured by Union Carbide and Carbon Chemical Corporation, that Gettens and Steen used, was considered a "versatile plastic" as it could be molded into objects for anything from personal to industrial use.[33] Today in the construction industry, PVAC's are most commonly used as water based emulsions as admixtures and bonding agents in concrete and masonry and can be found more commonly as an ingredient found in Elmer's® Glue.

[31] Ibid.
[32] J. Shields, *Adhesives Handbook*, 3rd ed. (London: Butterworths, 1984), 71.
[33] "Vinylite: The Versatile Plastic," *Union Carbide and Carbon Corporation*, 1934.

3.1 Polyvinyl Acetate in Conservation

PVAC was first utilized in a conservation context in 1932 "as a facing and attaching adhesive for the transfer of a fresco" by Gettens and Stout.[34] Since then, `PVAC has found a place in conservation for a wide variety of uses.[35] Variations in viscosity due to the polymerization process allow for a wide range of application use.[36]

According to Gettens, PVAC had extensive benefits in the field of conservation as an adhesive, consolidant, varnish, and fixative. One such asset is that it does not break down when exposed to extreme sunlight and has a low refractive index, which means that PVAC will not darken matte surfaces.[37] PVAC "is soluble in a range of solvents: acetone, alcohols like methyl and ethyl alcohols, esters as ethyl and amyl acetates, aromatic hydrocarbons like toluene, and benzene, chlorinated hydrocarbons as ethylene dichloride, and glycol ethers like cellosolve."[38] The ability for PVAC to be dissolved in various solvents allows for multiple factors to be manipulated, including evaporation rate and viscosity depending on the material and context.

3.1.1 On Wall Paintings

PVAC quickly became popular in the field of wall painting conservation. It was one of the earlier synthetic resins to be used; however, as more stable synthetic resins were developed such as acrylics, PVAC became less popular. When used as a fixative in a

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[34] C. V. Horie, *Materials for Conservation : Organic Consolidants, Adhesives and Coatings* (London; Butterworths, 1987), 94.
[35] Ibid.
[36] Rutherford Gettens, "Polymerized Vinyl Acetate and Related Compounds in the Restoration of Objects of Art," 19.
[37] Ibid., 18-19.
[38] Ibid. 19.

material such as a paint film or surface, optimal or ideal properties include cohesive strength, adhesive strength (where desired), depth of penetration, flexibility, controlled optical effects (i.e., no visual change or color saturation), biological resistance, resistance to atmospheric agents, static electricity and dust accumulation, non-toxicity, and controlled evaporation of the dispersant as well as reversibility.[39]

The benefits of PVAC, according to Gettens, was that it was stable in ultraviolet energy and does not readily embrittle or discolor when exposed to sunlight.[40] It will discolor when exposed to water, turning milky white when wet, but it will revert to transparent once dried.[41] PVAC is shown to be more durable when exposed to high salt content.[42] It appears that PVAC is also resistant to biological growth,[43] though it is biodegradable.[44] It has also been shown to become more brittle when exposed to accelerated degradation.

PVAC meets most of the required characteristics outlined by Mora et al. The material should be colorless, retain plasticity, be readily soluble in solvents so as to penetrate easily, and that said solvents are not too volatile, and finally, that materials can be dissolvable.[45] Treatments involving PVAC are not entirely reversible, though they

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[39] Paolo Mora, Laura Mora, and Paul Philippot, *Conservation of Wall Paintings*, Butterworths series in conservation and museology. (London: Butterworths, 1984), 216-222.
[40] Gettens, "Polymerized Vinyl Acetate and Related Compounds in the Restoration of Objects of Art," 19.
[41] Horie, 92.
[42] Xiang He et al., "Mechanisms of Preservation Damage: Restoration Materials Affecting Salt Distribution and Soil Expansion in Wall Paintings of Dunhuang," *Archaeol Anthropol* 11 (2019): 5175.
[43] A.M. Abdelghany, M.S. Meikhail, and N. Asker, "Synthesis and Structural-Biological Correlation of PVC\PVAc Polymer Blends," *Journal of Materials Research and Technology* 8, no. 5 (October 2019): 3915.
[44] Manfred Amann and Olivia Midge, "Biodegradability of Poly(Vinyl Acetate) and Related Polymers," *Advances in Polymer Science* 245 (January 2012): 167.
[45] Rutherford Gettens, "Principles in the Conservation of Mural Paintings," *Anthropological Papers* 8 (1951): 66-67.

have been shown to be dissolvable 30-40 years after application.[46] Of the most significant concern at Tumacácori is the visual impact of the PVAC on the wall paintings, especially in an uncontrolled environment.

3.1.2 On Matte Paint

When applying a consolidant to an intentionally matte paint, careful considerations must be made so as to ensure the optical qualities of the paint are not changed. Imparting a gloss and saturation darkening are of greatest concern when conserving matte paint due to the alteration of optical properties and thus effecting the way in which the surface is viewed.

Hansen, Lowinger, and Sadoff examined the impacts of consolidation on matte paint and attempted to create consolidation application methods that would reduce unwanted changes to matte paint including darkening or discoloration, increased gloss, and the appearance of tide lines.[47]

Discoloration (darkening or saturation) can be explained by two different scenarios "(1) the differences in the refractive indices of the treated pigment and vehicle; and (2) reverse migration of the polymer from the interior to the surface with solvent evaporation."[48] Of primary concern at Tumacácori is the visible gloss observed on areas of the plain undecorated gypsum background, which can currently be seen on

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[46] Horie, 92.
[47] Eric Hansen, Rosa Lowinger, and Eileen Sadoff, "Consolidation of Porous Paint in a Vapor-Saturated Atmosphere: A Technique for Minimizing Changes in the Appearance of Powdering, Matte Paint," *Journal of the American Institute for Conservation* 32, no. 1 (Spring 1993): 1.
[48] Ibid., 3.

the walls, particularly in the Sanctuary, as well as on hand samples. Gloss is caused by resin concentrating at the surface.

The easiest way to reduce gloss is to slow down the evaporation of the PVAC solution so that more time is given for the consolidant to penetrate the surface and become evenly distributed throughout the porous body or paint film.[49] For this reason, cellosolve and cellosolve acetate in Gettens' solution was critical, as these products reduce the rate of evaporation allowing the solution to penetrate and set. Controlling the environment by saturating the atmosphere with solvent is another way to control absorption of the fixative into the surface;[50] however, this would have been next to impossible at Tumacácori, even today.

3.1.3 Vinylite A™

Vinylite A™ was the line of PVAC products specified by Gettens and Steen used to conserve the wall paintings at Tumacácori. Vinylite A™, one of the Vinylite series, was a trademarked product from Union Carbide that entered the market in 1927.[51] Union Carbide advertising promoted the versatile nature of Vinylite A™ as a plastic that manufacturers could use to create a variety of shapes, including rods and tubes and household goods, such as trays and wine glasses.[52]

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[49] Ibid., 5.
[50] Ibid., 6.
[51] "'Vinylite' Resin Sample," Museum of Applied Arts and Science, accessed December 12, 2020, https://collection.maas.museum/object/238238.
[52] "Vinylite: The Versatile Plastic," *Union Carbide and Carbon Corporation*, 1934.

The Vinylite series was a precursor to the more commonly known AY resin series. The AY resin series consists of five different types of PVAC, which vary based on their molecular weights- AYAA, AYAB, AYAC, AYAF, and AYAT. According to Horie, Vinylite A™ was a precursor to AYAF.[53] The Dow Chemical Company purchased Union Carbine in 2001; unfortunately, they do not have any archival information on Vinylite A™ or AYAF.[54] In 1937, Union Carbide, which was then called Carbide and Carbon Chemicals Corporation, published promotional material on the Vinylite series, indicating that AYAF is of medium viscosity. AYAA is lowest in viscosity and AYAT is highest in viscosity.[55]

With the Dow Chemical Company's purchase of Union Carbide, the AY resins series has since been discontinued. Fortunately, in 2019, published conservation research reported on potential substitutes for the discontinued products. Based on the findings, Union Carbide's AYAF most closely matches Synthomer's ADS H155 and ADS H190, which the company has since renamed M40 and M45, respectively.[56]

3.2 Case Study- PVAC on Cave 85 at the Mogao Grottoes, Dunhuang

There has been very little subsequent analysis done on the use of Vinylite A™ on previous wall painting conservation treatments. At the Nelson-Atkins Museum, Gettens also recommended the use of Vinylite A™ for the conservation of a Chinese wall painting, *Paradise of Tejaprabha Buddha,* that was relocated to the museum in the

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[53] Horie, 94.
[54] Samantha Alderson et al., "Potential Substitutes for Discontinued Poly(Vinyl Acetate) Resins Used in Conservation," *Journal of the American Institute for Conservation* 58, no. 3 (June 12, 2019): 159.
[55] *Vinylite Resins: General Properties and Uses* (New York, New York: Carbide and Carbon Chemicals Corporation, 1937), 5.
[56] Ibid., 173.

1930s. Kathleen Garland, conservator at the Nelson-Atkins Museum, performed extensive pigment analysis on the mural and observed a "shiny resin" in the black outlines. She noted that the resin "could not be identified, but correspondence in the museum's archives suggest the resin might be Vinylite A™, a poly(vinyl acetate) resin recommended by Rutherford Gettens as a consolidant."[57] She noted that further analysis was not completed on the resin.[58] No other published evidence has been found, thus far on the use of Vinylite A™ as a consolidant or fixative on wall paintings either in-situ or on transfers.

In Cave 85 in the Mogao Grottoes in Dunhuang, polyvinyl acetate was used as an emergency treatment for reattachment. In 1999, the area saw extended periods of rainfall which led to "severe exfoliation and losses of the painted surface."[59] Previous treatment campaigns also included polyvinyl acetate. Until 1999, conservators preferred the use of synthetic resins due to their stability.[60] After the 1999 treatment with polyvinyl acetate, conservators opted to use an organic alternative with a slurry of clay and distilled water.[61]

Polyvinyl acetate entered the conservation field relatively soon after its commercial introduction in the 1930s and has played a very critical role within mural

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[57] Kathleen Garland, "Surveying Paradise: The Conservation Survey of a Yuan Dynasty Wall Painting on a Clay Base," in *Conservation of Ancient Sites on the Silk Road*, ed. Neville Agnew (Los Angeles, CA: Getty Publications, 2010), 301-03.
[58] Kathleen Garland, Conversation with Kathleen Garland, Zoom, March 24, 2021.
[59] Lori Wong and Neville Agnew, eds., *The Conservation of Cave 85 at the Mogao Grottoes, Dunhuang* (Los Angeles, CA: Getty Conservation Institute, 2013), 97.
[60] Ibid., 293.
[61] Ibid., 97.

painting conservation. Its use at Tumacácori is especially significant, as it appears to be one of the earliest examples of in-situ consolidation with PVAC and certainly the first in the United States. This forgotten treatment adds another layer of significance to the interior painted decorations of the Tumacácori Mission Church.

Section 4. Sample Collection and Preparation

As mentioned, the original intention was to travel to the site and perform in-situ evaluation, such as water absorption testing; however, a site visit became impossible due to COVID-19. Instead, samples previously collected from the site by the Center for Architectural Conservation (CAC) at the University of Pennsylvania were used for analysis, and facsimiles were used to perform physical tests to better understand the original treatment and its effects.

4.1 Sample Collection and Preparation

The first step in sample collection was to organize and assess the samples that the CAC had already collected, which were immediately available in the lab. All samples were collected from the nave. Samples with colored pigment were set aside, and a sample schedule was made (Appendix 6). Bulk samples were examined (Appendix 7), and a selection of those were then prepared for cross-section analysis. Cross-sections were made using Bioplastic™ casting resin. Following curing, they were cut using a Buehler Isomet 1000 and hand polished. Cross-sections were then adhered to slides using Meltmount™.

4.2 Facsimile Sample Preparation

Facsimiles of the scratch coat, ground and painted design layer were made in order to assess the effects of the PVAC consolidation on the surface finishes. Samples were made based on previous examinations of the plaster, gypsum ground, and painted design layer. The facsimiles served as samples on which physical tests were performed. Based on the trial tests, it was determined that only 4" disks were needed to complete the physical tests.

4.2.1 Plaster Preparation

Jang's 2016 thesis guided plaster preparation. As part of her methodology, she analyzed the plaster using gravimetric analysis and thin-section petrography.[62] From these examinations, she determined that the "scratch or lower layer of exterior plaster was composed of 20% to 25% binder."[63] Thus, the mixture of lime and aggregate was in a ratio of one part lime to three parts aggregate.

Sand from Tumacácori was used as the aggregate to make the replicas as accurate as possible. Following Jang's methodology, ASTM sieve No. 4 and No. 8 were used, following ASTM C136/C136M—19. The sand was mechanically sieved, with each batch being sieved for 10 minutes.

Type S hydrated lime was used as the binder, as this was what Jang recommended based on prior research on the plaster although lime putty would have been originally used. The plaster was mixed as outlined by ASTM Standard C305-14-

[62] Jang, 34.
[63] Ibid., 35.

Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency. Forty samples were needed in total. A test run was performed on 15 samples. Thirty more samples were made a week later. The samples were wet cured for a week under controlled moisture and temperature to prevent cracking and ensure a good set. The samples were then left to dry cure for an additional three weeks. In total, the samples were cured for 28 days as per ASTM.

4.2.2 Gypsum Ground and Paint Application

Terra alba, a fine-grained, white gypsum pigment was applied to the plaster discs as the ground. In order to prepare the gypsum for application, the gypsum was first ground on a glass plate with a glass muller. Only water (i.e., no binder) was used to simulate the most severe form of chalking As noted by Gettens and Steen and confirmed in-situ, the interior gypsum layer is approximately one to two millimeters thick. In order to replicate that thickness, the plaster samples were pushed down within their casting rings to create a two millimeter clearance to create the gypsum ground. The plaster samples were then sprayed with water and painted with the gypsum ground. They were left to cure for at least one day.

Following the curing of the gypsum, the pigmented design layer was then applied to the facsimiles. Hematite Red (Kremer) was used for the design layer as it is the most common color in the church after white. The pigment was also ground using a glass plate and a glass muller. Again, only water was used without any binder. The pigment was applied depending on what tests were to be done:

Table 2: List of Facsimiles and Tests Performed			
Set #	**Number of Samples**	**Pigment Application Style**	**Tests**
Set 1	20 Samples	All painted with 2 hematite stripes on the edges and a gypsum stripe down the middle	Chalking and Liquid Absorption
Set 2	20 Samples	10 all hematite, 10 all gypsum	Color, Luster, and Vapor Permeability

4.2.3 PVA Application

Gettens and Steen outlined the procedures for both mixing and applying the PVAC consolidant. Their procedure was followed in making PVAC for the replicas. While they did not outline every step, the PVAC solution was mixed following the strict safety standards outlined by the University of Pennsylvania.

As previously mentioned, the 1949 report outlines the fixative formula as follows:

- Vinylite A™ (medium viscosity)= 50 grams
- In solvent mixture:
    - Toluene= 700 ml.
    - Ethylene dichloride= 200 ml.
    - Cellosolve= 40 ml.
    - Cellosolve acetate= 40 ml.
    - Dibutylphthalate= 20 ml.

Gettens and Steen recommended a 5% solution of PVAC. Following the application of the solution, a thinner was applied, presumably to 'flash' any residual resin on the

surface resulting in a more matte appearance. According to the letters between Gettens and Harry Bacal, the person responsible for mixing the solutions, the thinner consisted of 50% toluene and 50% xylene.

In creating the adhesive solution, the solvents were mixed in a 6-ounce jar provided by Preval, as only enough adhesive was needed for twenty samples. All mixing was done in a fume hood. Once the solvents were mixed, the selected PVAC was then suspended in the solution using a cheesecloth. This allowed the resin to dissolve evenly. In a separate jar, 50% toluene/50% xylene was mixed. The jars were then sealed until time for spraying.

Spraying was done in a fume hood designed for aerosol spraying. Preval provided spray canisters that effectively attached to the jars to ensure no leaking and even spraying. The first pass of fixative was applied and allowed to dry. The spraying of the thinner followed this immediately as indicated in Gettens' report. Only half of the facsimiles were sprayed with consolidant.

Table 3: Consolidated Facsimiles	
Set 1	**Set 2**
1.1.2	2.1.1
1.1.3	2.1.2
1.1.4	2.1.3
1.1.5	2.1.4
1.1.12	2.1.11

2.1.10	2.2.1
2.1.12	2.2.2
2.1.13	2.2.3
2.1.14	2.2.4
2.1.15	2.2.5

Section 5. Laboratory Analysis

5.1 Optical Analysis

5.1.1 Visible Light Microscopy

All samples with identified pigment were examined under a Lecia MZ16a stereomicroscope using reflected light microscopy in order to examine texture and the overall state of the pigment. The samples were photographed using Nikon Digital Elements BR software (Appendix 7).

A few bulks samples were selected for cross-section microscopy. Selections were based on the location of the sample and assumptions about the PVAC treatment, primarily whether the sample was treated or untreated. In the end, three samples were assessed in cross-section microscopy, FTIR, and Py-GC/MS— samples 1, 25, and 27. Sample 27 is thought to be untreated and served as a control.

While only three samples were used for cross-section analysis, several samples were embedded and cut as a precaution. To prepare the samples for cross-section microscopy, bulk samples were scrapped using a scalpel to collect the pigment, plaster,

and gypsum. Buehler mold release agent was applied to small ice cube trays and an initial layer of Ward's Science Bioplastic®, mixed with the appropriate amount of catalyst, was poured into the tray. Once the initial layer was sufficiently cured, small labels that had been printed for each sample and the samples themselves were placed on the Bioplastic® and a fresh batch of Bioplastic® was poured over the sample and label. The samples were left to cure.

After sufficient curing, the samples were cut using a Buehler IsoMet low-speed saw with a polycrystalline diamond blade, using Stoddard's solvent as the lubricant. The cut cross-sections were polished using sandpapers of successively finer grit, using water as the lubricant. The cross-sections were then mounted on slides using Meltmount™.

Cross-section photomicrographs were taken of samples 1, 25, and 27 in visible light with a retrofitted Nikon Alphaphot-2 which allowed for observations in both visible and ultraviolet light .

5.1.2 Auto-fluorescent Microscopy

The retrofitted Nikon Alphaphot-2 has an excitation of 430-440 nm, dichroic of 455 nm, and an emission of 470 nm. Pure PVAC resin was examined in order to understand how PVAC should auto-fluoresce. The PVAC auto-fluoresced with a teal color (Figure 2). The cross-sections were analyzed for that color, though there was no evidence of PVAC. The facsimiles were also examined in ultraviolet light, and again, no PVAC was detected (Appendix 8).

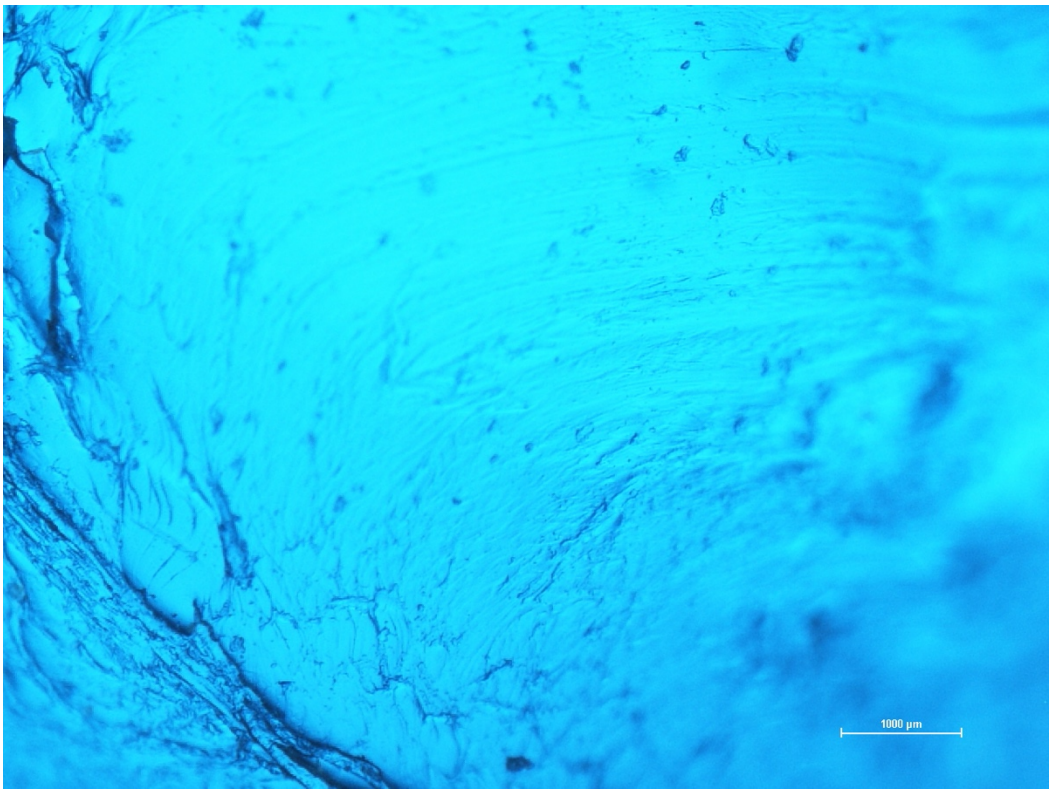

Figure 2- Pure PVAC resin in ultraviolet light

An examination of the PVAC solution was done, given the lack of autofluorescence on the samples and the facsimiles (Appendix 9). The PVAC solution was applied directly onto a slide and examined in both visible and ultraviolet light. Thirty applications were applied and there was still no evidence of autofluorescence. The process was repeated for the solvents, without the PVAC, and again, there was no autofluorescence. As a control, a blank glass slide was examined in both visible and ultraviolet light. The lack of autofluorescence is most likely due to the low concentration of PVAC.

5.2 Instrumental Analysis

Instrumental analysis was performed on bulk samples from the site to confirm the presence of polyvinyl acetate. Fourier-transform infrared (FTIR) spectroscopy and pyrolysis gas chromatography-mass spectrometry (pyGC-MS) were performed at the Winterthur Museum, Garden & Library Scientific Research and Analysis Laboratory (SRAL) by Catherine Matsen, scientist. The following has been provided by Catherine Matsen.

There is virtually no difference in the results of the pyrograms of the three samples (TUMA 1, 25, and 27). Mass spectra for compounds indicative of polyvinyl acetate (PVAc) - acetic acid, benzene, and napthalene - were not strongly detected. Presuming the polyvinyl acetate has hydrolyzed, partially or completely, over time to form polyvinyl alcohol, marker compounds for these pyrolysis products - acetaldehyde and crotonaldehyde - were not detected either. It was concluded therefore that due to the original low concentration of the PVAC in the plaster (5%) the amount was below the detection limit of the instrument. Even though the amount of plaster substrate material analyzed was large for pyGCMS, the fact that a maximum of 5% of that total material could be PVAc suggests that it's still below the detection limit of pyGCMS.

5.2.1 Fourier-transform infrared (FTIR) spectroscopy

FTIR microspectroscopy is an instrumental technique that permits the general classification of natural organic materials (such as waxes, proteins, oils, polysaccharides, and resins) and the specific identification of synthetic resins, inorganic pigments, and natural minerals. Sample material was isolated from the bulk as best as possible using a

#15 blade scalpel and the aid of a stereomicroscope (1.2-70 magnification). A small amount of material was placed directly on a diamond cell and rolled flat on the cell with a steel micro-roller to decrease the thickness and increase transparency.

The sample was analyzed using the Thermo-Nicolet Magna-IR Spectrometer E.S.P. attached to the Nicolet Nic-Plan IR Microscope (transmission mode); data was acquired for 120 scans from 4000 to 650cm^{-1} at a spectral resolution of 4cm^{-1}. Multiple spectra were taken from different areas within each rolled sample for reproducibility and for inhomogeneous appearing samples. Spectra were collected with Omnic E.S.P. 6.1a software and analyzed in this program with various IRUG and commercial reference spectral libraries (Appendix 10).

An acetone extraction was performed on Sample 1 in an attempt to solubilize and then isolate the polymer from the inorganic substrate. A few milligrams of pulverized plaster sample were added to a 2mL glass vial with approximately 1mL acetone (Fisher, HPLC grade) and heated to 50°C for approximately five minutes. The solvent was then decanted and centrifuged to settle out any small particles. The acetone extract was then transferred dropwise to a well-slide warmed on a heat plate at approximately 50°C to evaporate. The remaining residue was analyzed with FTIR.

5.2.2 Py-GC/MS (pyrolysis-gas chromatography/mass spectrometry)

Samples TUMA 1, 25, and 27 were analyzed by py-GC/MS with no chemical derivatization. Samples of pulverized plaster substrate were placed into a 50µL stainless steel Eco-cup fitted with an Eco-stick and placed into the pyrolysis interface where it was purged with helium. The Frontier Lab EGA/PY-3030D double-shot pyrolyzed system

was interfaced to a Hewlett-Packard 6820A gas chromatogram equipped with 5973 mass selective detector (MSD). A J&W DB-5MS Agilent 19091S-433 capillary column was used for separation (30m × 250µm × 0.25µm) with helium carrier gas set to 1.2 mL/minute. Samples were pyrolyzed using a single-shot method at 600°C for 12 seconds. The Agilent Technologies MassHunter Workstation GC/MS Data Acquisition (version 10.0.368) software was used with instrument conditions as follows: the split injector was set to 280°C with a split ratio of 30:1 and no solvent delay (9.26 psi). The GC oven temperature program was 43°C for two minutes, then ramped at 10°C/minute to 325°C, followed by a five-minute isothermal period, for a total run time of 35.2 minutes. The MSD transfer line was at 320°C, the source at 230°C and the MS quad at 150°C. The mass spectrometer was scanned from 33-600amu at a rate of 2.6 scans per second. Agilent Technologies MassHunter Qualitative control software was used for data interpretation.

5.3 Physical Testing

5.3.1 Chalking

ASTM D4214-07- Standard Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films was used to test chalking of the facsimiles. Black and white velvet strips were used for this test. The strips were wrapped around the pointer finger, and with appropriate pressure, stroked down each color. The strokes were then compared to the reference standard, in this case, test method D659 (Figure 3).

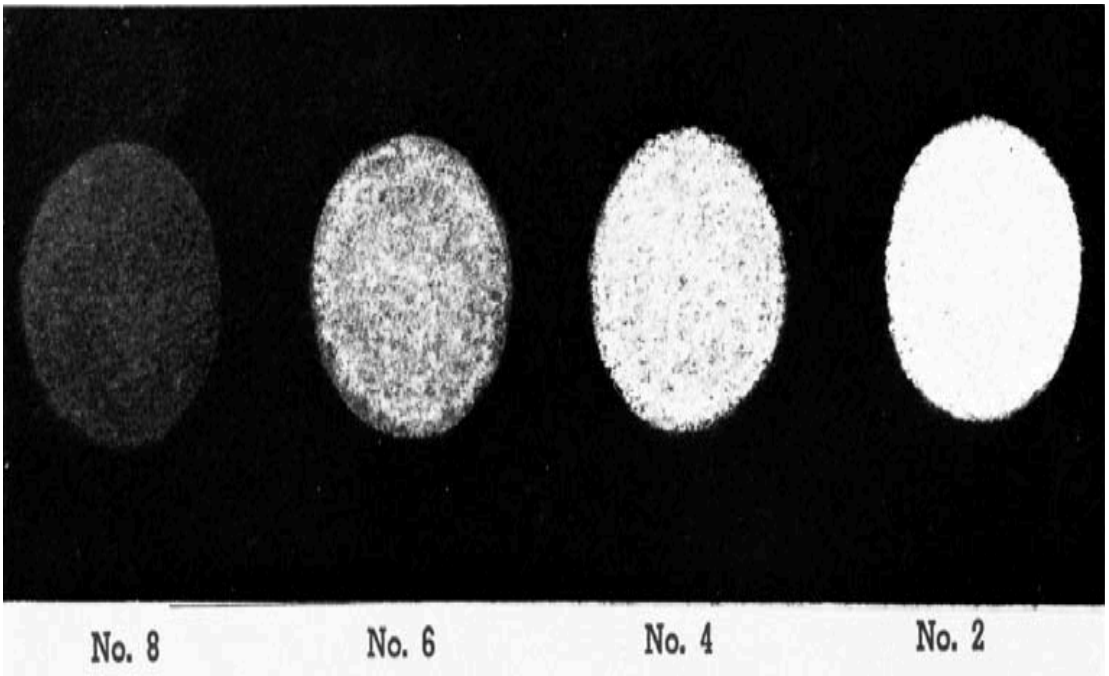

Figure 3- ASTM 4214 Photographic Reference Standard No. 1—Test Method D659

The chalking test was first performed on unconsolidated facsimiles. Given the level of chalking, only black velvet was used (Figure 4). Chalking was then tested on the consolidated facsimiles. Both black and white velvet was used, due to the light chalking of the red pigment (Figure 5). Based on the reference standard, it was determined that the unconsolidated pigments were identified to be most similar to Number 4; conversely, consolidated pigments were identified to be most similar to No. 6 for the red color and between No. 6 and No. 8 for the white color . The chalking test indicates that the consolidant effectively reduced the level of chalking by at least one level of gradation. The white gypsum appeared to be more responsive to the consolidant, with less chalking, compared to the red hematite, which seemed to show more chalking.

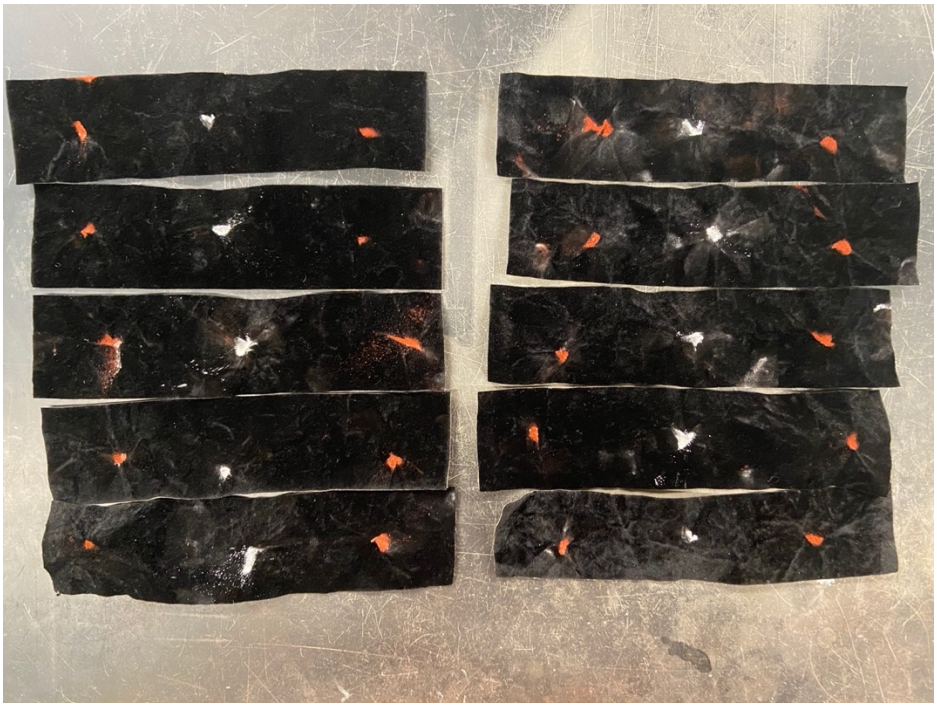

Figure 4- Results of chalking test for unconsolidated samples

Figure 5- Results of chalking test for consolidated samples

5.3.2 Color Change

Initially, a spectrophotometer was to be used to measure color change-ASTM E1349- Standard Test Method for Reflectance and Color by Spectrophotometry using Bidirectional (45°:0° or 0°:45°) Geometry; however, the spectrophotometer was not available at the time of the experiment. Instead visual observation with the Munsell color system was performed, using ASTM D1524-14- Standard Practice for Specifying Color by Munsell System, to determine any color alteration after the consolidant was applied. Prior to the use of the Munsell chips, the samples that were consolidated were noted to be slightly darker in color one day after application . The samples were visually compared with matte Munsell chips viewed in northern daylight.

Table 4: Color Change Observations

	Unconsolidated	Consolidated
Gypsum	N 9.5/0	N 9.25/0
Red Hematite	10R 4/6	10R 4/4

The matte Munsell chips indicate that the gypsum samples became slightly darker with the addition of the consolidant. In the Munsell color system, the first number indicates the value, with white being higher in value and black being lower in value. The consolidated gypsum decreased in value by one gradation and thus became darker. Conversely, the red hematite decreased in chroma by one gradation when the consolidant was applied. The Munsell color system describes this change as going from red to weak red. The consolidant causes the red hematite to become slightly grayer.

Rather than being affected by differences in refractive indices, that authors argue that the discoloration is a result of porosity. The change in color, according to Hansen, Lowinger, and Sandoff, is due to:

> a high surface concentration of consolidant…as a result of the migration of a resin solution that has penetrated a porous object back to the surface of the object with solvent evaporation as a consequence of capillary action.[64]

In the case of the facsimiles, the consolidant was applied, but evaporated before sufficient penetration could occur. The porosity of the scratch coat and gypsum allowed for some penetration, but it also enable reverse migration, which caused the consolidant to sit on the surface of the sample.

5.3.3 Luster

Again, a spectrophotometer was to be used to measure luster; instead, luster was observed using qualitative methods. A slight sheen was observed on both the original samples from the site and the facsimiles where consolidant was applied. While the exact original color and luster of the interior paints are unknown, previous analytical studies suggest the original painting was most likely an aqueous plant gum or animal protein resulting in a low to no sheen luster.[65] This is typical of distemper paints.

5.3.4 Vapor Permeability

The method for measuring vapor permeability was performed based on ASTM E96/E96M-16- Standard Test Methods for Water Vapor Transmission of Materials. The

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[64] Hansen et al, "Consolidation of Porous Paint in a Vapor-Saturated Atmosphere: A Technique for Minimizing Changes in the Appearance of Powdering, Matte Paint," 4.
[65] Steen and Gettens, "Tumacácori Interior Decorations," 1949, 42.

facsimiles were dried for a 24 hour period at 60°C. After sufficient drying, ¾ inch Scotch® Super 88 vinyl electrical tape was wrapped around the circumference of the disk. The tape prevented any leaks when the assembly was set up. The disks were weighed and placed in pre-weighed 100 mL polypropylene tri-cornered beakers, which contained 30 mL of water and cotton balls. The assemblies were then sealed with melted paraffin wax and weighed.

The assemblies were placed in two different desiccant chambers—one containing the red hematite disks and one containing the gypsum disks. All assemblies were measured at the 5 minutes, 15 minutes, 30 minutes and 1 hour marks, after which point, they were measured every 24 hours from the initial start time. Measurements were taken for 16 days and the data was graphed (Appendix 11).

Water vapor transmission (WVT) is calculate as:

$$WVT = \frac{G}{tA}$$

Where G = weight change (grams)
t = time (hours
G/t = slope of the straight line (g/h)
A = test area (cm^2)
WVT = rate of water vapor transmission, g/(h/cm^2)

The water vapor transmission was calculated for each assembly. On average, the application of PVAC to both the painted and unpainted samples greatly decreased water vapor transmission (Figure 6). The average water vapor transmission rate for the painted, consolidated samples was 0.00036 g/(m•s•Pa) whereas the average water vapor transmission rate of the painted, unconsolidated samples was 0.00045 g/(m•s•Pa).

For the unpainted samples, the average water vapor transmission rate for consolidated samples was 0.00037 g/(m•s•Pa) and the average water vapor transmission rate for unconsolidated samples was 0.00042 g/(m•s•Pa). Overall, the PVAC did affect water vapor transmission of samples.

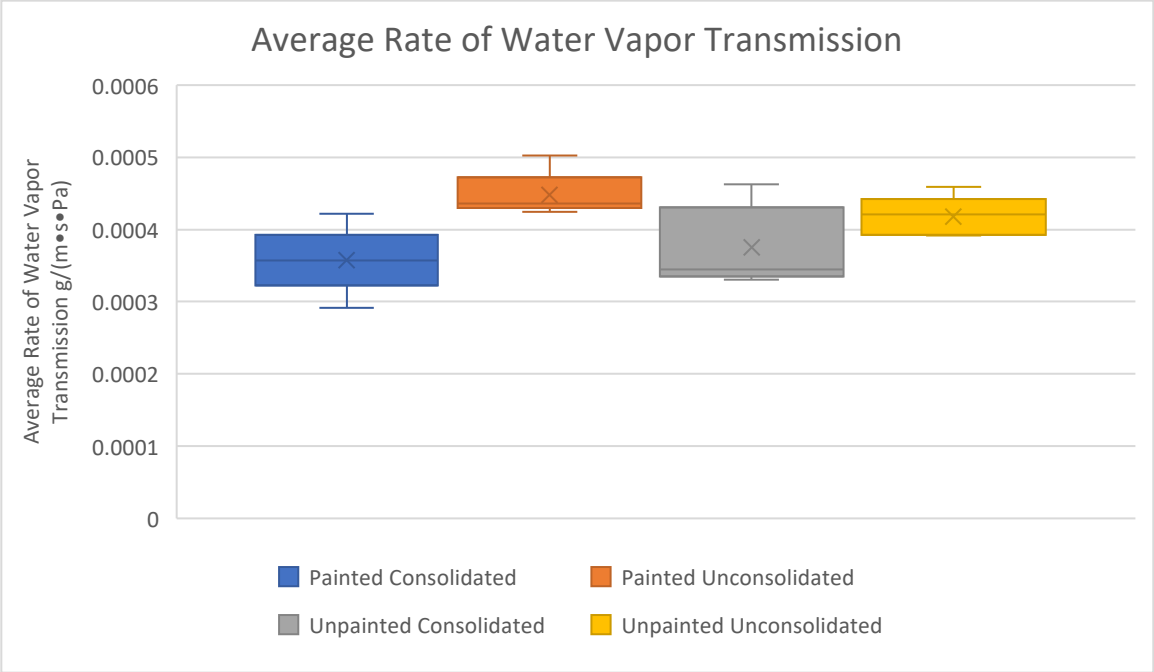

Figure 6- Average rate of water vapor transmission

5.3.5 Water Absorption

The method for measuring water absorption was done in accordance with the standards set by The National Concrete Masonry Association. This test followed CMU-WRI- 09- Standard Test Methods for Water Stream and Water Droplet Tests on Concrete Masonry Units. The disks were set up into two groups—treated and untreated. The temperature and relative humidity of the lab was 20.8°C at 26% RH. Five drops of water were placed on each sample at various locations using a bottle dropper filled with deionized water. The droplets were observed at one minute from application, five

minutes from application, ten minutes from application, and when necessary, fifteen and twenty minute intervals. Water dropped on a glass petri dish was used as a control

Observations were done qualitatively. The droplets were stated to be Standing (S), Partially Absorbed (P), Totally Absorbed (T), and Dry (D). The following are the observations for the samples:

Table 5: Water Drop Test- Unconsolidated					
Sample Number	1 Minute	5 Minutes	10 Minutes	15 Minutes	20 Minutes
1.1.6	T	T	T	D	
1.1.7	T	T	T	D	
1.1.8	T	T	T	D	
1.1.9	T	T	T	D	
1.1.10	T	T	T	D	
2.1.5	T	T	T	D	
2.1.6	T	T	T	T	D
2.1.7	T	T	T	D	
2.1.8	T	T	T	D	
2.1.9	T	T	T	D	

Table 6: Water Drop Test- Consolidated					
Sample Number	1 Minute	5 Minutes	10 Minutes	15 Minutes	20 Minutes
1.1.2	T	T	D		
1.1.3	T	T	D		
1.1.4	P	T	D		
1.1.5	T	T	D		
1.1.12	T	T	D		
2.1.10	T	T	T	D	
2.1.12	T	T	D		
2.1.13	T	T	T	D	
2.1.14	T	T	D		
2.1.15	T	T	D		

In general, water on treated samples tended to remain partially absorbed for the first 30 seconds, after which they became completely absorbed. Conversely, water drops on untreated samples were absorbed immediately. Additionally, treated samples seemed to have higher surface tension, as the drops did not spread across the surface; meanwhile, water on untreated samples had lower surface tension as the water tended to spread.

Most notable is the faster drying rate of water on treated surfaces relative to untreated surfaces. While all untreated samples required at least fifteen minutes to fully dry, all but two treated samples needed ten minutes to dry. The PVAC clearly reduced the water absorption and increased water desorption (drying) of the facsimile.

The water drop test was also done on original samples from Tumacácori in order to compare results. Three samples were used—Sample 17, Sample 25, and Sample 27. As mentioned, Sample 27 was believed to be untreated with PVAC. The following was observed:

Table 7: Water Drop Test- Samples from Site

Sample Number	1 Minute	5 Minutes	10 Minutes	15 Minutes	20 Minutes
17	T	T	D		
25	T	T	D		
27*	T	D	D		

* Sample was too small to apply 5 drops; only one drop was applied

Samples 17 and 25 had similar drying patterns to treated facsimiles. Sample 27 was too small for a proper test to be done, which could explain why the water dried so quickly.

Section 6. Conclusions and Recommendations

As a new material at the time of use, not very much was known about PVAC at the time of application in 1949 by Gettens and Steen. This investigation of the use of PVAC at the Mission Church of San José de Tumacácori required extensive research on the history and use of polyvinyl acetate, as a well as a laboratory investigation on the effects of the PVAC on the physical properties of the original materials. While the concentration of PVAC on the painted plaster is very low, the solution did affect the optical and physical properties of the painted plaster, gypsum, and scratch coat. While the PVAC does not auto-fluoresce, or appear in FTIR and PY-GC/MS analysis, color darkening and sheen was evident on the facsimiles, indicating that the PVAC does affect the pigments' appearance. PVAC also affected how moisture moves through the plaster. PVAC increased the drying rate of liquid moisture as well as reduced the overall rater of vapor transmission.

6.1 Recommendations for Future Research

Due to the limitations imposed by COVID-19, in-situ analysis was not possible; thus, for future research, the tests done in the laboratory should be repeated on site. In repeating these experiments on-site, the implications of PVAC can be better understood in an uncontrolled environment.

Should NPS decide to perform another treatment campaign, the compatibility of PVAC with other consolidants should be examined. As previously mentioned, an ideal consolidant would not effect a pigments optical properties, which PVAC, unfortunately did do, in its darkening and evident luster. As a result, PVAC should likely not be used

again unless it is determined that the existing treatment is not compatible with the treatment that is already present

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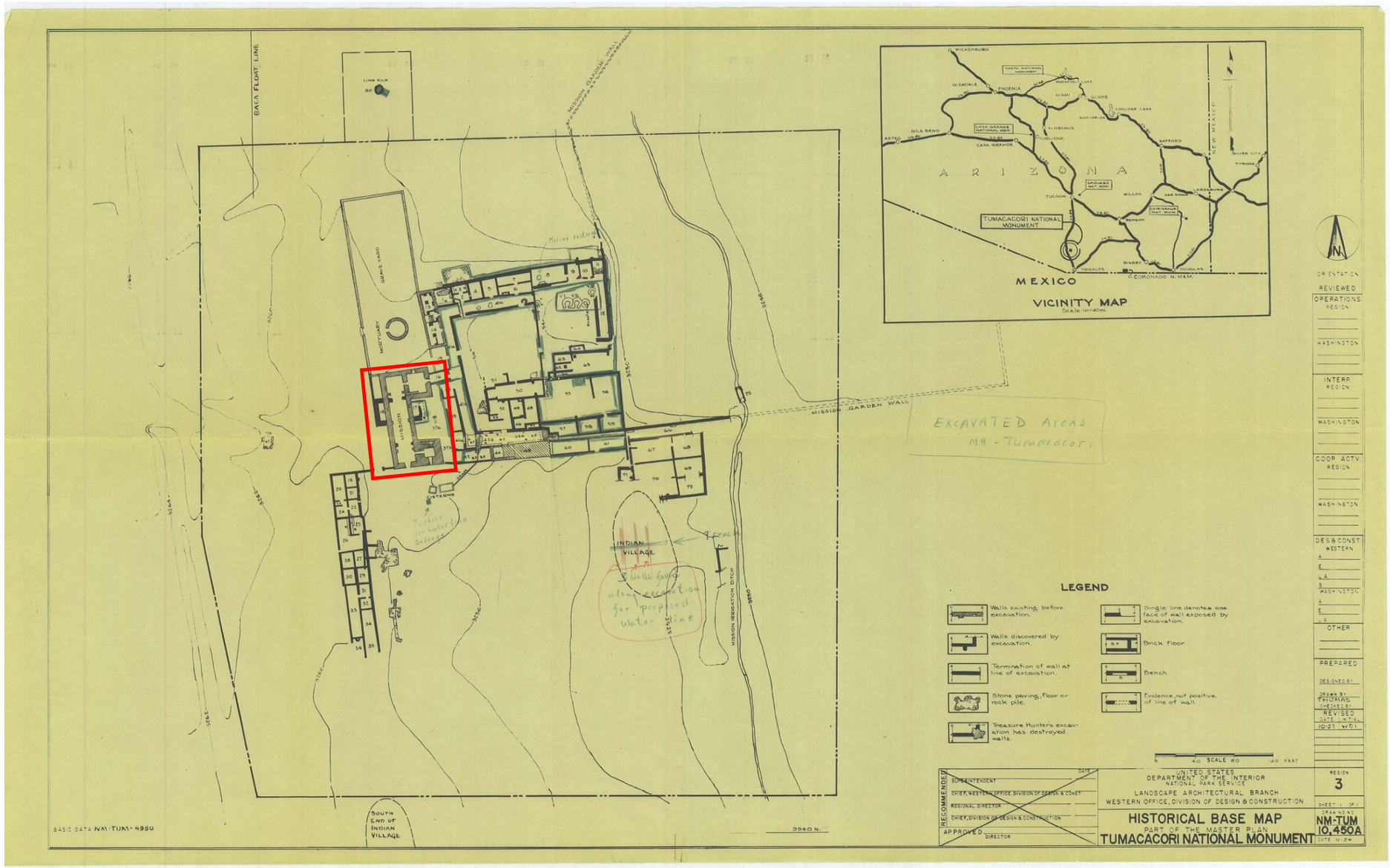
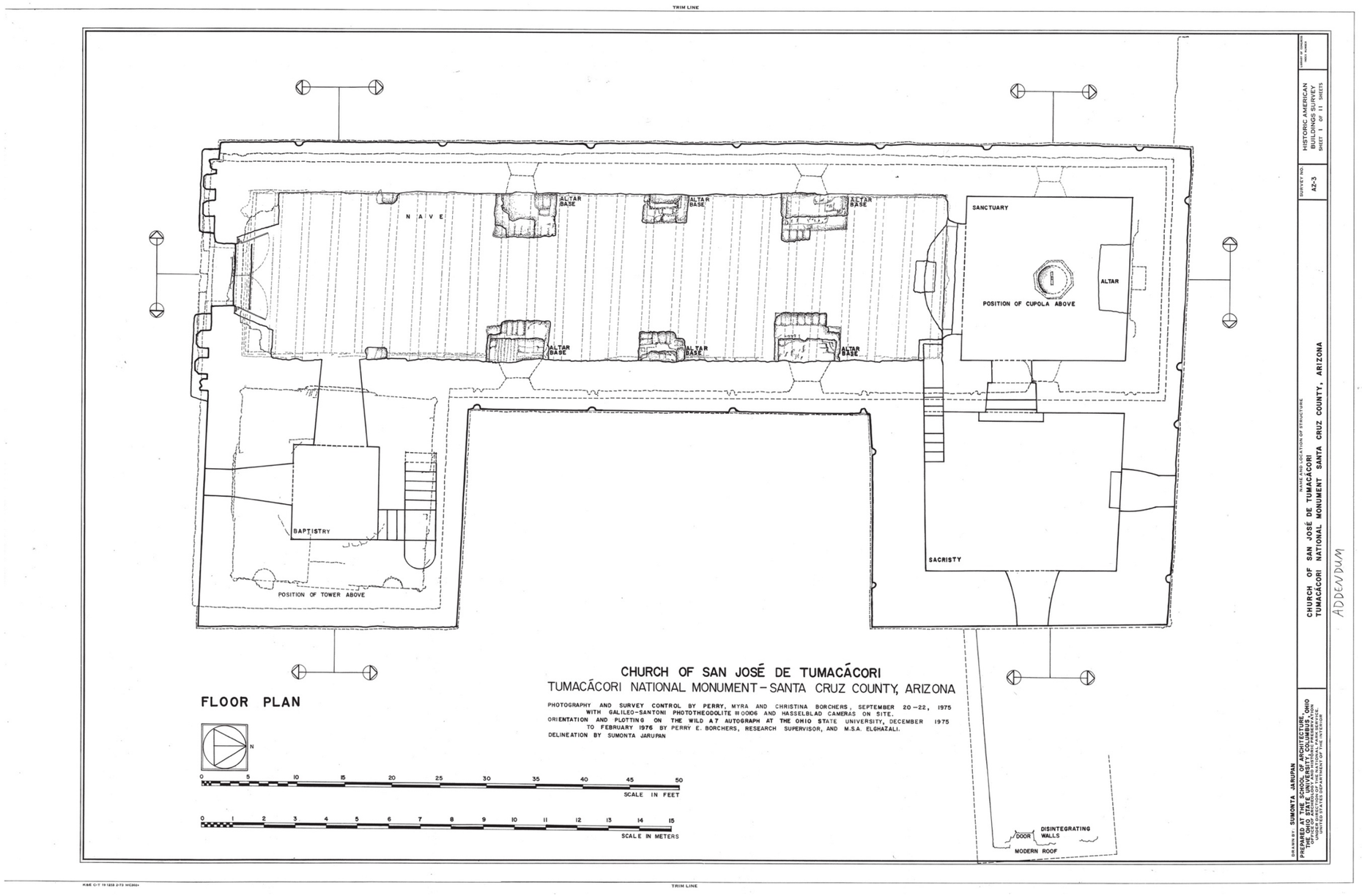
Appendix 1: Historic Map of the Mission of San José de Tumacácori



Appendix 2: HABS Drawings of the Mission Church of San José de Tumacácori



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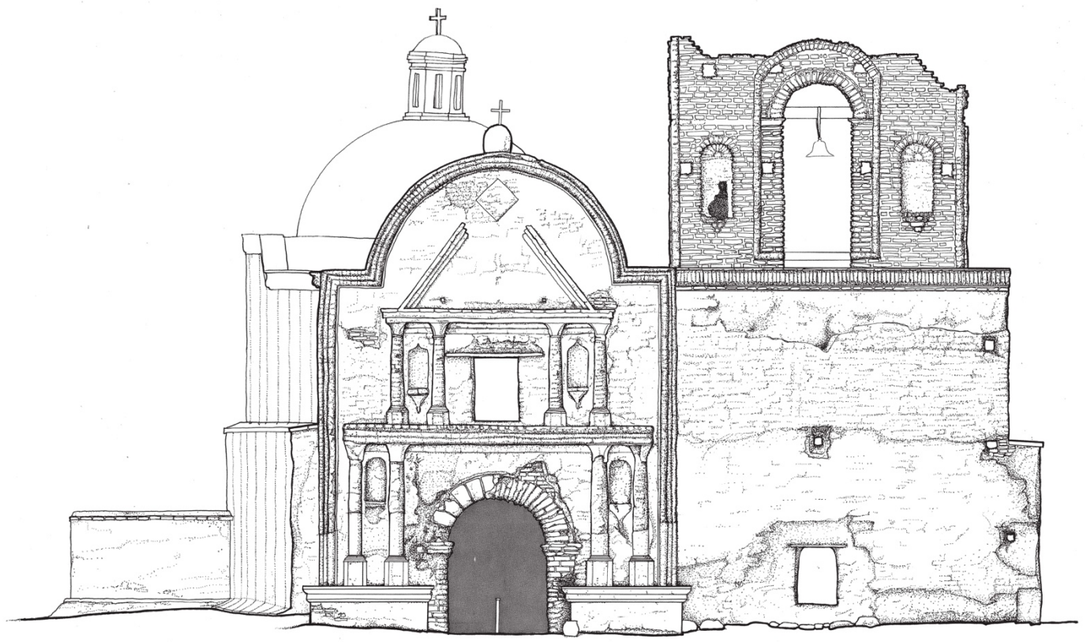

SOUTH (FRONT) ELEVATION – CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACACORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

PHOTOGRAPHY AND SURVEY CONTROL BY PERRY, MYRA AND CHRISTINA BORCHERS, SEPTEMBER 20 – 22, 1975
WITH GALILEO-SANTONI PHOTOTHEODOLITE #00106 AND HASSELBLAD CAMERAS ON SITE.
ORIENTATION AND PLOTTING ON THE WILD A7 AUTOGRAPH AT THE OHIO STATE UNIVERSITY, DECEMBER 1975
TO FEBRUARY 1976 BY PERRY E. BORCHERS, RESEARCH SUPERVISOR, AND M. S. A. ELGHAZALI.
DELINEATION BY HUGO MARIO ROMERO-RAMIREZ, MARCH 1976

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SCALE IN FEET

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
SCALE IN METERS

DRAWN BY HUGO MARIO ROMERO-RAMIREZ

OFFICE OF ARCHEOLOGY AND HISTORIC PRESERVATION
UNDER DIRECTION OF THE NATIONAL PARK SERVICE,
UNITED STATES DEPARTMENT OF THE INTERIOR

NAME AND LOCATION OF STRUCTURE
CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACACORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

ADDENDUM

SURVEY NO. AZ-3

HISTORIC AMERICAN BUILDINGS SURVEY
SHEET 2 OF 11 SHEETS

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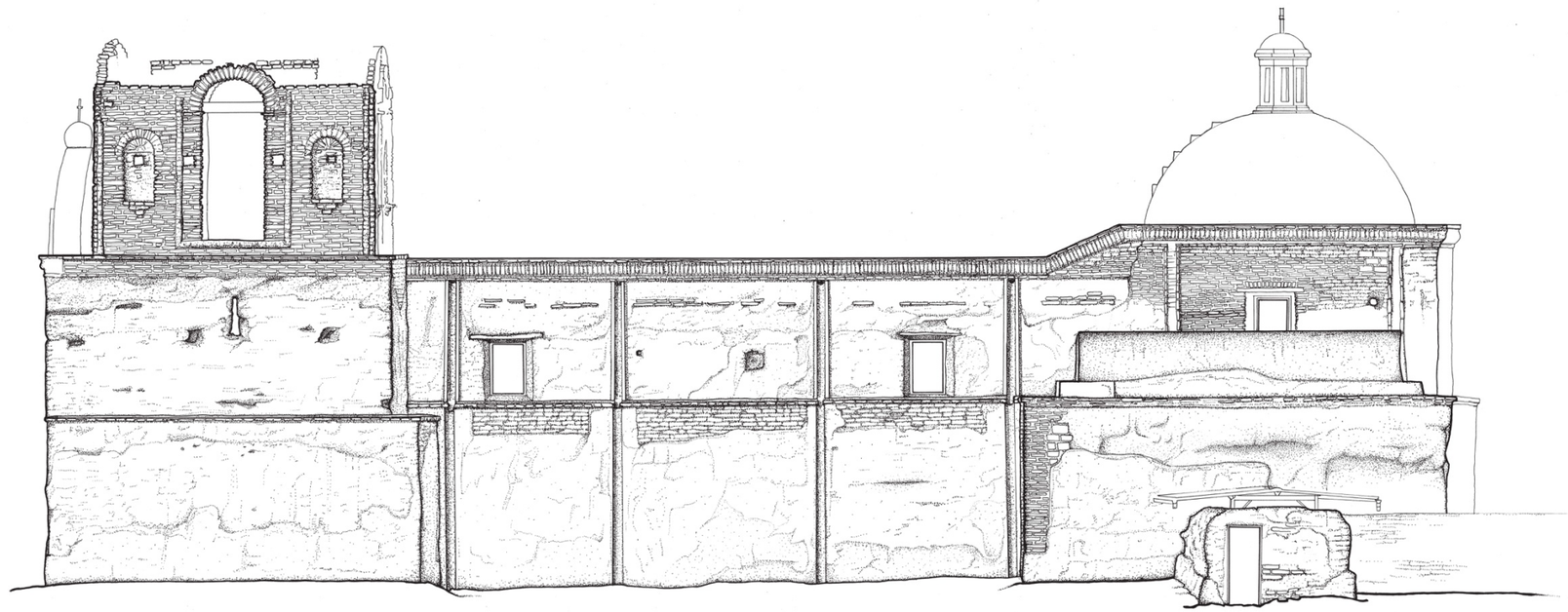

EAST ELEVATION — CHURCH OF SAN JOSÉ DE TUMACÁCORI

TUMACACORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

PHOTOGRAPHY AND SURVEY CONTROL BY PERRY, MYRA AND CHRISTINA BORCHERS, SEPTEMBER 20-22, 1975
WITH GALILEO-SANTONI PHOTOTHEODOLITE # 00106 AND HASSELBLAD CAMERAS ON SITE.
ORIENTATION AND PLOTTING ON THE WILD A7 AUTOGRAPH AT THE OHIO STATE UNIVERSITY, DECEMBER 1975
TO FEBRUARY 1976 BY PERRY E. BORCHERS, RESEARCH SUPERVISOR, AND M. S. A. ELGHAZALI.
DELINEATION BY HUGO MARIO ROMERO-RAMIREZ, MARCH 1976

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DRAWN BY: HUGO MARIO ROMERO-RAMIREZ

OFFICE OF ARCHEOLOGY AND HISTORIC PRESERVATION
UNITED STATES DEPARTMENT OF THE INTERIOR

NAME AND LOCATION OF STRUCTURE
CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACACORI NATIONAL MONUMENT — SANTA CRUZ COUNTY, ARIZONA

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SURVEY NO
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HISTORIC AMERICAN BUILDINGS SURVEY
SHEET 3 OF 11 SHEETS

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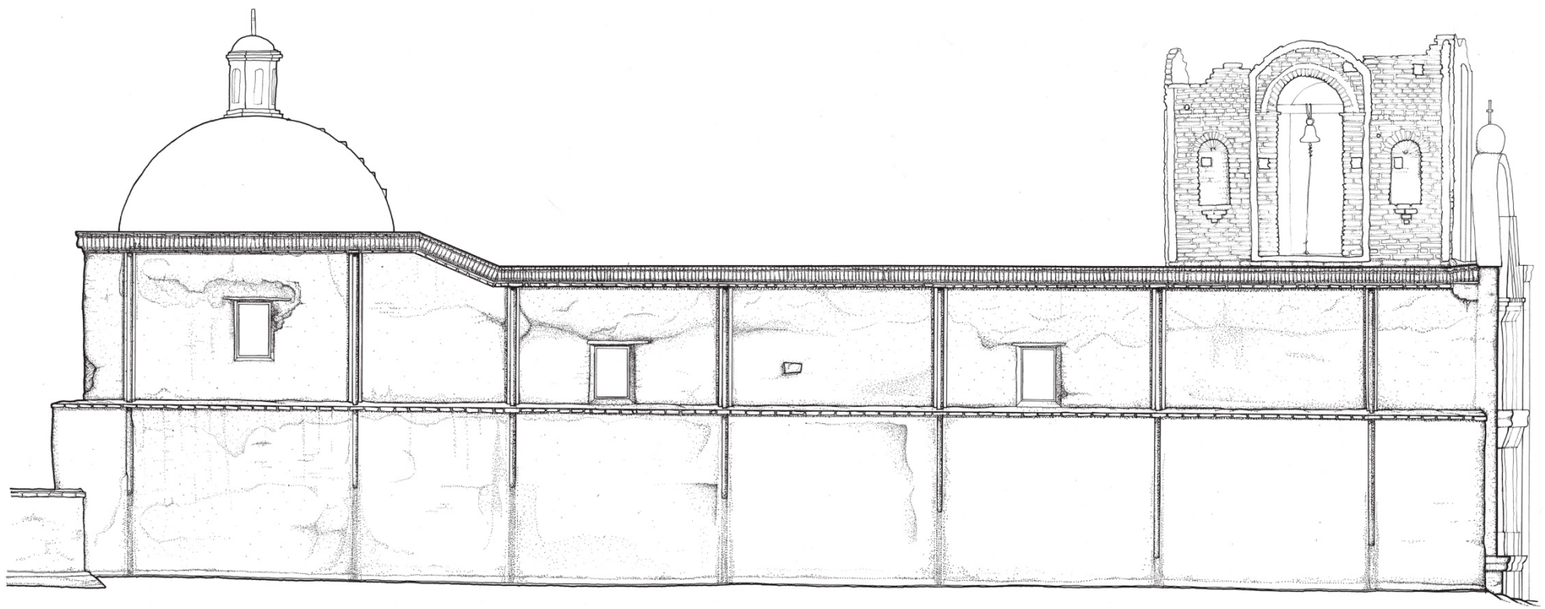

WEST ELEVATION – CHURCH OF SAN JOSÉ DE TUMACÁCORI

TUMACACORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

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DELINEATION BY HUGO MARIO ROMERO–RAMIREZ, MARCH 1976.

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DRAWN BY HUGO MARIO ROMERO-RAMIREZ

OFFICE OF ARCHEOLOGY AND HISTORIC PRESERVATION
UNDER DIRECTION OF THE NATIONAL PARK SERVICE
UNITED STATES DEPARTMENT OF THE INTERIOR

NAME AND LOCATION OF STRUCTURE
CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACACORI NATIONAL MONUMENT - SANTA CRUZ COUNTY, ARIZONA

ADDENDUM

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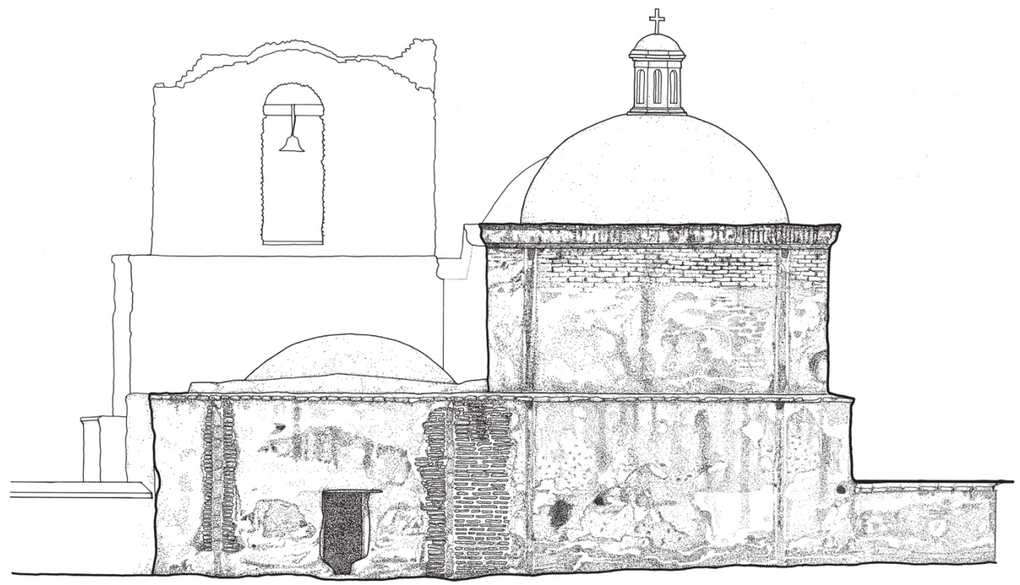

NORTH (REAR) ELEVATION — CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACACORI NATIONAL MONUMENT — SANTA CRUZ COUNTY, ARIZONA

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ORIENTATION AND PLOTTING ON THE WILD A7 AUTOGRAPH AT THE OHIO STATE UNIVERSITY, DECEMBER 1975 TO FEBRUARY 1976 BY PERRY E. BORCHERS, RESEARCH SUPERVISOR, AND M.S.A. ELGHAZALI.
DELINEATION BY VARATHORN BOOKAMAN, APRIL 1976

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SCALE IN METERS

DRAWN BY: VARATHORN BOOKAMAN

OFFICE OF ARCHEOLOGY AND HISTORIC PRESERVATION
UNDER DIRECTION OF THE NATIONAL PARK SERVICE
UNITED STATES DEPARTMENT OF THE INTERIOR

NAME AND LOCATION OF STRUCTURE
CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACACORI NATIONAL MONUMENT — SANTA CRUZ COUNTY, ARIZONA

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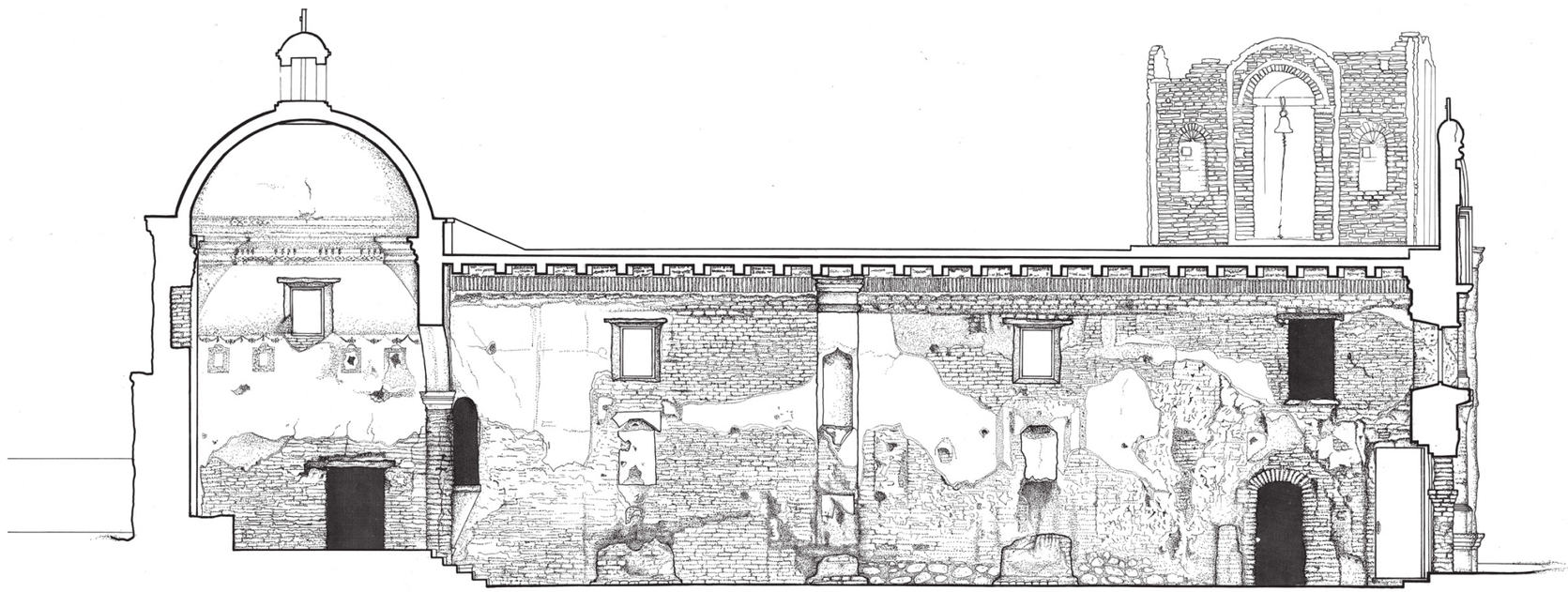

LONGITUDINAL SECTION THROUGH CHANCEL AND NAVE — LOOKING EAST

CHURCH OF SAN JOSÉ DE TUMACÁCORI

TUMACÁCORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

PHOTOGRAPHY AND SURVEY CONTROL BY PERRY, MYRA AND CHRISTINA BORCHERS, SEPTEMBER 20 – 22, 1975 WITH GALILEO-SANTONI PHOTOTHEODOLITE # 00106 AND HASSELBLAD CAMERAS ON SITE.
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DELINEATION BY **SUMONTA JARUPAN**

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DRAWN BY: **SUMONTA JARUPAN**

OFFICE OF ARCHEOLOGY AND HISTORIC PRESERVATION
UNDER DIRECTION OF THE NATIONAL PARK SERVICE,
UNITED STATES DEPARTMENT OF THE INTERIOR

NAME AND LOCATION OF STRUCTURE
CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACÁCORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

ADDENDUM

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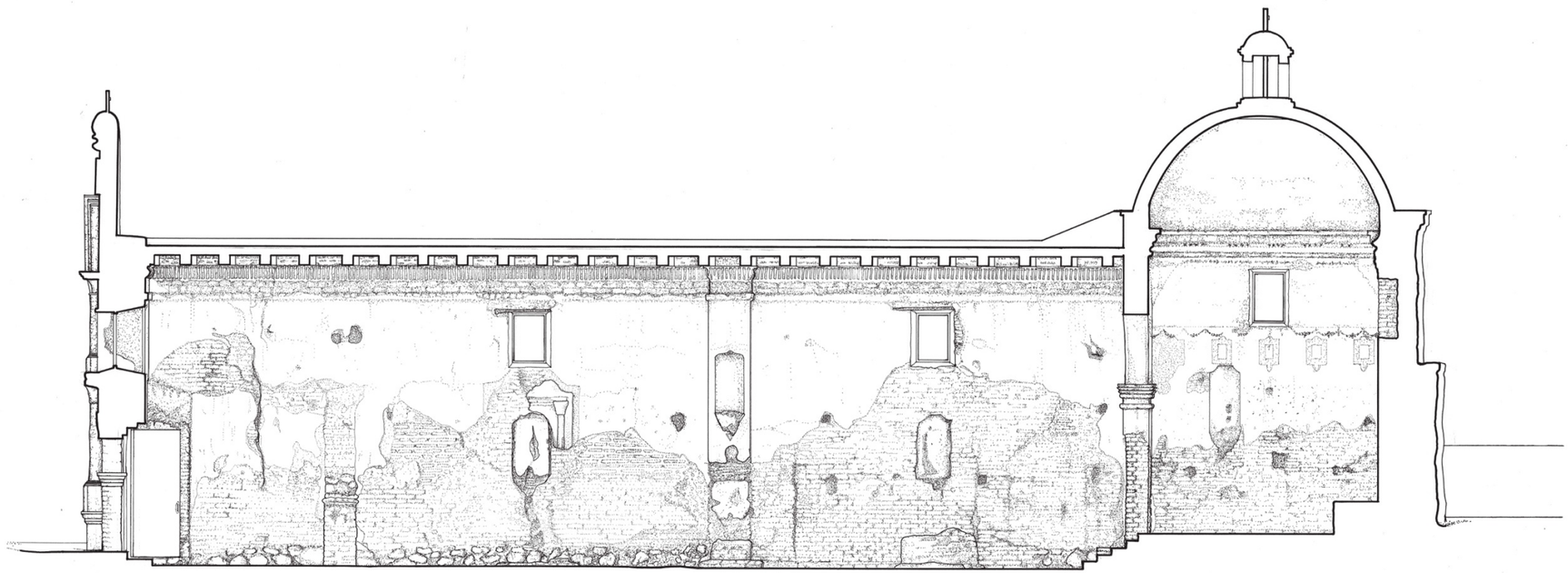

LONGITUDINAL SECTION THROUGH NAVE – LOOKING WEST

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TUMACÁCORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

PHOTOGRAPHY AND SURVEY CONTROL BY PERRY, MYRA AND CHRISTINA BORCHERS, SEPTEMBER 20 – 22, 1975 WITH GALILEO-SANTONI PHOTOTHEODOLITE #00106 AND HASSELBLAD CAMERAS ON SITE.
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DELINEATION BY VARATHORN BOOKAMAN

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SCALE IN METERS

DRAWN BY: VARATHORN BOOKAMAN

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UNDER DIRECTION OF THE NATIONAL PARK SERVICE,
UNITED STATES DEPARTMENT OF THE INTERIOR

NAME AND LOCATION OF STRUCTURE
CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACACORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

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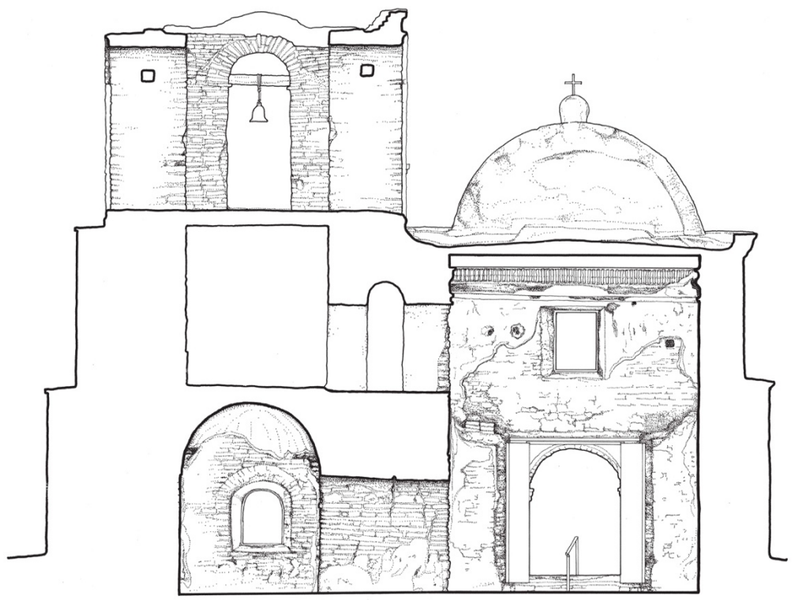

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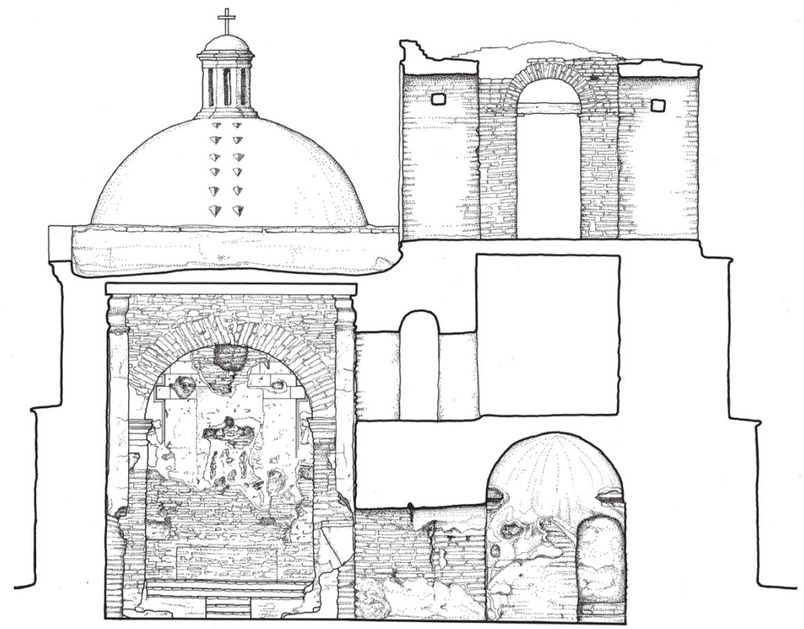

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AND BAPTISTRY LOOKING NORTH

CHURCH OF SAN JOSÉ DE TUMACÁCORI

TUMACÁCORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

PHOTOGRAPHY AND SURVEY CONTROL BY PERRY, MYRA AND CHRISTINA BORCHERS, SEPTEMBER 20 – 22, 1975 WITH GALILEO–SANTONI PHOTOTHEODOLITE # 00106 AND HASSELBLAD CAMERAS ON SITE. ORIENTATION AND PLOTTING ON THE WILD A 7 AUTOGRAPH AT THE OHIO STATE UNIVERSITY, DECEMBER 1975 TO FEBRUARY 1976 BY PERRY E. BORCHERS, RESEARCH SUPERVISOR, AND M. S. A. ELGHAZALI.

DELINEATION BY KUN-HYUCK AHN, JUNE 1976.

0 5 10 15 20 25 30 35 40 45 50
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DRAWN BY: KUN-HYUCK AHN

OFFICE OF ARCHEOLOGY AND HISTORIC PRESERVATION
NATIONAL PARK SERVICE
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NAME AND LOCATION OF STRUCTURE
CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACÁCORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

ADDENDUM

SURVEY NO. AZ-3

HISTORIC AMERICAN BUILDINGS SURVEY
SHEET 8 OF 11 SHEETS

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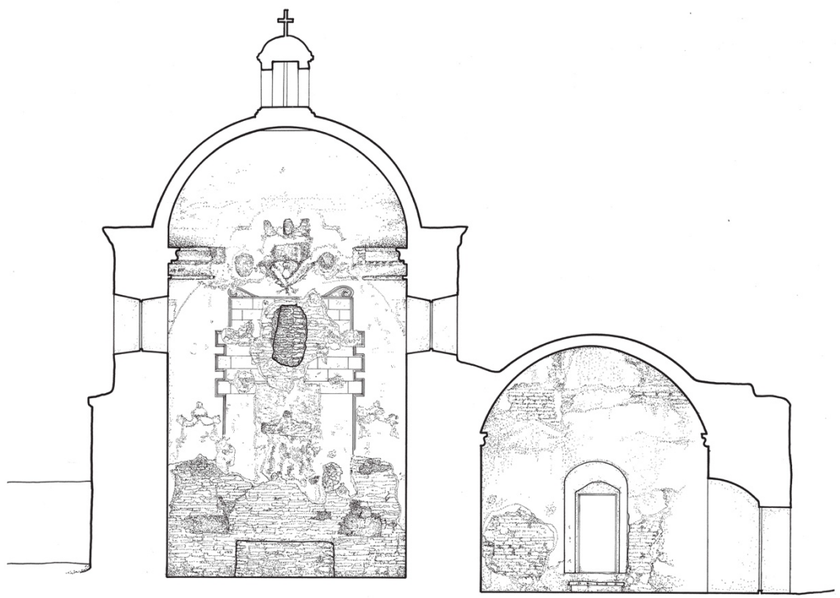

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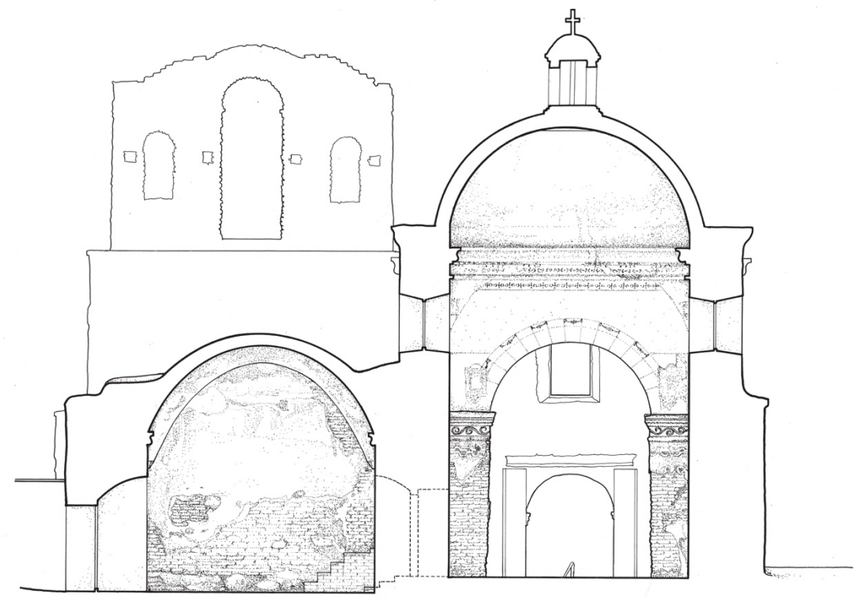

SECTION THROUGH CHANCEL AND SACRISTY LOOKING SOUTH

CHURCH OF SAN JOSÉ DE TUMACÁCORI

TUMACACORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

PHOTOGRAPHY AND SURVEY CONTROL BY PERRY, MYRA AND CHRISTINA BORCHERS, SEPTEMBER 20 – 22, 1975 WITH GALILEO – SANTONI PHOTOTHEODOLITE # 00106 AND HASSELBLAD CAMERAS ON SITE. ORIENTATION AND PLOTTING ON THE WILD A 7 AUTOGRAPH AT THE OHIO STATE UNIVERSITY, DECEMBER 1975 TO FEBRUARY 1976 BY PERRY E. BORCHERS, RESEARCH SUPERVISOR, AND M. S. A. ELGHAZALI.

DELINEATION BY VARATHORN BOOKAMAN JUNE 1976

0 5 10 15 20 25 30 35 40 45 50

SCALE IN FEET

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SCALE IN METERS

DRAWN BY: VARATHORN BOOKAMAN

OFFICE OF ARCHEOLOGY AND HISTORIC PRESERVATION
UNDER DIRECTION OF THE NATIONAL PARK SERVICE.
UNITED STATES DEPARTMENT OF THE INTERIOR

NAME AND LOCATION OF STRUCTURE

CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACACORI NATIONAL MONUMENT SANTA CRUZ COUNTY, ARIZONA

ADDENDUM

SURVEY NO. AZ-3

HISTORIC AMERICAN BUILDINGS SURVEY
SHEET 9 OF 11 SHEETS

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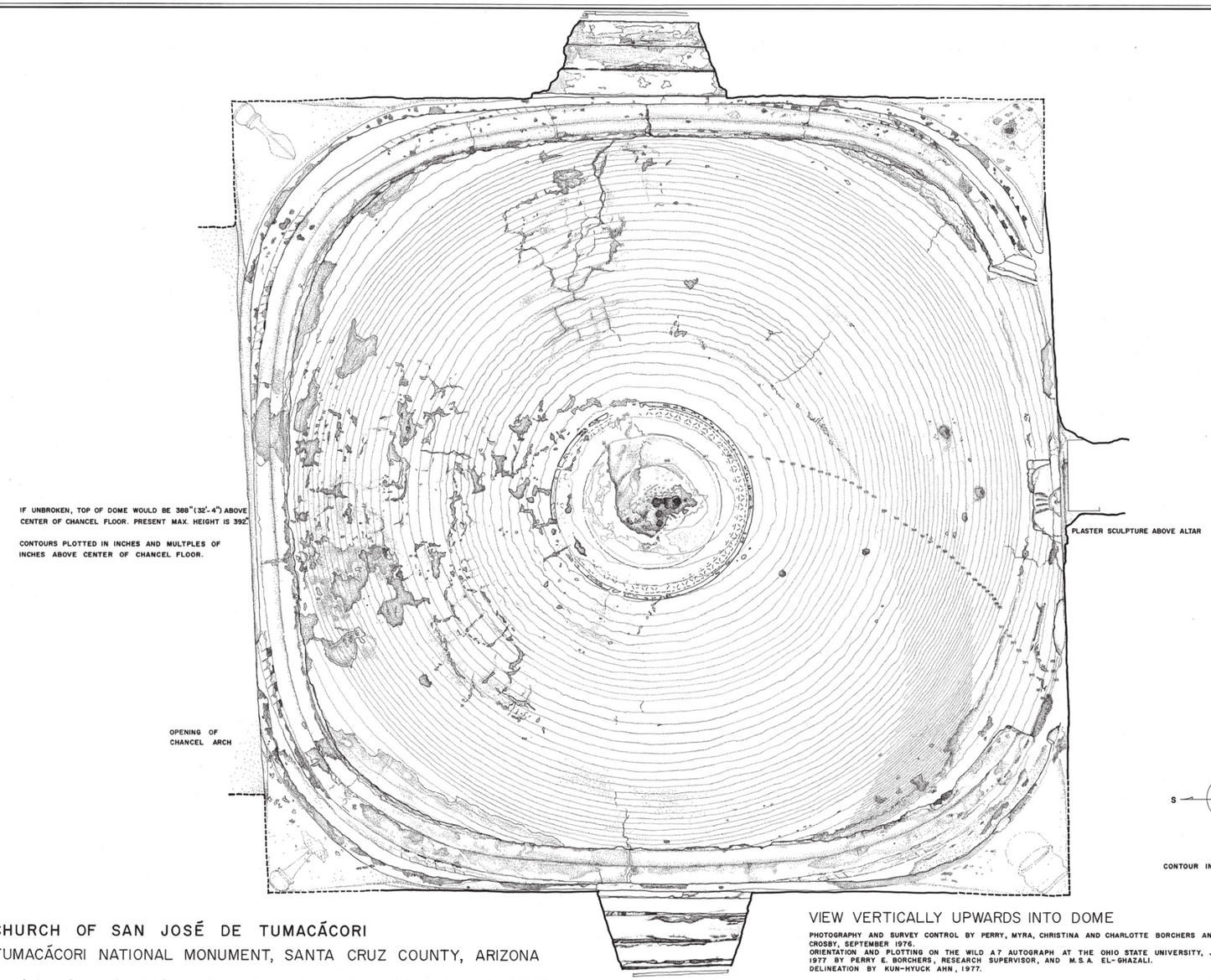

CHURCH OF SAN JOSÉ DE TUMACÁCORI

TUMACÁCORI NATIONAL MONUMENT, SANTA CRUZ COUNTY, ARIZONA

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PHOTOGRAPHY AND SURVEY CONTROL BY PERRY, MYRA, CHRISTINA AND CHARLOTTE BORCHERS AND ANTHONY CROSBY, SEPTEMBER 1976.
ORIENTATION AND PLOTTING ON THE WILD A7 AUTOGRAPH AT THE OHIO STATE UNIVERSITY, JANUARY 1977 BY PERRY E. BORCHERS, RESEARCH SUPERVISOR, AND M.S.A. EL-GHAZALI.
DELINEATION BY KUN-HYUCK AHN, 1977.

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DRAWN BY: KUN-HYUCK AHN
PREPARED AT THE SCHOOL OF ARCHITECTURE, THE OHIO STATE UNIVERSITY, COLUMBUS, OHIO
UNDER AUTHORITY OF THE HISTORIC AMERICAN BUILDINGS SURVEY, UNDER DIRECTION OF THE NATIONAL PARK SERVICE, UNITED STATES DEPARTMENT OF THE INTERIOR

NAME AND LOCATION OF STRUCTURE
CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACÁCORI NATIONAL MONUMENT, SANTA CRUZ COUNTY, ARIZONA

ADDENDUM

SURVEY NO. AZ-3

HISTORIC AMERICAN BUILDINGS SURVEY
SHEET 10 OF 11 SHEETS

SHEET OF STANDARD 4 SIZE DRAWING

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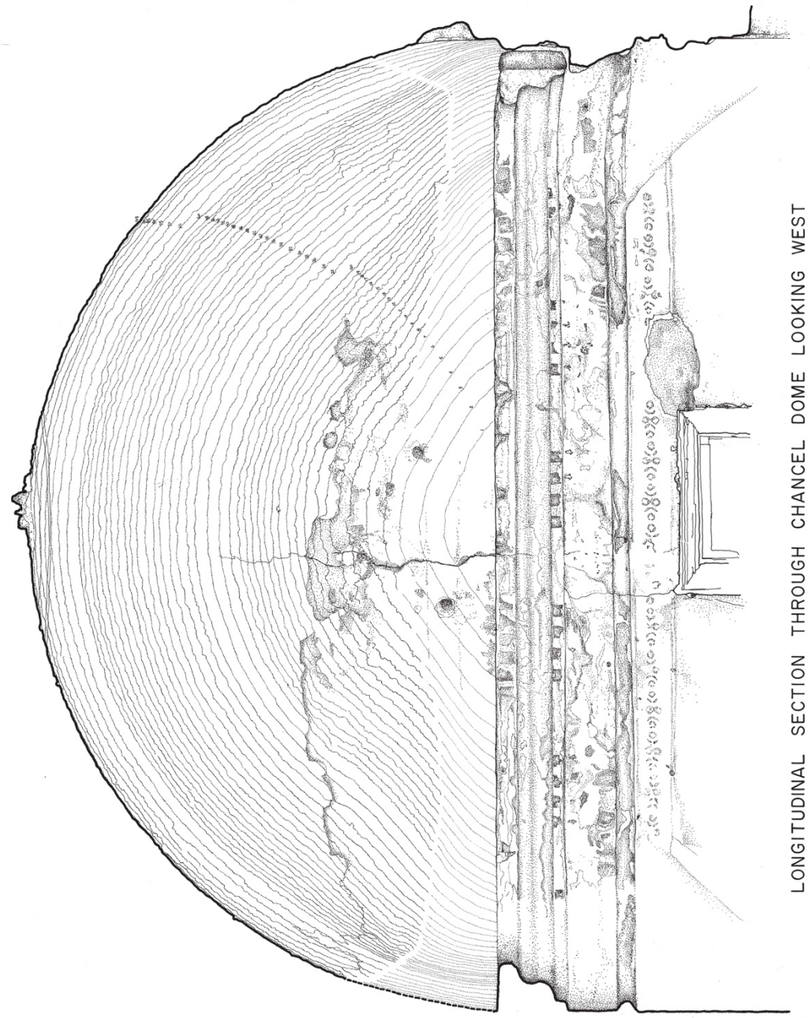
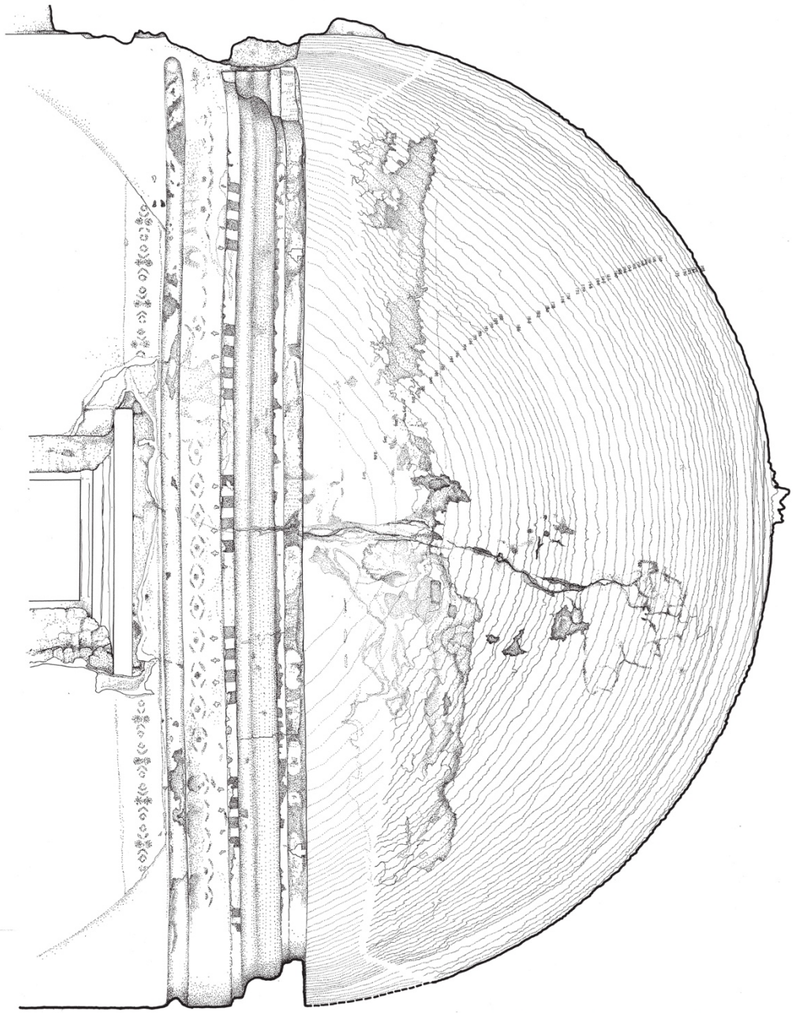
CHURCH OF SAN JOSÉ DE TUMACÁCORI — TUMACÁCORI NATIONAL MONUMENT, SANTA CRUZ COUNTY, ARIZONA



LONGITUDINAL SECTION THROUGH CHANCEL DOME LOOKING WEST



LONGITUDINAL SECTION THROUGH CHANCEL DOME LOOKING EAST

VERTICAL SLICES ARE IN INCHES AND MULTIPLES OF INCHES STARTING WITH 0 AT WALL ABOVE WESTERN WINDOW AND CONTINUING TO 209.5" AT WALL ABOVE EASTERN WINDOW.

CONTOUR INTERVAL IN INCHES

0 1 2 3 4 5 6 7 8 9 10 11 12 SCALE IN FEET

PHOTOGRAPHY AND SURVEY CONTROL BY PERRY, MYRA, CHRISTINA AND CHARLOTTE BORCHERS AND ANTHONY CROSBY, SEPTEMBER 1976.
ORIENTATION AND PLOTTING ON THE WILD A7 AUTOGRAPH AT THE OHIO STATE UNIVERSITY, JANUARY 1977 BY PERRY E. BORCHERS, RESEARCH SUPERVISOR, AND M. S. A. EL-GHAZALI.

DELINEATION BY KUN-HYUCK AHN.

SCALE IN METERS 0 1 2 3 4

DRAWN BY: KUN-HYUCK AHN
PREPARED AT THE SCHOOL OF ARCHITECTURE
THE OHIO STATE UNIVERSITY, COLUMBUS, OHIO
IN COOPERATION WITH THE HISTORIC AMERICAN BUILDINGS SURVEY
UNDER DIRECTOR OF THE NATIONAL PARK SERVICE
UNITED STATES DEPARTMENT OF THE INTERIOR

NAME AND LOCATION OF STRUCTURE
CHURCH OF SAN JOSÉ DE TUMACÁCORI
TUMACACORI NATIONAL MONUMENT – SANTA CRUZ COUNTY, ARIZONA

SURVEY NO. AZ-3

HISTORIC AMERICAN BUILDINGS SURVEY
SHEET 11 OF 11 SHEETS

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ADDENDUM

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TRIM LINE

Appendix 3: Reconstruction of the Mission Church of San José de Tumacácori

Figure 7- The Church in 1912, photographer unknown

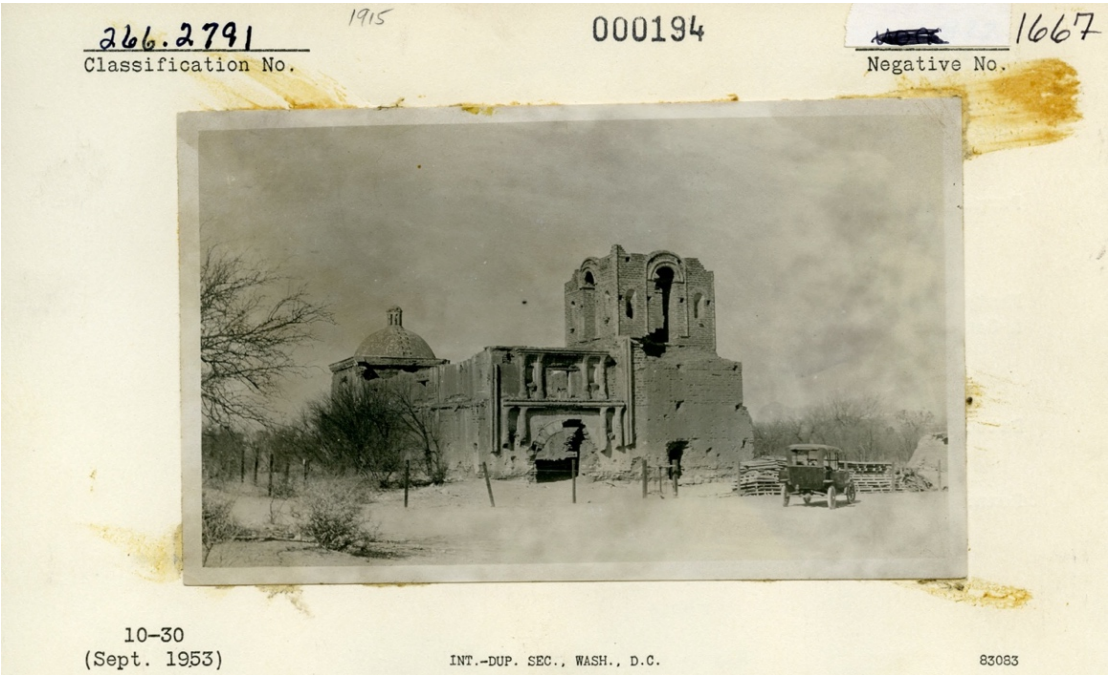


Figure 8- The Church in 1915, photographer unknown

Figure 9- The Church in 1922, courtesy of NPS

Figure 10- The Church in 1930, courtesy of NPS

Figure 11- The Church in 1967, courtesy of NPS

Appendix 4: Interior Images of the Church

Figure 12- Sanctuary facing north, CAC, 2017

Figure 13- Dome of the Sanctuary facing northwest, CAC, 2015

Figure 14- Detail of the Sanctuary, CAC, 2015

Figure 15- East wall of Sanctuary, CAC, 2017

Figure 16- West wall of Sanctuary, CAC, 2917

Figure 17- Sanctuary facing south towards the Nave, CAC, 2017

Appendix 5: Gettens and Steen 1949 Report

TUMACACORI INTERIOR DECORATIONS

by

Charlie R. Steen

and

Rutherford J. Gettens

6686

Plate 1

Mission San Jose de Tumacacori

View from Southeast

FOREWORD

Eighteen miles north of the border town of Nogales, Arizona are the ruins of the mission of San Jose de Tumacacori. A ten acre reservation contains the ruins of most of the structures which formerly were associated with the mission church. The protected area was given to the United States in 1908 and, on September 15 of that year, a presidential proclamation created the Tumacacori National Monument. It is now administered by the National Park Service, U. S. Department of the Interior.

This report is an account of work done in 1949 to protect and preserve the fine mural paintings which are still present on the interior walls of the church. This is not to be considered a history of the site, though a number of references must be made to early accounts of the mission and to the reports of others who have studied the site. The short introductory chapters are included to help place Tumacacori in regard to other Spanish missions in Arizona and Sonora.

For continuity, the chapters on analysis of pigments, prepared by Mr. Gettens, are tucked into the body of the report between the historical outline and the description of the work done in 1949.

ACKNOWLEDGMENTS

In any project such as this, so many persons furnish aid and assistance that one sometimes wonders whether the men whose names are on the title page did much more than assemble the material.

Special acknowledgment is made to Professor Clifford Frondel and to Miss Mary Mrose of the Department of Mineralogy, Harvard, for the X-ray diffraction analyses and the optical data reported here and to Dr. H. C. Harrison, also of that Department for the spectrographic analyses.

The following employees of the National Park Service furnished techhical assistance and, in several cases, stood around a drafting table for a total of many hours to argue what might have been.

Earl H. Jackson, Superintendent of Tumacacori National Monument
Dale S. King, Park Naturalist, Southwest National Monuments
Sallie P. Brewer, Archeologist, Region Three
Erik K. Reed, Regional Archeologist, Region Three
Charles R. Sigler, Regional Architect, Region Three
John B. Cabot, now Regional Architect, Region Two
Glenn R. Haynes, Photographer, Region Three
Miss Harriett Lassiter

The color illustrations were made by Mr. Jimmie Trujillo, of Taos Pueblo, a student at the Santa Fe Indian School.

INTRODUCTION

As Spain's small armies set about the conquest of the New World, the soldiers were always accompanied by priests -- members of religious orders whose purpose it was to convert the Indians to Christianity. Throughout the early activities of Spain in America, cross and sword were constant companions.

The business of conversion, as that of conquering, met with varying success according to the strength (temporal and spiritual) of the natives encountered. Some accepted Christianity readily or passively, other tribes remained obdurate for long periods until pressure of opinion from their neighbors, or inertia, made them give way to the new religion. A few doughty tribes made good their determination not to accept Christianity and, today, these remain as small cultural islands which apparently are firmly entrenched against any immediate onslaught by Christian missionaries.

Within the present boundaries of Arizona are the scenes of two early attempts by the Spanish to convert Indians to Christianity; the first ended in failure, the second was successful.

During the summer of 1540 two exploring parties, sent out from Coronado's main expedition, visited the Hopi towns of northeastern Arizona. Two other expeditions reached Hopi land during the 16th century[1], but it was not until 1629 that Franciscan missionaries went from Santa Fe to establish missions at the Hopi

(1) Espejo, 1583 and Onate, 1598

towns. The site selected for a headquarters mission was at the village which offered least resistance to the priests - Awatovi. Missions later were established at other Hopi villages but none was as successful as that at Awatovi.[2]

(2) Brew, 1949, p. 12

In 1680 the Pueblos, acting in unison throughout the northern part of the province of New Mexico, arose in revolt to drive the Spaniards from their homeland. Many Spaniards were killed, the rest driven back to Mexico. The reconquest of New Mexico by De Vargas, beginning in 1692, was successful in the Rio Grande Valley but less so among the western pueblos, especially Hopi. The mission at Awatovi was reestablished but the Spaniards were unable to influence the inhabitants of the other Hopi villages. During the winter of 1700-1701 the other Hopis (and refugees among them from the Rio Grande pueblos) sacked Awatovi, killed the men and enslaved the women and children. This was the end of the Awatovi mission, and of Awatovi as a town - it was never again inhabited.

There has never since been a successful mission at the Hopi villages. Several modern missions, with a few converts each, are situated outside the pueblos; the dominant religion of the Hopis is that which they have retained since prehistoric times.[3]

(3) For the best account of the history of the Hopi missions see Brew, 1949.

As a parenthetical statement, the role of a Christian Indian in communities such as Hopi and Zuni is not a happy one. I recall talking one day to a Zuni who had been converted at one of the missions. He obviously felt left out of things and spoke of Zuni much as a stranger would. During the conversation I called attention to some houses which were being rebuilt and asked why several rooms, in the center of the activity, were being left in ruins. The Zuni's answer was that, "Those people are afraid to build there. They believe a witch lives in that old house." It was apparent from his manner that he, too, believed in the witch but was afraid to admit it.

In contrast to the story of Spanish influence at Hopi, the mission history of Sonora, including what is now southern Arizona, is in general, one of success and progress.

THE PIMA MISSIONS

The reception of the Spaniards by the Pima was quite different from the attitude of the Western Pueblos. As a rule the Pima-speaking people of northwestern Mexico (which included modern southern Arizona) were happy to have missions established at their villages. It may seem cynical to write that the Pimas were influenced by herds of cattle and horses, and new crops such as wheat, which the Spanish introduced, but undoubtedly these benefits made Pima conversion easier.

Missions were established among the southern Pima in the early 17th century. In 1687 Fr. Eusebio Francisco Kino, of the Society of Jesus, arrived in Pimeria Alta to establish a group of missions in the country of the Opata, Sobaipuri, Papago, Gila River Pima, and Yuma Indians. Kino built a headquarters mission at Dolores, about fifty miles south of modern Nogales and, before that structure was completed, had started the series of exploratory journeys which would make him one of the foremost explorers and geographers of North America.

In late December, 1690, (4) at the village of Tucubavia, Kino

(4) Bolton, 1948, p. 119

was met by a delegation of Indians from Tumacacori and Bac who begged him to visit their villages. Kino immediately journeyed north, reached Guebabi and Tumacacori in January, 1691 (but did not go to Bac that year) and was favorably impressed by the location of the villages and the sincerity of the inhabitants. He made several other visits to these villages, and to Bac, during the next ten years and, in 1701, established a priest at the village of Guebabi. This man also administered to the needs of several other villages, including Tumacacori.

A small church was probably built at Tumacacori about this time and, although extant records are not clear, a second and larger church several years later. In 1767 the Jesuit order was expelled from Spain and all her possessions; in northwest Mexico the Jesuits were replaced by Franciscans. At the same time Apache raids in the Santa Cruz Valley were becoming so frequent and devastating that the Indians of Guevabi abandoned their homes and moved to Tumacacori, located in a portion of the valley which is wider and more easily defended. The mission headquarters was moved to Tumacacori by 1775.

The existing church of Tumacacori was started about, or just before, 1800. The mission was always a poor one and funds for construction were apparently scarce. The church was never completed but it was finished to the point where it could be, and was, used. It was not until 1822 that the burial register contains a statement that the bodies of two former priests were moved from the old church to the new. (5) The mission was apparently closed in

(5) Beaubien, 1937, p. 187 -- For a number of years it has been assumed that this represents the date the building was put in operation. For reasons given later in this paper it seems apparent that the church had been in use for several years.

1827 though there is some slight evidence that at least a few burials and baptisms were made at Tumacacori after that year. (6)

(6) Jackson, Ms.

The reason for the abandonment of the mission is that Mexico won her independence from Spain in 1823; without the financial support which the missionaries had received from Spain they were unable to continue their work, and the work of the missionaries was hampered by anti-clerical laws which limited their activities and secularized mission property.

In the light of rather extensive re-decorating jobs which became obvious during the work of cleaning and fixing the mural decorations, I believe that the church must have been in use for some time before the 1822 date. It must be that the priests only then got around to re-burying the bones of their predecessors. One possibility which presents itself is that the earlier church, which Beaubien (7)

(7) Beaubien, p. 205, et seq.

believes to have been located within the quadrangle east of the present church, was just then (1822) being demolished. If that was the case the bodies of the priests would have had to be removed.

The history of the building is as hazy after 1827 as it was during the years before. The few Indians left at Tumacacori at the time the mission was abandoned left, according to legends at San Xavier, for Bac, southwest of Tucson. They carried some church furniture (at least a few statues) and deposited them at the Mission San Xavier del Bac. This church, also abandoned by missionaries, was protected and cared for by the Indians of the village until the mission was re-established in 1855 from the Archdiocese of Santa Fe, New Mexico.

Early American accounts of Tumacacori (1849-1864) are brief (8)

(8) Browne, Cozzens, and others

and give little information other than that the church was in ruins. It is not known when the roof of the nave was removed. Local legends say that ranchers took the roof timbers for their own buildings. The earliest known, dated, photographs of the interior were taken on July 4, 1889 by Mr. George Roskruge of Tucson. These show the interior to be in much the same state as at present. Some additional plaster has fallen since that time and, because of details shown in the Roskruge photos we are able to reconstruct a few features which have long been destroyed.

Much damage was done by those who searched for the "treasures of the Jesuits". Beaubien, (9) during his 1934 excavations, found

(9) Beaubien, 1937, p. 186, et seq.

little undisturbed soil either within the church or in the quadrangle. It is strange that the stories of Jesuit treasure are so prevalent concerning a building which is entirely Franciscan in origin. It is even more strange to read (10) that the Jesuits were plagued by a

(10) Treutlein (Translator)-Pfefferkorn, p. 277

general belief that they were amassing great treasures in their churches during the 18th century, when it must have been obvious to their contemporaries that the missions were extremely poor.

THE KINO MISSION CHAIN

The churches of the "Kino Chain" are located principally along the Rio Altar and the Santa Cruz River. The Rio Altar rises west of the present town of Nogales on the international boundary, then flows in a general southwesterly direction to the Gulf of California. The Santa Cruz rises in Arizona and curves into Sonora before flowing northwest to the Gila River. Most of the Indian villages at which the missions were located have persisted into modern times; in fact, some of the villages are now towns of several thousand inhabitants and are completely Mexicanized. Some existing churches in Sonora are still in use as parish churches. None of the extant church buildings date from Kino's time; they were all constructed after the Franciscans assumed charge of the Sonora missions.

The principal missions were:

In Sonora

Nuestra Senora de los Dolores - on the Rio San Miguel. This was Kino's first church and his headquarters. The mission was abandoned in 1732 (11) and nothing but a few low foundations now remain of the church.

(11) Woodward, 1935, p. 70

San Ignacio de Caborica - Five miles north of the town of Magdalena. Existing building probably contemporaneous with Tumacacori church.

Santiago de Cocospera - At the village of Cocospera. A beautiful old church with the roof now collapsed and the walls washing badly.

San Antonio de Oquitoa - On the Rio Altar, a few miles north of the town of Altar.

San Francisco de Ati - at the village of Atil, a few miles north of Oquitoa.

Nuestra Senora de la Concepcion de Caborca - one of the most beautiful of the mission buildings; similar in many respects to San Xavier. The rio Altar has cut into its bank behind this church and has washed away much of the rear of the church and nearly all of the attendant buildings.

San Diego del Pitiquito - (sometimes spelled Pitquin) - at the modern town of Pitquito on the Rio Altar.

San Pedro y San Pablo de Tubutama - at the town of Tubatama; this is the largest of the mission churches in the chain and one of the best preserved.

In Arizona

San Gabriel de Guebabi - on the Santa Cruz, 12 miles southeast of Tumacacori. Few walls now stand of this mission which formerly was the principal mission for the Santa Cruz Valley. Guebabi was abandoned about 1770.

San Jose de Tumacacori - mission ruins standing. Formerly a visita of Guebabi but, after about 1770, the mission headquarters for this section of the valley.

San Xavier del Bac - southwest of Tucson. The only one of the "Kino Missions" which is still in use as a mission to the Indians, San Xavier is also the best preserved and, to many people, the most beautiful of all the missions.

Other missions in the same chain were either shorter-lived or lacked the importance of those named. Each of the missions in Arizona had several visitas, but the locations of most of these have been lost.

Section of cleaned wall (west side of nave). The exposed adobe bricks at lower left mark the position of ~~this~~ the choir loft. The vertical section was formerly covered by the pier for the arch; the horizontal scar indicates the floor. The round holes through the plaster were holes in which scaffolding was attached at the time the church was built.

TUMACACORI UNDER THE NATIONAL PARK SERVICE

At the time Tumacacori National Monument was established, no single government bureau was organized to administer park areas. National Parks reported directly to the office of the Secretary of the Interior, and the National Monuments were farmed out to the Secretaries of Interior, Agriculture and War. The monuments which came under the jurisdiction of the Interior Department (Tumacacori was in this class) were handled by the General Land Office until 1916 when the National Park Service was created. Soon after the Park Service began functioning, most of the National Monuments in the southwest were grouped, for administrative purposes, and directed by a Superintendent of Southwestern National Monuments. With but few changes in organization since that time, that is the set-up which still holds. In 1934 administration of all National Monuments was vested in the National Park Service.

By 1920 it became apparent that if repairs were not made to the Tumacacori Mission immediately, the remaining shell of building would soon crumble into a shapeless and meaningless mass. Little money was available for the work, and if it had not been for the willingness of several public organizations in Nogales, Tucson and Phoenix to furnish funds the initial repairs could not have been made. The job consisted of putting a new roof over the nave, repairing the facade, and making a general cleanup of the church interior.(12)

(12) Pinkley, 1936

With the exception of a few small jobs of patching plaster on the exterior walls, the next big project at the mission was the excavations made in 1934 by Paul L. Beaubien of the National Park Service. (13) Beaubien did most of his work in the quadrangle

(13) Beaubien - 1937

east of the church but also a little inside the building.

In 1946 Dale S. King, Park Naturalist for the Southwestern National Monuments, stabilized the facade of the church, where the attached columns were showing signs that they would soon fall, and replastered large sections of the exterior wall - particularly on the west wall of the building. While working at Tumacacori that year King noticed that dry rot had set into the heavy roof timbers erected by Pinkley in 1921. The following year (1947) the roof was replaced.

All this time the interior walls of the church remained untouched. This was not because the interior needed no work but because the various Park Service technicians involved had no idea what to do. The plaster remaining on the walls was dirty, as were the traces of paint which could be detected under the dirt. An excellent view of the amount of dirt which overlay the white plaster walls of the nave is shown in Plate II in which cleaned and uncleaned sections of wall show. In addition to the coating of dirt, some plaster, especially in the dome over the sanctuary, was continually flaking off.

In the spring of 1949 the National Park Service invited Mr. R. J. Gettens, Chief of Technical Research for the Fogg Museum of Art, Harvard University,[14] to visit Tumacacori to determine what could be done to protect and preserve the plaster and

(14) Now of the Freer Gallery of Art, Washington, D. C.

paintings.

In June, 1949, Gettens and Steen spent four days at Tumacacori during which time Mr. Gettens was able to make a close inspection of the problems involved. On his return to Cambridge Mr. Gettens devised a formula for a lacquer to be sprayed on the walls and also made the analysis of the pigments which forms a major section of this report.

Steen returned to Tumacacori in October, 1949 and spent two months cleaning and fixing the walls. As the work progressed, and dirt-covered fragments of painting were revealed, it was realized that a fairly accurate reconstruction of the mural decorations of the church could be made. This report, then, is to record, as completely as possible what was found on the walls of the church and to reconstruct pictorially, again so far as possible, the appearance of the church during mission times. Some details are so far gone that it is now impossible to re-create the original designs, but by comparing the fragments found with somewhat similar designs in other mission churches of the same period we can feel fairly sure of accurate results.

The reconstruction of the Reredos is the result of much head scratching, argument and recourse to illustrations of other early Mexican altars and reredos. No one involved was completely satisfied with the result, but, unless an accurate, early drawing of the altar is someday found we shall probably never know just how the altar was decorated.

REPORT ON INSPECTION AND RECOMMENDATIONS FOR
TREATMENT OF PLASTER WALLS AND WALL PAINTINGS OF THE
MISSION CHURCH AT TUMACACORI NATIONAL MONUMENT, ARIZONA

By R. J. Gettens

At the invitation of Mr. H. A. Tolson, Acting Director of the National Park Service, Washington, the undersigned visited Tumacacori National Monument, Tumacacori, Arizona, June 12-16, 1949, to inspect the interior of the ruins of the Mission Church, and to make recommendations for cleaning and preserving the plaster and especially the remnants of painted decoration on it. He was accompanied by Charlie R. Steen of the Southwestern National Monuments. A preliminary description of the wall paintings and of the problem had already been made by Mr. Earl Jackson, Superintendent of Tumacacori in a memorandum for the Regional Director, Region Three, dated February 5, 1948.

This report is divided into several main parts which are as follows:

I. Cleaning of Plaster
II. Cleaning of Painted Areas in the Sanctuary
III. Stabilization of Plaster
IV. Fixing of Wall Surfaces and Painted Decorations
V. Materials and Equipment
VI. Sampling of Materials for Identification Purposes
VII. Technique of Applying the Painted Decorations
VIII. Related Problems
IX. Summary

I. CLEANING OF PLASTER

It was estimated that there still exists about 2,000 square feet of plaster area in the nave and a like amount in the sanctuary, totaling about 4,000 square feet. Most of it can be reached only by ladder or staging.

(A) Plaster of Nave:

Where still remaining this appears to consist of two grayish scratch coats of lime-sand mortar. Over these is a thin white finish coat apparently brush applied. In a few small places the under scratch coat is exposed where top scratch coat has dropped off. (Note: the two under rough coats appear to be identical in composition and texture.) In general, however, there has been little cleavage between the coats; the principal separation has occurred between the adobe brick wall and the first plaster coat. There are occasional holes and mars. There was no sign of efflorescence or salty incrustations. In general the plaster of the nave is undecorated except for a faintly visible frieze at top of the wall which consists of a row of semicircles faintly incised in the plaster with a compass (the compass center point still shows) and filled in solidly with reddish color. There are also traces of paint on the plaster low around the side altars.

The plaster is covered almost completely with adobe drip, in places as much as $\frac{1}{4}$ inch thick. This had formed from upper exposed white streaks where rain drip has partially cleaned the plaster; much wind-blown dust has also lodged in irregular patches; there are bat and bird droppings on capitals of pilasters and other projections.

It was found by experiment that much of the dust and dirt could be removed by simple brushing. In one trial, an area about two feet square, high on the east side, was cleaned with a fibre floor brush mostly with an up-and-down motion. No. 00 sandpaper was also effective. The white finish coat did not wear through easily. The treatment left it white and not noticeably streaked, but it was slightly chalky. Another area, a capital on the west side, was cleaned in the same way with satisfactory results. An attempt was made also to clean a small area with aid of brush and water but it was quickly found that this treatment washed off the white finish coat and worked adobe mud into the plaster. Any kind of water treatment seems undesirable.

Recommended Treatment

1. After erection of scaffolding the surface should be carefully examined for traces of painted decoration.

2. The entire area within reach can then be gone over lightly with a fibre brush to remove the thickest accretions.

3. The area can next be worked over with any suitable brush or even sandpaper to give the white surface the best possible appearance. Care, of course, should be taken not to wear through to the scratch coat because that would expose a grayish surface.

4. Extra care should be taken at the top of the wall where the painted frieze is located. Those areas should be treated as the painted surfaces of the sanctuary (see below). Special care should be taken not to obliterate the incised outlines of the frieze.

5. Finally, the plaster area should be examined for cleavage and loose pieces at the edges.

(B) Plaster of Sanctuary

Fortunately, because it has always been roofed by the dome, the plaster of the sanctuary is in much better condition than the nave. There is no adobe drip. The vertical walls are blotched with adobe dust, and painted decorations are partially concealed. Plaster is gone from lower walls to hand-reach level. There are scars and holes at higher levels. To a height of about 15 feet the wall is white with the exception of a decorated band of red drapes and black conventional designs. The white finish coat here seems thinner than in the nave. In places the finish coat is almost abraded away showing the grayish rough plaster beneath. An attempt was made here to clean the white surface with coarse brushes but the white abraded through. About all it will stand is cleaning with a 4-inch long bristle paint brush.

From the lower level of the windows up to the moulding the plaster is surface tinted, yellowish pink, except for the pendentives which are decorated. The pinkish surface is covered with adobe dust. This was found by trial to brush off readily with the wide paint brush. The pink tint was not removed or abraded. A 3 x 4 foot area was treated this way with satisfactory results.

Recommended Treatment

Because of the thinness of the finish coat and presence of the painted decorations, cleaning will have to procede much more cautiously here.

1. The entire area up to the moulding should first be brushed down with a bristle brush to remove all superficial dirt. This includes the tinted surface higher up.

2. The areas around the middle frieze should be dusted with care with narrow softer brushes, taking pains not to smudge the painted designs. (For final cleaning of the painted designs see section II)

3. Areas which have resistant dirt will have to be cleaned by such means as seems feasible, based on experience gained from work on the nave.

(C) Cleaning of the Dome Ceiling

It was not possible, without staging, to examine closely the dome ceiling. It is still white and appears to be in good condition except for places where it is flaked and where it is water-stained. There is evidence from fallen chips that there are two layers of finish coat on this ceiling. (See section VI) As seen from the floor there is some evidence of curling and peeling of the surface.

Recommended Treatment

No detailed recommendations can be given here. It is presumed that this will be the last area cleaned and that sufficient experience will have been gained from the nave and sanctuary to establish a method of treatment. It may need little treatment or there may be little that can be done.

II. CLEANING OF THE PAINTED AREAS IN THE SANCTUARY

(A) Plain Tinted Surfaces

The condition has already been described above. The surface is darkened and mottled with wind-blown dust which can easily be brushed off.

Recommended Treatment

This is simple brushing as already recommended for the white walls of this area.

(B) Painted Designs (stencil designs, conventional motifs and stripes).

The paint of the repeated stencil designs, especially the black, is friable and is easily disturbed even by gentle brushing. In places, because of slight ridges formed at edge of the design, lodgement of dust appears to have been favored. In some places the designs have completely disappeared. The geometric designs, especially those on the inside of the engaged columns that separate sanctuary from nave, are outlined by shallow compass-made incisions in the plaster. The painted straight line around the middle wall of the sanctuary, the black and blue lines on the inside of the arch and the lines that surrounded the reredos seem more secure.

It was found that one of the units of the black stencil design half way up its west wall was easily smudged when a paint brush was passed over it. The smudged edges were cleaned up with aid of a typewriter brush and a pastel stomp. The pastel stomp was especially good for cleaning around the edges of the black design. Pastel fixative was applied with mouth atomizer. After drying, the black no longer smudged under the paint brush.

Recommended Treatment

1. Superficial dust and dirt should be removed from around design details with small brushes and pastel stomps. Attempts should be made to give the surface of the painted details a gentle brushing to remove the more easily detached dirt.

2. The area of the design should next be sprayed with a light fixative the same as that recommended in Section IV below. The surface should immediately be sprayed with thinner to drive the fixative into the plaster and to bind the pigment particles. Care should be taken not to use thinner in excess so that liquid will drip and carry down unfixed pigment. When dry (next day) the surface of the paint may be gone over again with suitable brushes to remove more dirt. Experimentation will have to be done on the site to develop correct procedure and to determine optimum concentrations of spray materials.

III. STABILIZATION OF PLASTER

Some thought was given to the question of possible methods for stabilizing the remaining plaster, especially that on the walls of the nave. Apparently little plaster had fallen since the nave was re-roofed in 1919. Small pieces of plaster, however, still break off from the jagged edges. The plaster body itself seems quite solid and does not crumble and for the most part the white finish coat is intact. In places, where the plaster has fallen off, the stumps of old plaster keys still remain in cracks between the adobes. These are numerous and heavy. It is presumed that most of the remaining plaster is still fairly well keyed.

~~(A) Consolidation of Plaster Body~~

~~The possibility of forcing some kind of binding material into the plaster was considered. This might be done with a synthetic resin solution or emuc~~

21

(A) Consolidation of Plaster Body

The possibility of forcing some kind of binding material into the plaster was considered. This might be done with a synthetic resin solution or emulsion or other organic binder. This idea was discarded, however, because of its obvious impracticability. It would be difficult or impossible to drive any amount of binder into the body from the surface because of thickness of the plaster. It would be almost impossible to get sufficient amount of binder between the plaster and the adobe where it is most needed. In the process there would be danger of discoloring and of loosening the walls. It would be difficult to follow the penetration of material and to judge the effectiveness of treatment. Any such treatment would require skilled labor.

Recommended Treatment

None.

(B) Reinforcement by of Keys

Consideration was also given to the possibility of strengthening the bond between plaster and adobe by inserting metal keys with heads which would tie plaster to adobe. An experiment of this nature was tried on some remaining patches of plaster on an outside wall in the corridor leading into the sacristy. An attempt was made to cut a two-inch-square hole in the outer plaster leaving one-half inch layer of plaster to retain the key head. With a quarter-inch star drill a hole was made into the adobe but this was found difficult because stone pebbles in adobe caught the drill or deflected it. Further experimentation along these lines was considered futile. It would be difficult to drive holes in the adobe and the pounding for drilling might dislodge plaster. It would be difficult to tie key heads to the plaster and last of all it would be difficult to plaster over the key heads to conceal them.

Recommended Treatment

None.

(C) Fastening of Broken Edges

The broken edges of plaster of the nave need some securement to prevent breaking away of small pieces. Tying of the edges would probably better the security of the entire adjacent plaster area.

Recommended Treatment

1. Broken edges of the plaster may be pointed with lime mortar or cement in accordance with the practice of ruins stabilization. This mortar should be keyed into the adobe as well as possible.

2. Where possible, grouting material can be run into cracks and voids to effect binding action. Care should be taken that weight of grout or cement is borne mostly by the adobe and not by the plaster.

IV. FIXING OF WALL SURFACES AND PAINTED DECORATIONS

After cleaning, the white wall surfaces will be left in a slightly chalky condition. This will favor lodgement of wind-borne dust and will impede periodic cleaning. The painted decorations, especially the stencil patters, are chalky and friable. The colors are subdued in tone from lack of binder and from dust. A moderate amount of clear fixative applied to the entire plaster surface would accomplish the following:

(1) Diminish lodgement of dust and aid in periodic cleaning.

(2) Stabilize the decorative paint so it could be cleaned.

(3) Enhance the brilliance of colors and make the designs more readable. In fixing the surface it will be necessary, if possible, to avoid:

(1) Gloss.

(2) Accentuation of irremovable stains.

(3) Darkening of the scratch coat beneath, where it may be exposed.

Recommended Treatment

1. After cleaning the white walls should be given a spray of a thin solution of a colorless or nearly colorless plastic solution. The fixative spray is to be followed immediately by a spray of pure thinner, same as that used to dissolve the plastic. This is to force the fixative into the surface to effect only a bonding of the grains and to avoid formation of a continuous film of the plastic at the surface. A continuous film at the surface would cause undesirable sheen and might eventually cause peeling.

2. This same fixative solution can be used in proper quantities to fix the color areas in process of cleaning.

V. MATERIALS AND EQUIPMENT

Various synthetic resins of the polymer type could be used for fixing purposes. These include polyvinyl acetate (Vinylite), polyvinyl acetal (Alvar), or butyl methacrylate. These should be used in a solution containing no more than five percent solids. The solution should be a balanced solvent mixture to give moderately slow evaporation rate.

(A) Fixative Formula

A working laboratory formula is as follows:

Vinylite A (medium viscosity)	50 grams
In solvent mixture:	
Toluene	700 ml.
Ethylene dichloride	200 ml.
Cellosolve	40 ml.
Cellosolve acetate	40 ml.
Dibutylphthalate	20 ml.

The solvent mixture above can be made up as thinner.

(B) Procurement of Materials

It was estimated that about 20 gallons of this fixative solution would be required to fix the entire wall surface and about 10 gallons of thinner. It would be undesirable to attempt formulation of this material at the site. With this problem in mind a visit was made to the Pioneer Paint and Varnish Company at Tucson, Harry S. Bacal, Manager. Mr. Bacal was cooperative and it was soon learned that he was well acquainted with synthetic resin formulation. He said he could formulate Vinylite or any similar material according to specifications and deliver to Tumacacori.

(C) Equipment

The only special equipment needed for the application of the fixative is a spray gun of 1 quart capacity. Standard spray equipment and compressor may be used.

(D) Hazards of Spraying

Since the spraying is to be done in open, well-ventilated spaces, no special hazard from inflammability and toxicity of solvent vapors is expected. Spraying should be done intermittently to avoid building up of high local concentrations. Lighting of matches in vicinity of spraying operations should be avoided.

VI. SAMPLING OF MATERIALS FOR IDENTIFICATION PURPOSES

While opportunity afforded itself, there was some reason for taking samples for identification of the pigments used in the decoration of the Mission church. Mr. Jackson has numerous inquiries about the pigments and the reasons they have lasted so long. We should like to increase our knowledge of painting materials of the southwest during the Spanish occupation. These studies could tie in with studies now being made at the Fogg museum on pigments used on New Mexican santos of the same period.

(A) Samples Already Analysed

Some samples of painted plaster were sent to Cambridge by Mr. Jackson in the spring of 1949 for preliminary studies. The following observations were made during brief examination:

1. The scratch coats of plaster consist of approximately half lime and half coarse sand.

2. The thin white finish coat is composed mainly of gypsum.

3. The blue pigment of the thin blue paint layer between the double finish coats on ceiling plaster from the dome is indigo or a similar organic blue pigment.

4. The black pigment on the surface of one of the fragments is carbon black.

(B) Samples of Paint Taken at Tumacacori

During examination of the walls 18 small samples of paint were taken for microscopic identification. It will be necessary to return these samples to the Fogg Museum where proper facilities for analysis are available. Specimens of a few other materials were also taken, including the glazed surface of the canales, slag and brick used in decorating outside walls, etc. A supplementary report will be rendered later on the results of these analyses.

VII. THE TECHNIQUE OF APPLYING THE PAINTED DECORATIONS

(A) Questions have arisen about the vehicle or binding material used for the pigments. It is doubtful if they can be entirely answered. There is no indication that the method of painting is true fresco. It is doubtful if drying oil (linseed oil) was employed. In all probability the paints were applied as distemper with an aqueous medium. Water soluble gums, animal glue or even milk might have been used. Detection of any considerable amount of nitrogen in the paint samples would narrow down the possible mediums to a protein substance like animal glue or milk.

(B) The repeated designs, especially the black conventional designs, raise more questions. They may be stencil designs although that is not entirely certain because of minor inconsistencies in pattern and because of the thickness of the paint. This problem can best be studied when staging is erected so that accurate measurements can be made, and also after the decorations are more clearly revealed by cleaning.

VIII. RELATED PROBLEMS

There are related problems but these are outside the scope of this particular problem of the cleaning of the interior walls. These are:

(1) Exclusion of bats and birds.

(2) Waterproofing of base of walls.

(3) Stabilization of the exterior.

There is no doubt that the solution of these problems can be solved by the regular techniques of ruins stabilization.

IX. SUMMARY:

It is felt that the interior walls of the Tumacacori Mission Church can be brightened, freshened, secured and given a cared-for appearance by carrying out the following:

1. Removing most of the adobe drip, dust and bird droppings by careful brushing.

2. Fixing the surface lightly with a synthetic resin spray.

3. Pointing the broken edges of the plaster.

It is felt that these operations can be done with local help under direction of Park Service staff members.

THE PIGMENTS AND INTERIOR PLASTER MATERIALS
OF TUMACACORI MISSION CHURCH IN ARIZONA

by

R. J. Gettens

In the summer of 1949 an inspection and study was made of the old Spanish Mission Church of Tumacacori at Tumacacori National Monument in Southern Arizona for the purpose of developing a plan for cleaning and restoring the much-ruined and defaced interior walls. (The mission was completed by the Franciscans in the period of 1790 to 1820; it was abandoned about the year 1827 and gradually fell into complete ruin until repairs were started in 1921.) During the inspection advantage was taken of the opportunity to take samples of the paints and wall materials for analysis and identification. In interpretation of the ruins officials of the Park Service had found a need for more detailed knowledge about the pigments of the painted decorations and the technique of their application.

There are now no representative paintings in the interior. The paint specimens were secured solely from wall decorations which consist of stencil designs, garlands, strips, frames, bands and background tints. Most of the samples were taken from the sanctuary where the colors are best preserved. Samples of about 0.5 sq. cm area were removed with a knife point and placed in a vial. They were brought to the Fogg Museum, Harvard University, for analysis.

Identification of the pigments was made chiefly by microscopic and microchemical methods. Recognition was much aided by comparison of the samples with known pigments in the large collection of historic painting materials in the Fogg Museum. A comparison microscope was found useful. Since the paints were applied to a gypsum-coated plaster wall, all samples contained a large impurity of gypsum; in most samples that material offered little interference in recognition of the color. Although 20 samples were examined, the number of separate pigment kinds identified is only a half dozen.

The observations on materials are divided into five sections as follows:

I. Plaster support

II. Plaster finish coat

III. Pigments

IV. Medium and technique of painting

V. Table of samples

I. Plaster support:

(A) Plaster of the interior walls.

The thick adobe walls of the church were covered on the interior with two coats of thick lime-sand mortar. The under or scratch coat, which is 1 to 2 cm. thick, is well keyed into the crevices between the adobe bricks. The second or brown coat is about 1 cm. thick and appears to be identical in composition with the scratch coat. The color is light gray. Over the entire plaster surface was spread a thin finish coat of gypsum (see Section II below).

The plaster body is readily disintegrated by dilute hydrochloric acid with strong effervescence caused by decomposition of the calcium carbonate binder and release of carbon dioxide. The particles of the sand residue are medium coarse, and heterogeneous in color and composition. Most of them are clear quartz, but red, black, white and yellow particles of other minerals are also abundant. It was estimated that the wall plaster contains 20-25 percent by weight of lime. (See (B) below.) The plaster is firm but can be easily scored with the fingernail and crushed between thumb and finger. It contains no animal hair or other fibrous material.

(B) The floor plaster

The original flooring is gone, but a small one-inch-square sample of red-coated plaster, that appears to be the original flooring, was available. This bore on its smooth-troweled surface a single layer of red ocherous hematite. There is no gypsum layer between color and plaster base. The plaster seems visually to have the same ingredients as the wall plaster above, but it is a little darker in color and appears to have less lime. Compared with the wall plaster it is definitely harder under the fingernail and not so easily crushed. Still another difference was observed; when a lump of this flooring plaster was treated with dilute hydrochloric acid there was vigorous effervescence, but unlike the wall plaster described above, the lump retained its shape and did not disintegrate. Microscopic examination showed there is left undissolved some white cementive material which binds the sand grains together. This material is crusty and amorphus looking. It is estimated to have refractive index between 1.49 and 1.50. It encloses and surrounds small particles of quartz and would be difficult to isolate even for X-ray diffraction studies. It was not identified. It might be silica deposited from dissolved silica in soil water.

A rough analysis was made to determine the comparative lime contents of the wall and flooring plasters. Samples of each weighing about 1 gram were placed in weighed fritted Gooch crucibles and the crucibles reweighed. The samples were treated with excess dilute hydrochloric acid and crushed until effervescence ceased. The sand residue was then washed and crucibles dried and reweighed. Loss in weight was taken as a rough measure (perhaps within $\frac{1}{2}$ percent) of the lime (calcium carbonate) content of each plaster sample. The results were:

	Loss in weight (approximate lime content)
Wall plaster	23.3 percent
Floor plaster	20.5 percent

These results confirmed earlier visual observations that the wall plaster appears to contain more lime than the floor plaster but the lime content difference is not enough to explain the apparent difference in hardness or the difference of purpose. They throw no light on the composition of the acid-insoluble cementive material mentioned above.

(C) Plaster of the exterior canales

A small chip from the smooth surface of one of the canales on the exterior north side of the church was also examined. Under a binocular microscope this plaster appears identical with the floor plaster described above. It has the same surface coat of red iron oxide (thinner and more weathered, but easily seen when the surface is wet) and apparently the same proportion of lime and sand. On treatment with acid there is much effervescence, but the red layer and the surface particles of sand hold together. There was indication also that the sand particles were bridged and tied together with thin white translucent films like that observed with the floor plaster. The retention of the smooth surface after over a century of out-of-door weathering may, in part, be caused by the iron oxide layer at the surface. The resistance of iron oxide to weathering is well known.

II. Plaster Finish Coat

A thin white finish coat covers the entire interior wall plaster surface of both the nave and the sanctuary. The white material is mainly burned gypsum, which has reverted back to the dihydrate, $CaSO_4.2H_2O$. The raw gypsum was heated, apparently, to form the hemihydrate (plaster of Paris, $2CaSO_4.H_2O$) and rehydration occurred at time of wetting for purpose of application to the wall. The bulk of the material consists of fine crystal aggregates which have more the particle characteristics of set plaster of Paris than of ground raw gypsum.

In addition to the fine crystalline calcium sulphate dihydrate, which makes up the bulk of the white finish coat, there is a fair amount of coarser fibrous crystalline material not ordinarily found in gypsum plaster. (See Plate 3, A and B) In a specimen of the white plaster from the moulding at base of the dome (sample No. 1) one can see, even with a pocket magnifier, little bundles of these fibrous crystals laid parallel. Optical and X-ray diffraction pattern studies of these crystals indicate that they are composed of the mineral anhydrite (anhydrous calcium sulphate, $CaSO_4$), although they do not have the usual habit of anhydrite. An X-ray powder picture of the white finish plaster gives a diffraction pattern characteristic of gypsum, but also there are extra lines of some other substance in lesser amount. These extra lines match for anhydrite. Bundles of the fibrous material were isolated with a needle; these give a characteristic anhydrite pattern. (See figure 2) /ue

Some optical characteristics of the fibrous material are as follows: The crystals are moderately birefracting and show parallel extinction; they are biaxial positive and have positive elongation; α =1.570, β =1.575. These coincide with the optical characteristics of anhydrite.

It is probable that the anhydrite occurred as a natural impurity in the original gypsum and suffered no chargeduring either the burning or rehydration of the gypsum. Although the fibrous particles of anhydrite are probably of no great significance, it is remotely possible that they might be useful in locating the original source of the gypsum or in comparing gypsum coatings or plasters in different buildings of the region.

The gypsum layer is only 1-2mm thick and was probably applied as a water paint or whitewash. Although it is now moderately friable and rubs off with the hand there has been little tendency for it to peel or loosen from the plaster surface. On the dome ceiling at least two thick coats of this whitewash were applied.

III. Pigments

(A) Red, orange red, and pink: The color component of all of these is earthy iron oxide or ocherous hematite. These iron oxide pigments in several shades and tints are the ones most plentifully used. Although earth reds from more than one source were probably employed, the various specimens differ little microscopically. Iron red was observed in deepest shade and concentration on the specimens of floor plaster. It was used as an under layer beneath metal and green in the fluting of the corbel over the main altar. In the upper sanctuary walls it occurs as a pale background tint. In all samples iron oxide was recognized by its dull salmon red color, high refractive index and difficult solubility in strong acids. Microchemical tests for iron with potassium ferrocyanide on the dull reds were in all cases strongly positive.

metallic

Natural iron oxide pigments like these are fairly widely occurring and might have been obtained from local sources.

(B) Bright Red: The red of the painted draperies and tassels at mid-height around the walls of the sanctuary is dull red, but when scratched or abraded shows bright flaming red. This pigment is the pulverized red mercuric sulphide mineral called cinnabar. The artificial kind is known ~~at~~ to artists as vermilion. The particles are irregular in size and shape and have the fractured and broken appearance of fragments produced by the comminution of coarse crystalline materials. Particle size and character compare well with 200 mesh cinnabar in the Fogg collection. Observed microscopically in strong transmitted light the particles are deep crimson red and highly refracting. The red is insoluble in concentrated hydrochloric or nitric acids, but readily soluble in aqua regia. A microchemical test for mercury with cobalt acetate and potassium thiocyanate to form characteristic bright crystals of cobalt mecuric thiocyanate was strongly positive.

Cinnabar occurs in various localities in the Southwest and in Mexico.

(C) Bright Green: A tinted band of fairly bright green surrounds the sanctuary wall just beneath the molding under the dome. Best specimens of green were obtained from the flutings of the corbel-like ornament on the north wall over the main altar. Here the green is applied over ocherous hematite and is easier to isolate than in the flat wall tints where particles of green are thinly dispersed in much gypsum.

The green is an unidentified copper compound and from particle characteristics appears to be a ground-up copper mineral. Although very finely divided, the particles are irregular in size and shape. The color by transmitted light is pale blue-green, almost colorless. Particles have a crusty amorphous character and are birefracting. Refractive index is variable but lies in the region 1.65-1.70. Test for copper (with ferrocyanide) is strongly positive. On addition of acid the pale green color quickly disappears; the particles do not entirely dissolve however, but leave a colorless skeleton residue. Identification by X-ray diffraction analysis was attempted, but without success. One sample of green (No. 6) gave gypsum lines only; another (No. 2) gave a faint pattern which could not be identified by comparison with the patterns of known copper minerals. Although the optical properties of the copper mineral do not check for chrysocolla (a common copper silicate) it is suspected from the limited chemical properties that this green might be a silicate but not a sufficient amount of it was available for satisfactory analysis. The unknown green does not compare with any of the known artificial copper pigments.

(D) Blue: Although a first glance of the remaining interior walls gave no impression that blue was part of the color scheme, traces of a stain-like blue were found which has the properties of the natural organic dyestuff indigo. This blue is used in a narrow painted line above the piers of the sanctuary arch. On the sanctuary floor the superintendent, Mr. Jackson, occasionally finds white chips which appear to have fallen from the white dome ceiling. On these chips are two thick layers of gypsum finish coat and between these a thin staining of blue. This suggests that the dome ceiling was originally tinted blue to simulate the vault of heaven, but was later whitened to give better background for the present conventional designs.

From both locations the blue color component is non-crystalline and stain-like. The color by transmitted light is dull greenish blue and compares well with known samples of natural indigo. The blue resists the action of dilute nitric acid but is discharged by concentrated nitric; it is not decolorized, however, by dilute sodium hydroxide. The presence of much gypsum in all samples makes critical study difficult. Indigo was grown in Mexico for dyestuff purposes at an early date. The writer has frequently identified indigo on 'santos' of the XVIII century from the Rio Grande Valley in New Mexico. In the Southwest, azurite (mineral copper carbonate) was rarely used as a paint pigment. Indigo apparently was the common pigment blue.

(E) Black, gray and blue gray: This is carbon and the particle characteristics indicate that it is derived from powdered charcoal. The black opaque particles are fairly coarse, irregular in size and a large proportion of them are elongated and splintery in form (see figure 3). Microscopically the black appears identical with known samples of powdered charcoal. Where painted thinly over white or mixed with white, charcoal is well known to give cool gray tones.

(F) Metallic yellow: On the corbel-like projection high on the sanctuary north wall is a small area covered with dull brown-gray tone. In the brown layer, which is laid over iron oxide red are numerous thin metal flakes which analysis shows to be a copper-zinc alloy or bronze gilt. The metal is tarnished and dull and is hardly recognizable as metal. On addition of dilute hydrochloric or nitric acids the flakes glisten briefly golden yellow, but soon dissolve in the acid. Because of this ready solubility in acid the metal is not gold. Microchemical tests for copper (with ferrocyanide) and for zinc (with potassium mercuric thiocyanate) were positive. Spectrographic analysis confirmed the presence of copper and zinc and the absence of gold. It showed the zinc to be present in lesser amount than the copper.

The finding here of what obviously is imitation gold is to be wondered at. The use of red iron oxide paint beneath the imitation gilding is in the old Italian gilding tradition in which red bole (iron oxide colored clay) was used as a foundation for gold leaf. Little appears to be known about the early history of so-called "bronzing powders", but it is possible they were produced in Europe in the late XVIII century.

IV. The Paint Medium Vehicle and the Method of Painting

In all the microscopic and microchemical observations made, there was found no indication of the present existence of vehicle or binding medium. A microchemical test for nitrogen (Emich's) was applied to two specimens of the painted surface, but in both it was negative, indicating there are now no residues of protein-type mediums like egg or milk. The presence of the thin finish coat of gypsum over the plaster eliminates the employment of true fresco technique. We can only suppose that some sort of aqueous medium was used for application of the pigment, but we don't know the kind. When used very thinly aqueous mediums, over long periods of time, seem to vanish.

V. Table of Samples

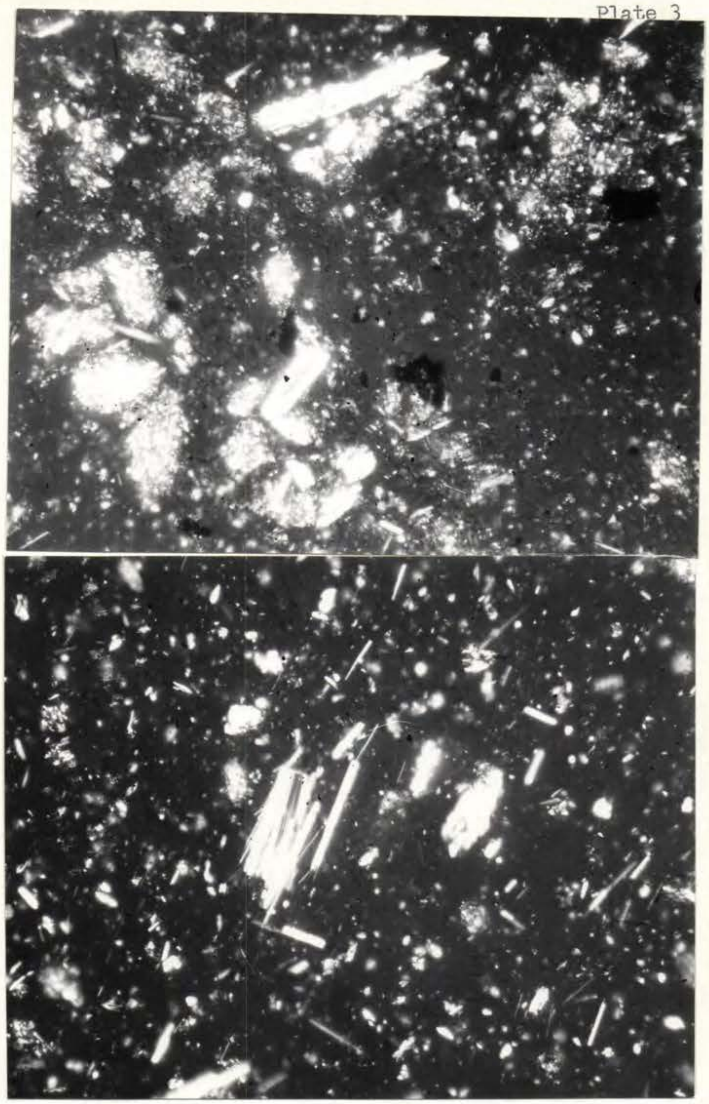
Sample Number	Color	Location	Identification
1	Orange red	Sanctuary, north wall moulding at base of dome	Ocherous haematite (iron oxide)
2	Pale green	Sanctuary, north wall, band below moulding at base of dome	Copper mineral
3	Pale pink	Sanctuary, north wall, background color of pendentives	Ocherous haematite
4	Bright red	Sanctuary, north wall, "tassel" below center ornament (corbel) above main altar	Cinnabar vermilion (mercuric sulphide)
5	Brown gray	Sanctuary, north wall, body of tassel (see above)	Copper-zinc metal powder
6	Green	Sanctuary, north wall, flutings in center ornament (corbel) above main altar	Copper mineral
7	Bright red	Sanctuary, north wall, painted draperies, left of main altar	Cinnabar vermilion
8	Orange red	Sanctuary, high west wall, tinted wall surface	Ocherous haematite
9	Blue Gray	Sanctuary, south wall at cornice above east pier of arch	Charcoal carbon
10	Orange Red	Sanctuary, south wall at cornice above east pier of arch	Ocherous haematite
11	Orange Yellow	Sanctuary, south wall, cornice above east pier of arch	Mainly ocherous haematite
12	Green	Sanctuary, south wall, band below cornice of east pier	Copper mineral
13	Black	Sanctuary, north wall, stripes outlining reredos	Charcoal carbon
14	Orange red	Nave, high west wall, half circle designs below cornice	Ocherous haematite
15	Green blue	Sanctuary, south wall, narrow line above east pier	Indigo

Table of samples (continued)

16	Red orange	Arch, between nave and sanctuary, under side	Ocherous haematite
17	Black	Sanctuary, east wall, stencil design of lower border	Charcoal carbon
18	Blue	Sanctuary, dome ceiling covered by present white surface coat	Indigo
19	Red	Nave, surface of original floor plaster	Ocherous haematite
20	Red	Exterior, north wall, surface of canale	Ocherous haematite

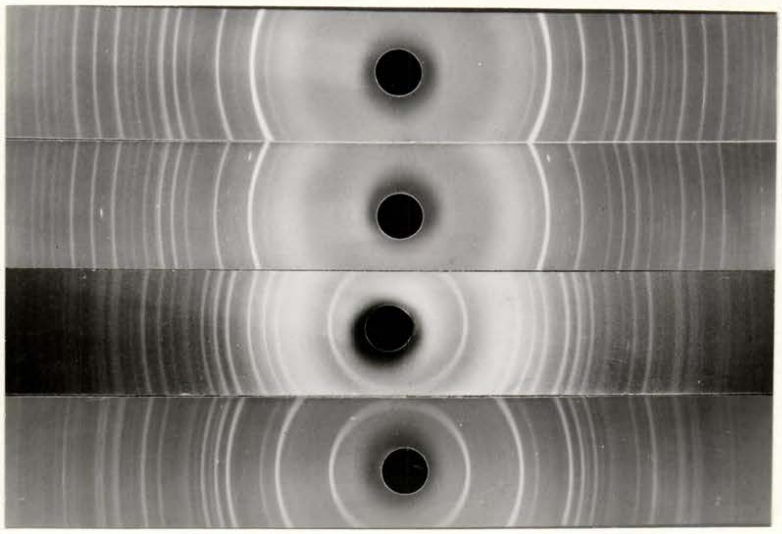
These studies, unfortunately, do not answer all questions and in several instances they raise new ones. It is hoped that as stabilization and conservation of similar Southwest monuments progresses, our knowledge of materials used in construction and decoration will increase and existing gaps will be filled in.

Plate 3



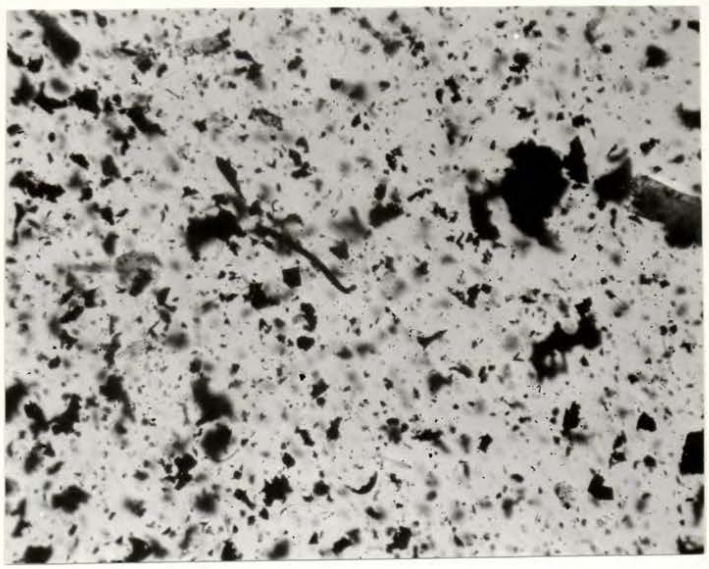
Photomicrograph (200X) of the materials of the white finish coat of the interior walls taken in polarized light. The fine aggregates are of gypsum formed from calcium sulphate hemihydrate. The lath-like particles are fibrous anhydrite which occurs in the typsum as an impurity.

Plate 4



X-ray powder patterns of the gypsum material of the white finish coat compared with powder patterns of known materials; (a) is pure anhydrite ($CaSO_4$) from Salzburg, Germany; (b) is of pure white fibrous material isolated from the white finish coat at Tumacacori; it is also pure anhydrite; (c) is the complex pattern given directly by the material of the white finish coat of Tumacacori. It is a mixture of gypsum and anhydrite as seen by comparison with the pure anhydrite of (a) above and with known pure gypsum ($CaSO_4 2H_2O$) from Braden, Chili, below. (X-ray powder patterns taken by Miss Mary Mrose, Dana Laboratory, Department of Mineralogy, Harvard University.

Plate 5



Photomicrograph (200X) of the black pigment. The elongated and splintery shape of the particles indicate that the black originated as charcoal.

METHODS AND MATERIALS

Scaffolding

Tubular steel scaffolding enabled us to reach all parts of the church interior, with little time used in changing the position of the staging. We used end frames of three heights (three, five and six feet) and eight and ten foot cross braces. These different sizes gave flexibility to the scaffolding so that we had no trouble reaching any portion of the walls or dome.

Brushes

Most of the cleaning was done with brushes. Several types of brush were used and each proved satisfactory for one or more phases of the work but the best all-round brushes proved to be the whisk broom and a typewriter cleaning brush. The latter was of the type which consists of a four inch wooden handle with two rows of half inch bristles set vertically in the handle. It was particularly useful in cleaning around the painted designs. In addition to these we used a fibre scrub brush and, for dusting off wall surfaces, two and four inch paint brushes.

To clean large areas of white plaster we found that the easiest, and quickest, method was to grasp a whisk broom by the straws to form a compact, circular brushing surface and then rub hard.

Soaps and Detergents

Mr. Gettens and I determined in June, 1949 that the walls should be "dry cleaned" for any water applied to the walls carried fine dirt deep into the porous plaster so that it was more difficult than ever to clean.

In the nave, just under the cornice, the pendent half circles were painted with red and/or orange pigments. Where the pigments remained within the half circles they were often covered with a heavy layer of dirt. The paint was fugitive and in order to remove the dirt enough pressure had to be applied to the brush so that the paint came off also.

To remove the dirt without destroying what little paint remained, I tried two commercially prepared products. "Tide", a well known product, manufactured by Proctor & Gamble Company, proved to be fairly satisfactory but the results were not noticably better than when we gave the painting a gentle brushing.

I then tried a preparation with the intriguing name "L-Bo Grease". This is manufactured by Moore and Son, University Station, Tucson, Arizona. An emulsion of L-Bo Grease and water applied gently with a cloth actually did dissolve the dirt over the painting and removed surprisingly little of the pigment. It could be applied to a few square inches of wall at a time so that we could prevent streams of water from running down the wall. This product proved quite satisfactory for cleaning sections of wall which were solidly covered with pigment and heavily covered with dirt. It was used only in those areas, however, which could not be cleaned satisfactorily with a brush; nor did we attempt to use it around the rather delicate designs in the sanctuary.

Spackling Plaster and Lime Plaster

Throughout the ruin we patched cracks and loose edges of plaster with Spackling. In some instances, especially at the broken edges of large sections of plaster which were free of any bond with the adobe wall, small strips of metal lath were nailed to the wall and the edges of the plaster caught up and pointed with lime and sand plaster.

Fixative

Each section of wall, as soon as cleaned, was sprayed with the vinyl acetate lacquer formulated by Mr. Gettens. A second coat, of thinner only, was then sprayed over the wall to drive the lacquer into the plaster and to lessen the possibility of a gloss on the plaster surface.

The lacquer treatment proved highly satisfactory. Colors were enhanced so that the designs and decorations have a much more pleasing effect than formerly and the paintings now can be brushed gently, to remove dust, without the danger of removing the pigments.

The Roskruge Photos of Tumacacori

A - North end of the nave and the sanctuary. Note the palladium pediment of the side altar at left and the moulding over the sanctuary arch.

B - This view, from the sanctuary toward the entrance, shows the adobe arch which supported the front of the choir loft and broken pediments of the superstructures of the south side altars.

MATERIALS AND CONSTRUCTION OF THE BUILDING

Tumacacori, like all the frontier missions, was built entirely of materials which could be found, or made, at the building site. The foundation is of cobblestones (available in the river bed, a quarter mile away, and on the old river terrace) set in adobe mortar. The walls are of adobe bricks laid, in traditional manner, with adobe mortar. A peculiar feature of the adobe walls, which might be typical of those times, is that the bricks, thinner than our modern bricks, are separated by mortar beds as thick as the bricks themselves.

The walls of the nave, five feet thick up to the exterior offset at the window line and three and a half feet thick above that, are built entirely of adobes. The nine foot thick walls of the bell tower, however, are of cobble rubble faced with two thicknesses of adobes. All walls are capped with fired bricks. These bricks were made of ordinary adobe, fired, in all probability in the same sort of kiln still used in rural Mexico. The bricks to be fired form the kiln and 'eyes' for the firing are left at the base of the pile. The result is that the bricks close to the fire are overbaked, the bulk of the pile is fairly well baked and the exterior bricks merely dried out a little. The latter are usually put into the next firing. The resulting brick is a fine looking red brick but it is quite soft and breaks easily. These bricks were laid with lime mortar.

The upper story of the bell tower is of rubble faced with fired brick and the sanctuary dome and the barrel vaulted roof over the sacristy entirely of fired brick. Limestone was burned in a large kiln, the ruins of which are located about a hundred yards north of the church, outside the monument boundary. The bricks were apparently fired in an area about a hundred yards south of the church building and, as the lime kiln, outside the boundary of the monument.

The exterior walls of the church were plastered with stucco; the interior walls with two coats of lime plaster. The floor of the church was of broken brick laid in lime mortar with a hard smoothed red painted plaster wash for the surface.

THE NAVE

As one enters the ruin of the Tumacacori church today he sees a long, narrow, and high room with a flat wooden roof. Large patches of white plaster cling to the adobe walls and, at the far end of the room, is an arch through which the brightly painted plaster walls of the sanctuary are visible. To the right of the entrance an archway leads through a nine foot wall into the small, square baptistery.

At the time the building was in use the perspective of the room was different; this was because a choir loft crossed the nave over the entrance. The scars left by the arch are plainly visible on the church walls. One of the Roskruge photos, of 1889, (Plate VI) shows the arch still in place though the balance of the choir loft had been destroyed by that time. The arch was low and flat and built entirely of adobes. As nearly as can be determined by scaling the known width of the church to the dimensions of the photograph, the highest point of the arch was six and a half feet above the floor (plus or minus a few inches). The floor of the choir loft was flat and, undoubtedly, of wood. The loft floor was, roughly, eight and a half feet above the church floor.

To one peering under the arch from the church entrance the nave must have given the impression of soaring to great heights. The roof was probably quite similar to that which is now over the nave. The long, narrow room was made to appear even more narrow by the presence of four side altars - two on either side of the nave - and by the attached columns which protrude from the walls midway from the choir loft to the sanctuary.

The presence of the side altars within the nave gives a crowded appearance to the room. Such altars normally are located in the wings, or transepts, of a cruciform church. There is some evidence that the original plan for Tumacacori called for transepts; Beaubien [15] found foundations outside the church walls which may

(15) Beaubien, 1937, p. 190; Tovrea and Pinkley, 1936 (b)

have been bases for the transept walls, though he thought not. In addition, near the sanctuary end of the nave, there are vertical cracks, or breaks in the bond of the adobe walls, on either side of the nave from floor level to a height of eight and a half feet. From that level up the walls are properly bonded over the cracks. It looks as though the idea of building transepts was given up while the walls of the church were being built.

The attached columns which rise from floor to roof are also difficult to explain. Pinkley [16] believed that the padres intended to construct a barrel vaulted roof over the nave, as was

(16) Pinkley, 1930, p. 14

done at San Ignacio but Tovrea [17] showed that the walls of Tumacacori could not withstand the stress of a barrel vault.

(17) Pinkley and Tovrea, 1936 (a), p. 45 et seq.

Pinkley's idea was that an arch, which could help support the vault, would spring from the columns. We should not rule out the suggested barrel vault, however, merely on the grounds that the walls would not support one for the missionaries did many things which an architect would not. A vault was built on weak walls at San Ignacio and great buttresses had to be built at the sides of the church to help support the pressure.

As is common in churches of northern Mexico, the painted decorations of the nave were restrained and confined principally to the cornice, dado and niches.

STATIONS OF THE CROSS

On the east and west walls of the nave are twelve wall scars which are commonly believed to be the locations of twelve of the stations of the cross; two more were placed on the church side of the arch which supported the choir loft (evidences of these are to be found in photos of 1889).

It has been supposed that moulded plaster medallions were used for the stations but a close examination of the scars on the wall, particularly that which is most nearly complete (Plate VII) suggests a different type.

After the wall plaster was firmly set, i. e. sometime after the interior of the church was completed, oval patterns were made on the walls and the top layer of plaster removed. The plaster was cut with a curved chisel. The pattern left by the cutting edge of the chisel can clearly be seen in the illustration. Few measurements can be taken on most of the stations but all which can be compared are exceptionally close in size.

I believe that stations of carved or painted wood were received, the walls marked with the wooden plaques as guides, then the plaster knocked out and the wooden pieces were set in the walls. The plaques must have been about flush with the wall and then were held in place by drapery-like mouldings of plaster.

If all this is true then another possibility becomes apparent. All the stations of the cross were removed from the church building and it seems logical to assume that they were removed at the same time that the local Indians removed the statuary to San Xavier mission. It is quite likely, then, that the Tumacacori stations still exist in some storeroom at San Xavier. One should look, I believe, for a series of oval wooden plaques about 20 inches high and 11 inches wide.

PILASTERS OR PIERS

Near the middle of the nave walls is a pair of pilasters, one on either side of the ~~wall~~ room. It has been suggested (18) that these were

(18) Pinkley, 1930, p. 14

to have supported an arch for the postulated barrel vaulted roof. In each of the pilasters are two niches; one near the floor, the other well up on the pilaster. The latter have corbeled abutments at the bases.

The two lower niches were rectangular in cross section; it is doubtful that they were intended as niches for statues. Quite likely they were built solely as ornaments, though in order to break the line of the pilaster with a niche of this sort the strength of the pilaster was destroyed; the side walls of the niches were no more than eight inches thick. No definite traces of pigments remain in these niches. A hard yellow stain suggests, though, that they were painted.

The upper pilaster niches were certainly made to hold statues and, judging by the treatment of the plaster around the niches, I should say that statues actually stood in them.

These niches have flat, plastered floors, no recess at the back, and curved tops with Moorish type peaks. The only remaining pigment in the niches is near the top where some shelter was given during the years when the church roof was missing. The niche was painted blue, and on the blue a stylized floral pattern in vermilion. Here, for the first time, I noticed a peculiar phenomenon in which the cinnabar red suddenly turns to a very dark blue or black in portions of the design.

Above and on either side of both the upper niches is a crudely drawn canopy. The canopies are incised in the plaster, no pigment remains, nor is there any evidence that these canopies were ever painted. They were obviously made by a poor draftsman (the same person, probably, who made the chalice and vine designs under the sanctuary arch) who was imitating the painted canopies which lie on either side of the reredos.

SIDE ALTARS

In contrast to the pilasters, which were built as integral parts of the wall, the four side altars in the nave were afterthoughts. They were constructed after the nave had been finished; (the painted dado continues on the walls behind the altar) and the niches were dug out of the massive adobe wall.[19]

(19) Beaubien, 1937, pp. 188-189; Pinkley and Tovrea, 1936

No side altar is now complete nor are there enough wall scars left of any one to give an accurate picture of their dimensions. Each altar stood on a brick platform four inches above the floor, and apparently was of faced brick with a rubble core. The entire structure was then plastered.

The altar superstructures were made of plaster - and plaster alone. Pilasters and pediments were modeled in plaster which was merely struck onto the wall plaster - no keys were used. All four altars were similar except that the two southern altars had broken pediments; the two near the sanctuary had palladium pediments. Presumably all were built at the same time.

There is no trace of any paint on the superstructure of the side altars. What remains of the moulded plaster has a fine coat of gypsum.

Details discernible on the walls are augmented by photographs of the interior of the church which were taken by Mr. George Roskruge of Tucson on July 4, 1889 (Plate VI). These photos clearly show features which have long since disappeared. So far as I know, they are the only records of the curved pediment over the north side altars and of the flat arch which supported the front end of the choir loft.

DECORATIONS AT TOP OF THE WALL

A cornice of large moulded bricks caps the wall of the nave. The bricks are, with few exceptions, new bricks, made in 1921. The only cornice bricks which undoubtedly are old are seven, or possibly eight, at the southwest corner; these are partially covered with original plaster.

Below the cornice brick are three courses of adobe bricks, then a moulding which was made by laying a course of fired brick so that it projected some two and a half inches beyond the vertical line of the wall. Below the moulding the wall is of unfired adobe. The moulding bricks were not rounded; the curved surface of the moulding was created with plaster.

The treatment given the top of the wall, i.e. from cornice to the area immediately below the moulding, was constant along the east, south and west walls. No original plaster remains at the top of the north wall (over the sanctuary arch). Roskruge photos 1889, show a short section of moulding straight across the wall, over the arch, with, barely visible with a strong glass, pendant half circles. The moulding over the arch had no foundation of brick; it was built up of plaster.

Judging solely by the small area of plaster which covers the cornice bricks at the southwest corner I should say that the cornice was plastered and then painted with ochre. The few square inches of painted surface which remain are reddish-orange.

Between cornice and moulding are approximately eight vertical inches of plaster. Most of this panel is missing throughout the room. Only small pieces remain and, again, only in the southwest corner is there any indication of a design. In the corner, and extending for about a foot along both south and west walls, are faint traces of curved blue lines which appear to have been similar to the blue painted design below the spring line of the arch in the sanctuary. The reconstruction drawing (Plate 12) is based on the assumption that the two designs were of the same character and that they were probably drawn by the same person.

The moulding was probably painted a solid color for its entire length. Wherever the paint remains on the moulding it varies in shade from a deep orange-red to a washed-out yellow; the original color was probably a deep ochre. A black line, one fourth of an inch wide was painted at the base of the moulding.

Pendant from the moulding is a row of half circles. The circles were first scribed with a compass, then filled in with color. The compass used was not too reliable; it was possibly made with two sticks tied with a length of string. Center holes are present in each half circle and the outer lines are often so far off that a second, or even a third, line was marked. The lines are grooved into the plaster in such a way that it is apparent that the plaster and the gypsum wash were well set when the lines were made. Each half circle has two arcs - one with a radius of about two inches, the other of about four. Measurements taken of four consecutive half circles on the east wall are typical of all:

Distances between centers -	9 1/8"	8 3/4"	10 1/4"	
Radii of inner circles -	1 5/8"	1 5/8"	1 7/8"	2"
Radii of outer circles -	4 1/8"	4 1/2"	4 1/2"	4 1/4"

A gap of an inch or more separates the half circles at the moulding line; these gaps were probably filled in with designs de~~s~~- scribed below. delay

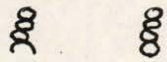
The half circles were filled in with solid color. Not enough pigment remains in any of the half circles to answer the question "What colors were used?" It seems probable, from remnants of pigment, that the outer portion was painted a deep reddish-orange (the same as the moulding) and the inner portion with a diluted paint - more of a yellowish orange.

Two half circles are bordered with a black line and since such a line runs part way down the side of several more, it seems likely that all were bordered with black. In addition, there are enough remnants of black-painted designs between the pendant half circles to make it seem probable that figures were painted in all the gaps. All the existing inter-half circle designs are on the west wall.

Over the north side altar, on the west wall of the nave, a bell-like design has always been visible from the floor. When a heavy coating of dirt and re-deposited pigment were removed from this section of the wall two more bell-shaped designs were found, one on either side of the first.

The bells are suspended from the moulding by a loop of paint. A portion of a fourth bell was painted in the southwest corner of the nave; this was the largest found, and is also suspended by a similar loop. The latter is painted in the corner; half of the bell, on the west wall, is intact, the half on the south wall has disappeared. This bell was seven inches high (including the loop) and the base of the remaining half is two inches wide. A similar design, but not so complete, is in the northwest corner; there probably was a large bell in each corner of the room.

In the spaces between nine pairs of pendant half circles are black painted figures which vaguely suggest the entwined serpents of the caduseus. The figures are both open and closed - so:



One peculiarity of the black pigment used for the bells and the entwined lines must be mentioned. In several cases, the southernmost of the three bells and in six of the entwined lines, the pigment has completely vanished. What remains is a plaster surface to which dirt has not stuck so that the design appears as a negative one - an area of clean plaster surrounded by grimed plaster. Something in the pigment, or possibly the carrier, has acted as a sizing agent for the plaster so that although no color remains, the design can still be made out.

It should also be noted that this phenomenon of a negative design due to decomposed paint was found nowhere else in the mission ruin except for one possible example in the sanctuary.

DADO

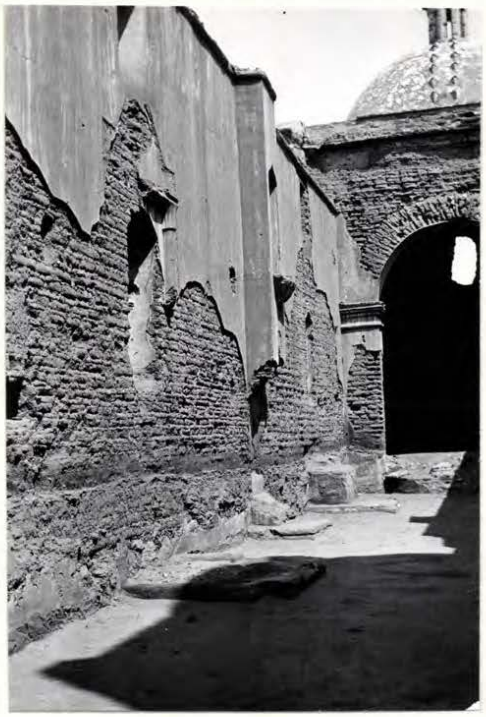
So little remains of the dado at the bases of the nave walls that it is now impossible to reconstruct the design. Traces of the panels may be picked out in corners and on the plaster which runs behind the side altars.

The dado apparently consisted of a solid black panel, which extended about three feet above the floor. The top was bordered with two or three narrow red and orange lines.

A - Pendant half circles and bird in choir loft.

B - The best preserved location of a station of the cross.

Plate 8

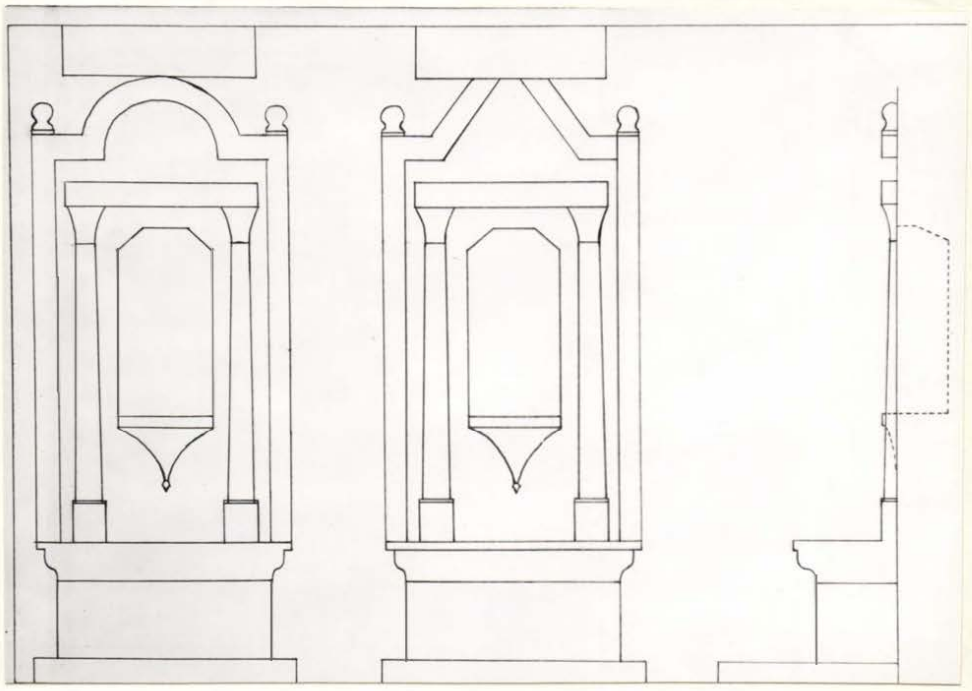


1921 photo of west side of nave.

A - Portions of two pendant half circles with entwined lines.

B - Pendant half circles on west wall.

Plate 10



Elevations of side altars. North altars on left; south altars on right.

THE CHOIR LOFT

In that part of the nave which was occupied by the choir loft only two walls (the south and west) are covered with enough plaster that traces of decorations remain. On the east wall of the choir loft there are no more than four or five square feet of plaster, and that is badly washed and in poor repair.

The west wall of the loft shows no further ornamentation (near the top) than the larger portion of the wall - in the nave proper. The incised and painted designs here have already been described.

On the south wall things are different. To begin with, the window is set a few inches higher than the windows in the east and west walls. Because the window is higher there is no room for the row of pendant half circles over it; the half circles stop on either side of the opening.

Seven and a half inches below the bases of the pendant half circles (south wall) a straight, horizontal, line was incised in the plaster. This line was drawn with a straight edge about four feet long. Below this line two coats of gypsum wash were painted on the wall. Where the outer coat has flaked off are traces of red pigment which was painted on the under coat. These are particularly numerous on the south wall but the panel seems to have been painted on the west wall also, and, by inference, also on the east wall of the choir loft.

It was impossible to determine, with certainty, whether a large panel or dado had been painted around the choir loft or a rather large series of designs. My impression is that the latter was the case for near the southwest corner the color seems to form a formalized floral pattern. Unfortunately the outer gypsum coat is heavy enough so that when the wall was wet with fixative the underlying design or panel did not show through.

Around the top and west side of the window (no plaster remains on the other two sides) is a narrow band of incised lines (Fig. 2). The workmanship on this panel is crude enough so that I believe it must have been made by the same person who did the other free-hand incised decorations around the niches in the nave. The bounding lines which contain the curved design were made with a short (about 2') straight edge.

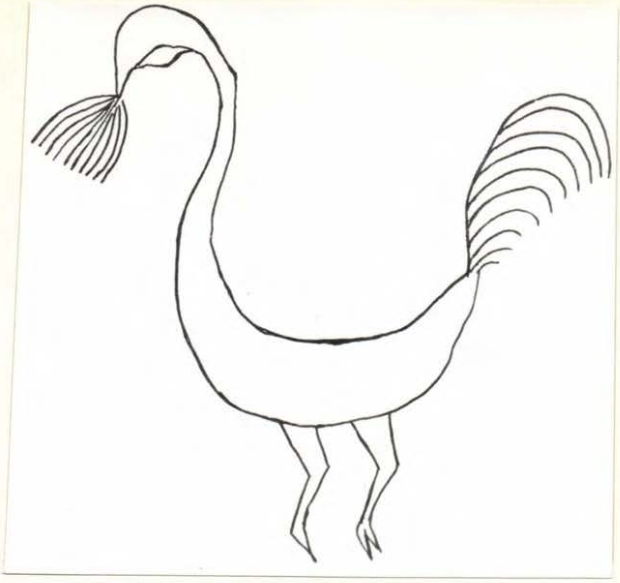
That sums up the description of what is left of formal, or planned, decorations in the choir loft. As might be expected in such a place there are numerous scratches, initials and small designs which were scratched into the plaster. The initials are large, poorly formed letters and nowhere do they form a name. Most of the scratches are meaningless, at least at present. On the west wall, and near the front of the loft, is a small incised basket filled with flowers (Fig. 2) and east of the window is a lively representation of a bird which resembles a fighting cock (Fig. 2 and Plate VII). A foot below this bird is another similar figure which was either never finished or has been damaged.

Plate 11

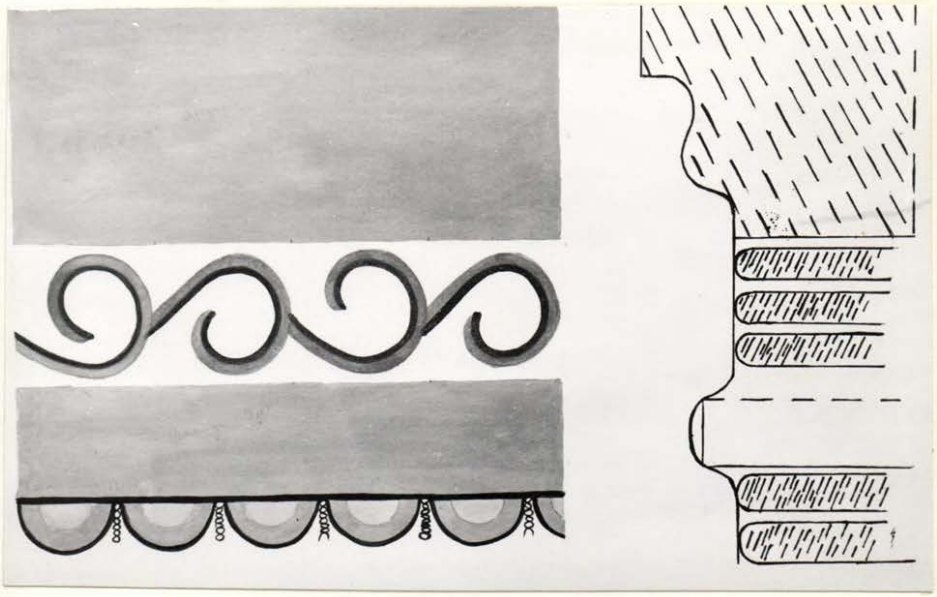
A - Moulded plaster at Spring line of sanctuary arch.

B - Remanants of symbols wine and grape design on west side of sanctuary arch.

Plate 12

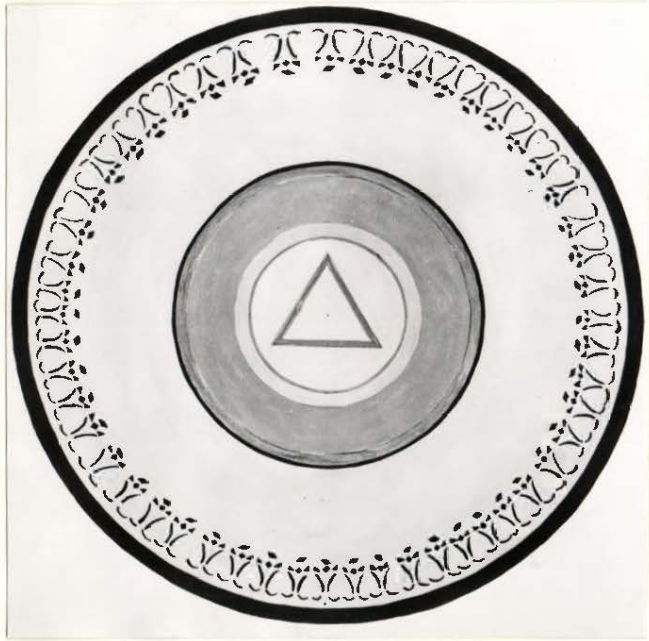


A - Incised bird from choir loft

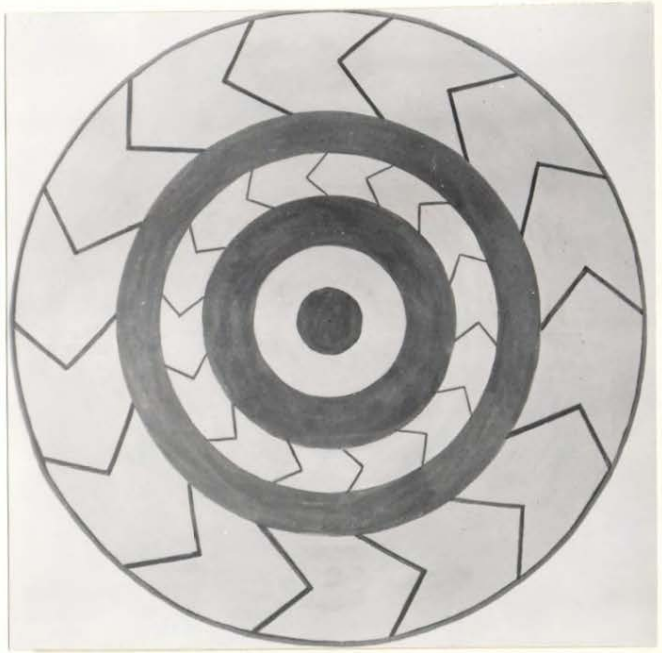


B - Reconstruction of design at top of nave wall

Plate 13



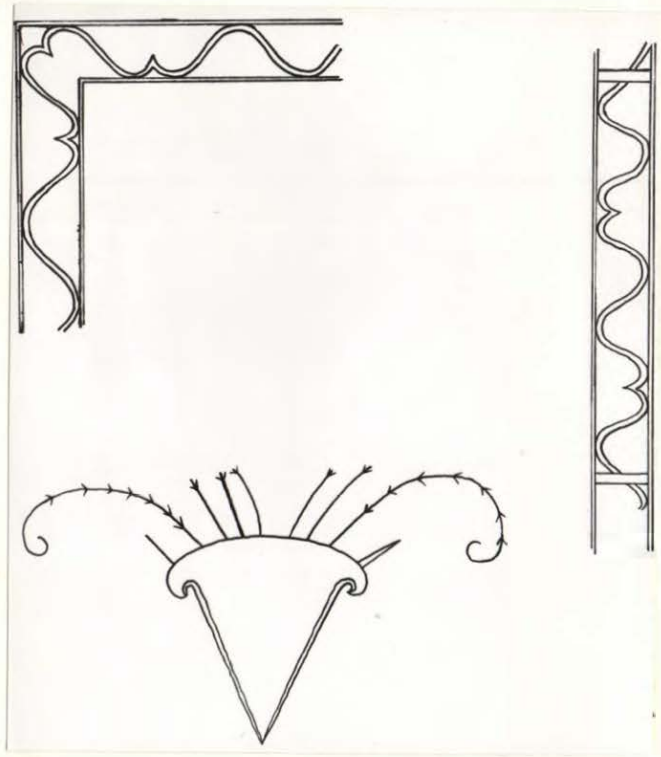
A - Reconstruction of medallion at apex of sanctuary dome.



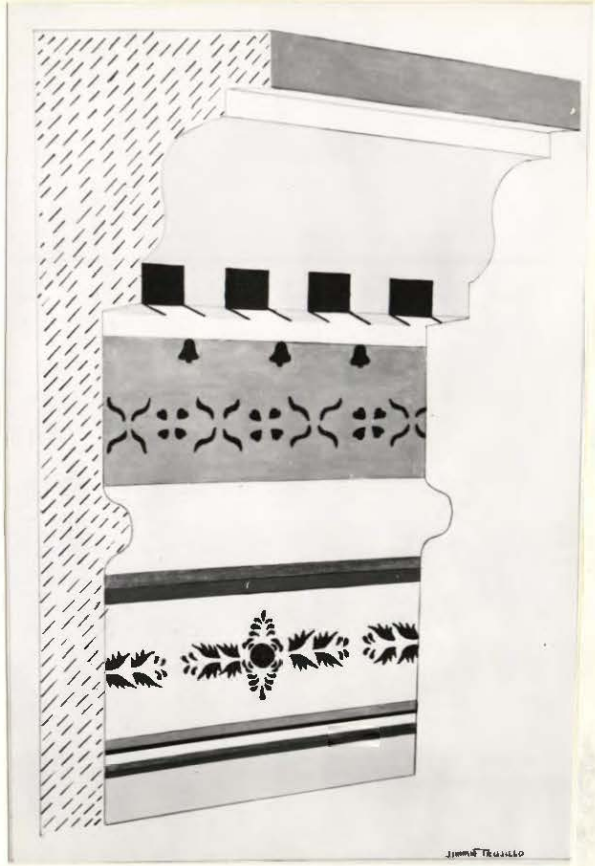
B - Reconstruction of medallion at apex of sanctuary arch.

PLATE 13

Plate 14

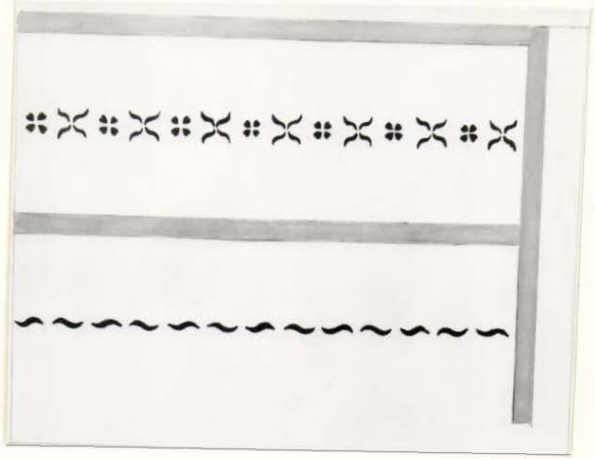


A- Incised designs from choir loft
a - window border
b - flower basket, north wall

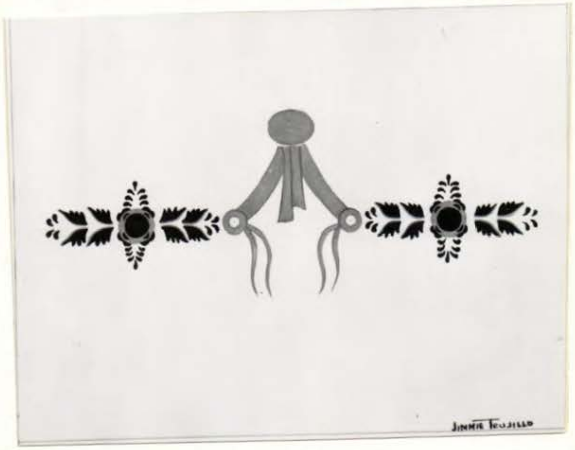


B - Reconstruction of panel at springline of sanctuary dome.

PLATE 14

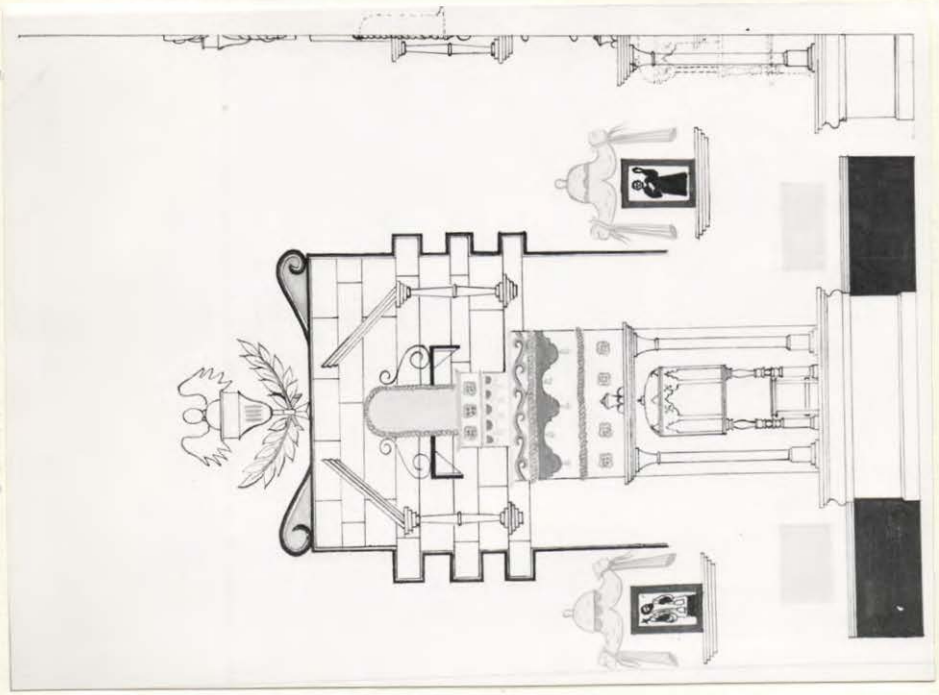


A - Reconstruction of panel at base of sanctuary dome.

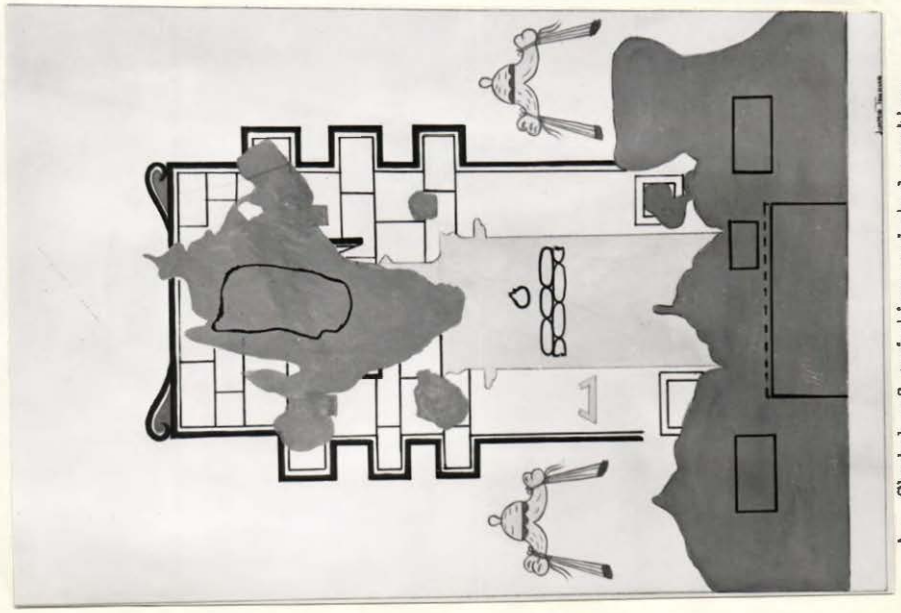


B - "Rose and drape" stencil pattern from sanctuary.

Plate 16



B - Reconstruction of reredos



A - Sketch of existing painted portion of reredos.

THE SANCTUARY

The highly decorated sanctuary has, unfortunately, been so damaged that many details have been lost. In spite of the damage, however, we can reconstruct the major elements of the sanctuary designs.

The block of adobe bricks which stands in the altar position may well indicate the original size of the altar. During the years the church stood abandoned local people held Easter ceremonies in and around the church [20] and an old Opata Indian, Pedro Calistro,

(20) Gastellum, 1936

was a sort of self appointed sacristan who lived adjacent to the church for many years and kept the structure clean.

It seems probable that during those years the original altar was repaired for use during the Holy Week ceremonies, until now it would be difficult to determine just how much of the altar belongs to the mission period. The present block is several inches lower than altar height but it seems, from the lack of wall scars, that the horizontal dimensions of the present structure are the same as those of the original.

The big argument in the sanctuary must concern the reredos. This, as it was intended, is the cynosure of church decoration. It is the magnet which forces attention altarwards. And it, too, is so battered and destroyed that we cannot be certain of the original design.

ARCH BETWEEN NAVE AND SANCTUARY

The plaster under the arch was tinted a light cream or ivory color. At the apex of the arch is a medallion, about one third of which is completely destroyed. The medallion consists of a series of concentric rings which were laid out with a compass. From the inner circle (vermilion), alternate bands, or rings are also vermilion. The intervening bands are blue or ivory. (Plate XII)

Two of the bands have vermilion chevrons. Here, as in the niches over the side altars, is the same phenomenon of the vermilion paint suddenly becoming dark blue; often the two colors are in the same chevron.

The vermilion paint is thick and fugitive; where it has turned blue the pigment is quite hard and does not rub off easily. It is probable that some impurity in the pigment has caused a chemical change in portions of the designs.

About three feet below the medallion, on the east side of the arch, is a series of four contiguous circles, engraved with a compass. No pigment is apparent in or around the circles. The circles, one and three fourths inches in diameter, are neither part of an existing design nor, apparently, part of a projected one.

At the bases of the arch, and on either side, is a crudely done symbolic painting. These are both so badly washed that the design is just barely apparent; much of the design has been completely destroyed.

The base of each consists of an inscribed semicircle, with a five inch radius, which rests on the springline of the arch. The semicircles are filled in with black pigment.

Above each semicircle is a span of about two inches with no apparent design, then a goblet, outlined with black paint, and half "filled" with red. Springing from the "wine" in the goblets are several grape vines which rise up for about three feet before looping over. Some tendrils and a few clusters of red grapes which are barely visible leave no doubt that the intent of the artist was to portray grape vines. In the same symbolism one would expect to find a few stalks and ears of wheat, but if they were ever painted, they have been destroyed.

On either border of the under side of the arch is a bounding strip composed of a light blue band with bordering, narrow lines of dark blue. Only the band on the sanctuary side is well preserved; that on the nave side has been so washed or damaged that only traces remain.

THE SANCTUARY DOME

Two coats of gypsum plaster have been painted onto the sanctuary dome above the cornice which forms the springline for the structure. The undercoat was painted indigo; a re-decoration job is responsible for the existing white finish and medallion. While we were working under the dome, however, we found no traces of the indigo paint on the north half of the dome. I cannot explain the phenomenon - there was no clear cut line of demarcation visible.

Mr. Gettens has suggested that either at the time the dome was decorated the priest in charge suddenly decided that he did not like a blue dome or that he realized there was not enough indigo to cover the entire surface.

It is possible that the south half, only, of the dome was painted indigo though more likely that a large design lay on that portion of the dome. Whatever the original design may have been, it was not revealed when the plaster was wet with lacquer.

Much of the plaster of the lower two feet, and all of the plaster on the south side of the dome, is in bad condition due to moisture which has worked through the bricks.

Except for the medallion there is only a simple band on the dome above the springline. This design consists of two bands of bright green, each an inch and a quarter wide. These are parallel to the base of the dome and at heights of 16 and 33 inches respectively above the cornice.

In the panel which lies between the stripes is a series of stencil designs (Plate XIII); a simple stencil, similar to a leaf pattern, was used in the lower panel. Both stencil designs were painted with black pigment.

On either side of the altar the cornice ends so that the dome rises directly from the church wall on the north side. The green stripes also end at the same places and the design is closed by vertical lines of green which drop to the ends of the cornice.

Plate 17

Medallion at apex of dome

A - Detail of false masonry on sanctuary arch

B - False masonry on sanctuary arch

Plate 19

A - Moulding and painted design at spring line of sanctuary arch.

B - West spring line of sanctuary arch.

SANCTUARY - THE DOME CORNICE

Here, at the cornice which forms the springline for the dome, was a series of brightly colored bands (Plate XIV). Most of the colors have now faded and large sections of the surface plaster have peeled from the walls so that the somewhat gaudy decoration is now drab.

The upper, vertical, face of the cornice was painted vermilion. From there down are bands of white, peach, pink, turquoise, pink, dark green, dark red, white, dark red, black, white, bright green and dark red. Nearly every color to be found in the church is in this panel.

In addition, there is a series of false viga ends done in black. These are small, about two inches square, with stripes to represent a beam projecting from the wall. The "vigas" are arranged in sets of four and from each viga hangs a painted representation of a bell.

Below the bells is another band of stencil designs, the same pattern used on the dome. Still another stencil, the rose pattern found lower in the sanctuary walls, fills the lowest white band in this panel. This rose stencil is done in black only with no vermilion retouching as in the lower band.

SANCTUARY ARCH - SANCTUARY SIDE

A redecoration job is apparent on this wall surface - at least in the section between the spring line for the arch and the panel of bands just below the cornice. When the plaster was wet with lacquer it became apparent that the wall had formerly been painted orange from the band above almost to the top of the arch. From the bottom of the orange panel there was an extension of the same color to the arch (Fig. 3). Since the lacquer treatment, traces of the orange may yet be seen underlying the upper coat of peach and the false stonework which was painted over the arch.

After the redecoration, the wall bears a panel which extends 58 inches from the bottom of the cornice bands. This height (58 inches) is only at each side of the arch. On the sides the bottom edge is squared until it hits the false masonry which is painted around the arch; the band follows this "masonry". This panel is a pale orange-red, so pale that it might be termed "peach".

At the base of the peach panel is a half inch stripe of bright green, then another half inch band from which the color is completely missing. The latter could have been black, which also has disappeared from design elements in the nave. Suspended from this band are the vermilion drapes which alternate with the black and vermilion floral stencils.

The "masonry" was incised in the plaster, then pale blue pigment painted in the grooves. No other pigment (other than the black and vermilion stencils and drapes which adorn alternate blocks) is discernible within the pattern. It is possible, though no evidence remains, that the opposite face of the arch bore a similar design, for the decorators of Tumacacori seem to have gone out of their way, on occasions, to balance their designs.

Cornice bricks were used at the spring line for the arch. Here, as above, at the dome springline, the priests used the angled and curved faces of the brick as boundaries for nearly every color in their pots.

In the largest vertical panel of the cornice is a repetition of the scroll-like design found in the southwest corner of the nave cornice.

Below the cornice bricks the walls were painted dark blue and, over the blue is found the same crudely done, stylized floral pattern that was painted in the niches over the side altars.

THE SIDE WALLS OF THE SANCTUARY

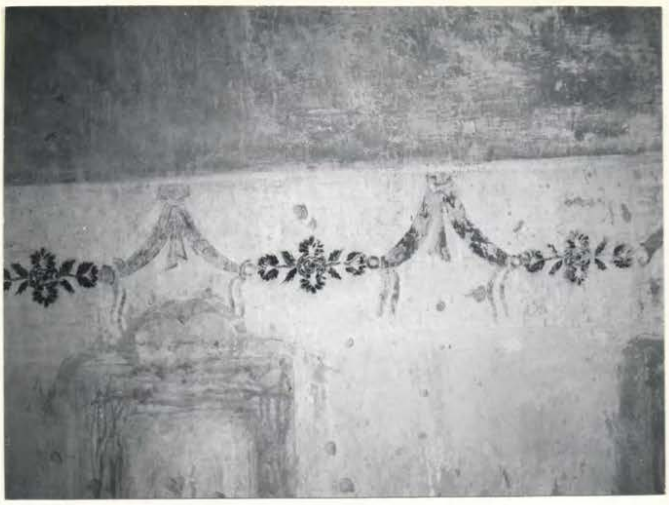
The 58 inch band of peach was also painted on the east and west walls. The lower end of the band is flush with the window bases. Below the peach is a band, about a foot high, which gives the impression of having been sized, but not colored. On this band is a series of rose stencils in black and red, with red intervening drapes, a reconstruction of which is shown in Plate ~~XIII.~~ 15B

The stencil used marked only the black portion of the design. The red trim and draperies were done freehand.

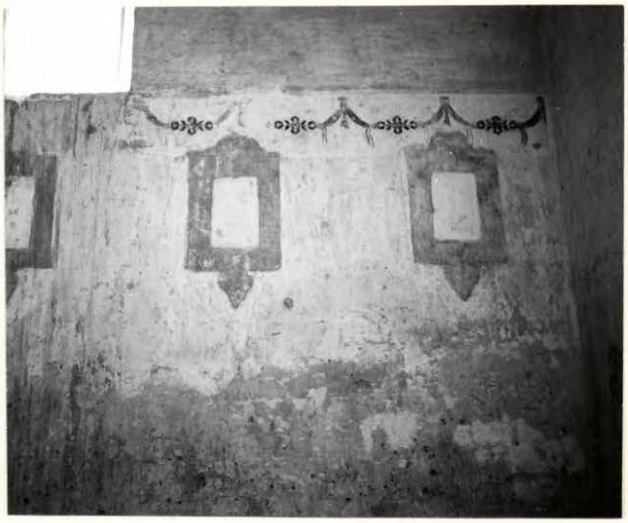
On each of the side walls are five scars of what must have been plaster picture frames (Plate XX). These were made late in the decorative history of Tumacacori. The finished plaster was scratched to make a bond for the frames. Two additional frames were on the south wall, one on either side of the arch. It has been suggested that these held pictures of the twelve apostles.

The only remaining plaster on the lower four feet of wall is a tiny wedge in the southwest corner. From the slight evidence furnished here it appears that the east and west walls of the sanctuary had a dado similar to that in the nave. We have assumed, in the reconstruction of the altar wall, that the dado was carried around the walls to the altar.

Also on the west wall is a niche (Plate 11), the walls of which seem to have been painted with gypsum wash, but not colored.



A - Detail of rose stencil and drapes.



B - Stencil designs and scars of picture frames on west wall of sanctuary.

A - Detail of painted viga ends and bells in sanctuary.

B - General view of panel below dome cornice.

THE PENDENTIVES

In each of the four pendentives is a painting which is probably symbolic although the symbolism is not clear in each case. These paintings are of a castle, a wall, a palm tree (which grows from a large jar) and a figure which has been variously interpreted as a lighted candle or small tree such as an arbor vitae. The base of this last painting is also a jar.

The method of painting the pendentives is unique among Tumacacori frescoes. The pendentive was first given a good coat of gypsum; this was then covered with a pale pink wash. The design was then created by rubbing out, or erasing, the top coat to create a negative design. Enough of the pink wash was also rubbed into the white wash so that the contrast is poor. A few lines of diluted black pigment were painted in the figures to emphasize the form.

All four designs have been damaged by vandals who have used them as targets; the two which have suffered most are the castle and palm tree.

A -

B -

Pendentives
A - the "candle"
B - the castle

Plate 23

A -

B -

Pendentives

A - the well
B - the "palm tree"

A -

B -

Pendentive - the well
A - detail of bucket and chain
B - the well

THE REREDOS

The body of the reredos consists of wall which is painted to simulate masonry. A series of black and brown lines spring from a point nine feet above the floor and rise almost to the cornice line. These lines contain a pattern of straight black lines which imitate cut stone masonry.

An attempt was made to create an illusion of relief in the border by deliberately smearing the corner lines to form a "shadow". Unfortunately for the artist, his sense of perspective was not equal to the task. All the lines, on either side of the reredos, are smeared in the same direction so that the work looks messy, rather than appearing as a relief.

Between the reredos niche and the altar is a large rectangular area which appears to have extended to, or almost to, the altar top. There is no finish coat of plaster on the rectangle but many irregular patches of lime plaster still adhere to the scratch coat. It seems probable that this surface was modeled in plaster, then painted. The top of the rectangle has projections into the painted area of the reredos which form the patterns of cornice silhouettes; it seems likely that imitation cornices were carried completely across the top of the modeled area.

Centered in the modeled rectangle is a double row of fired brick, with, just above, a roundish hole in which is some more broken, fired brick. No indication remains of the original form of the bricks.

Higher on the reredos is another cause for argument. A niche-like depression is a prominent feature of the wall over the altar. Pinkley [21] thought that treasure hunters knocked out the wall

(21) Pinkley, 1936, p. 28

behind a niche in a search for gold. It is just as possible, I believe, that a window once pierced the wall here.

The principal arguments for window versus niche are presented here.

For window:

a. The Roskruge photos show the opening in its present shape.

b. Photos taken on the outside of the church, about 1921, show a vertical line of brick edges at the lower edge of the "window" on the west side and a fairly regular line on the east face. Anyone who has ever knocked a hole through an adobe wall knows that it is practically impossible to shear the wall in a vertical line.

c. Windows over the altars sometimes occur in old Mexican churches though they are not common.

For niche:

a. A niche high in the reredos is a common feature of Mexican churches.

b. If the opening was a window it was framed in a different manner than all other windows in the church. All the other windows in the nave and sanctuary have heavy lintels which extend into the walls. There is no indication of lintels here.

c. The free columns and broken pediment which framed the opening indicate a niche rather than a window.

The balance of the argument, I believe, favors a niche - certainly it makes a more pleasing design in this case, but, it is also possible that a small window originally pierced the wall.

Two pairs of brick "keys" (one on either side of the niche-window) seem to have been attachments for columns which stood free of the wall and, in turn, supported a broken pediment which was made of moulded plaster. Scars of the pediment are visible on the wall and, in the keys at the tops of the pediment, are pieces of the plaster which still retain the shape of the moulded surface.

The reredos proper is crowned by a pair of scroll-like ornaments and flanked by vermilion painted canopies. Below the canopies are keys which indicate that a shallow brick shelf was built beneath each. It is probable that paintings of saints on wood or, possibly, statues of saints, stood on the shelves.

The only remaining features of the reredos are two plaster picture frames whose scars appear just above the altar, and, on the west side, the base of an equilateral triangle in pale blue.

Surmounting the reredos is a fine example of what the builders of Tumacacori church could do with plaster. A conventional wreath is modeled in high relief and with excellent proportions. The band of ribbon-like plaster which binds the wreath is painted with the gilt paint mentioned by Mr. Gettens. The hollowed "ribs" of the wreaths were painted red but apparently not gilded.

Above the wreath is a corbel-like projection of plaster-covered fired brick which apparently served as a base for a figure which has been completely destroyed. From the shape of the wall scars it seems likely that the head, shoulders and wings of a cherub or angel rested on the corbel.

Two plaster medallions, with the designs missing, flank the wreath and corbel. The whole is bordered by a decorative band of black, white and vermilion which springs from the ends of the sanctuary cornice.

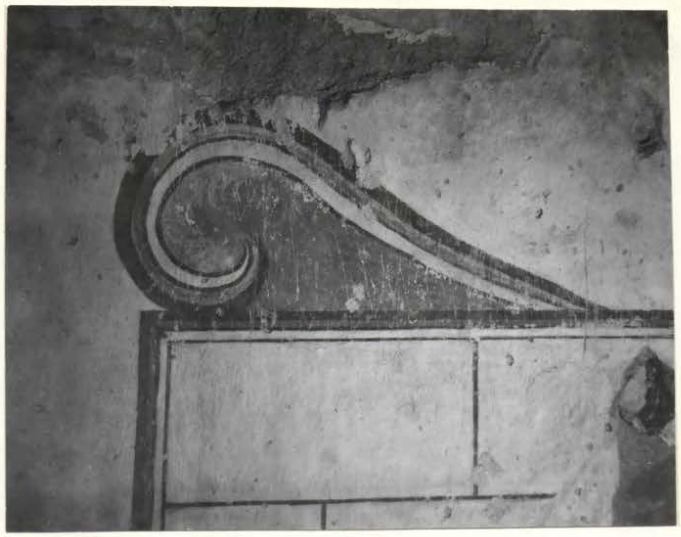
BAPTISTERY AND SACRISTY

No trace of any painted decoration remains in either of these rooms. The only plaster in the baptistery is that on the domed ceiling and apparently one sacristy never received a finish coat of plaster.

the

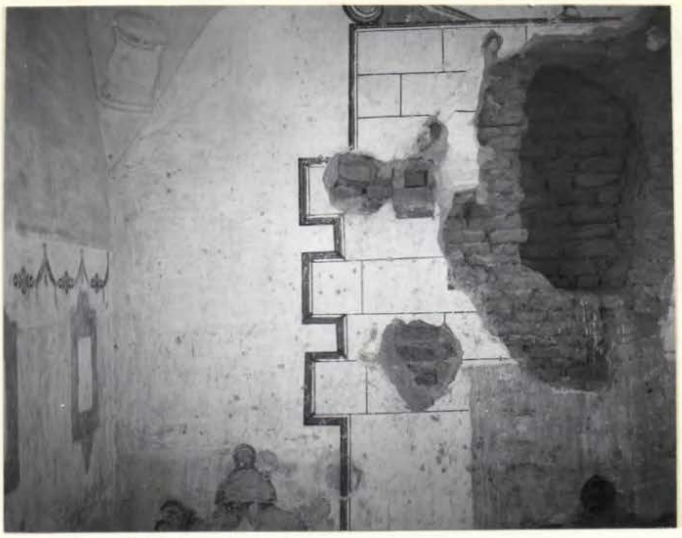
Plate 25

The reredos



A - Detail of upper left corner of reredos.

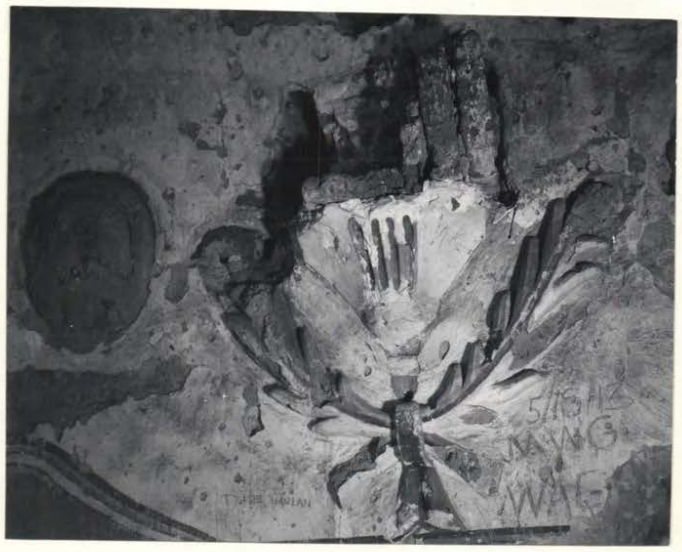
B - Upper portion of reredos. The small plaster keys and scars which indicate a pediment show clearly in the photo.



A - Detail west side of reredos

B - Detail of painted canopy

Plate 28



Two views of moulded palm fronds and corbel-like projection above the reredos

SUMMARY AND CONCLUSIONS

Close study of the mural decorations has revealed some interesting, but not particularly important, details of the construction of the church. Beaubien,[22] and Pinkley and Tovrea[23]

22 - Beaubien, 1937
23 - Pinkley and Tovrea, 1936

have called attention to a number of evidences of changes in plans while construction was in progress and the same holds true for the painted decorations within the church.

It is my feeling that most of the painting was done by one man and that man was a European; probably the priest in charge. This is in contrast to the general belief that many of the existing interior designs at San Xavier del Bac were done by Indians. At Tumacacori many designs were laid out with compass or straight edge by a man who either had poor tools or was not skilled in their use (probably the former). Most of the free-hand decorations (scrolls, painted draperies, etc.) were of fine execution but all are European designs, not Indian.

The various stencils were well cut and made clear patterns. The stencils could easily have been purchased at Mexico City or sent from another mission for it is probable that stencil making materials were scarce at Tumacacori.

The principal changes in design were in the choir loft and sanctuary. The nave seems to have been painted once and then forgotten. Late additions seem to have been the stations of the cross and the moulded plaster picture frames in the sanctuary; the latter partly cover several painted designs.

An earnest, but hopelessly unskilled, person was responsible for several crude designs. These are the incised imitations of painted drapes which were scratched around the upper niches in the nave pilasters; the incised design around the choir loft window and the crudely painted cup and vine paintings under the sanctuary arch. These all seem to have been applied late in the occupancy of the church.

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Appendix 6: Sample Schedule

Nave	Section	Plaster Fragment Number	Description	Personal Notes	Personal Identification	Color	Microscopy	Magnification	Munsell (Matte)	Cross Section
West	A1	2	Plaster fragments, west wall (nave interior)	Beige plaster layer	1		sheen, alligatoring, tannish brown pigment, soil deposits one layer of gypsum	x1	5YR 7/4	Yes
West	A2	1	Gypsum layer		2					
West	A2	1	Red pigment on finish		3	Yes				
West	A2	1	West wall plaster		4		Red spots, black and white splotches, soil desposits on the surface, fibers in the gypsum	x1	7.5 YR 9/2 & 7.5 YR 7/2	Yes
West	A2	2	Finish plaster with some red pigment		5	Yes	Bursh strokes, red, maybe black, two layers of gypsum, soil deposits	x1	7.5 YR 9/2, 7.5YR 7/2, 5YR 7/4	Yes
West	A2	3	Finish plaster with red- tried to save but all scratch gone		6	Yes	Too small for hand sample analysis, reddish pink pigment, 2 layers of gypsum		10R 8/6	Yes
West	B1	1	Plaster sample		7		Thin plaster coat, fibers	x1	5YR 9/1	Yes
West	B1	2		biogrowth?	8					
West	B1	3		Plaster	9		crack through gypsum, two layers of gypsum		5YR 7/4	
West	B2	1	Gypsum plaster finish		10		Very little sheen, brownish tan pigment, alligatoring, one layer of gypsum, brush strokes evident, thick gypsum on one side	x1	closest to 5YR 7/4	Yes
West	B3	1	Finish plaster		11					
West	B4	1	Finish plaster		12					
West	B4	2	Finish plaster		13		2 gypsum layers, alligator (?) cracking pattern, chalking	x.71		Yes
West	B4	3	Finish plaster with scratch coat		14		Some gloss			
West	B5	1	Finish plaster in arch of nicho, blue pigment		15	Yes	dark bluish-gray pigment, dark brown residue (soil?), little chalking	x1	7.5YR 8/2	Yes
West	C3	1	Finish plaster with pigment		16	Yes	brown pigment, two layers of gypsum, dark speck	x1	7.5YR 8/2 & 7.5YR 6/4	Yes
West	C4	1	Big chunk of plaster, double design roundel with finishes		17		tannish-brown pigment, two layers of gypsum	x1		Yes
West	C5	1	Finish plaster corner		18		Some brown pigment, gypsum on two sides of plaster	x1	10YR 7/1	Yes
West	C7	1			19					
South	A2		Finish with scratch		20					
South	A2		Finish with scratch		21					

South	B2	2	Yellow color above dado		22	Yes	Yellow pigment, alligatoring, one layer of gypsum, brown residue on edge (could be soil or PVA?)	x1	7.5YR 9/2	Yes
South	B2		Plaster with finish coat		23		uneven gypsum on surface, cracking on surface, soil deposits in divets, 2 layers of gypsum in some areas, one layer in others, brush strokes evident in raking light, gypsum exposed in areas where there is pigmemt (abrasion? Intentional?)	x1	7.5YR 8/2	Yes
East	A1	1	Plaster fragment with gypsum finish		24					
East	A1	2	Plaster fragment with gypsum finish		25		Pigmented or soiled?, grayish white and brown reside along one side, cracking, brown deposits, brush strokes, one layer of gypsum	x1	5YR 9/1	Yes
East	A5	2	Plaster with gypsum on surface		26					
East	A5	4	Original scheme of black finishes on plaster substrate		27		Likely untreated by PVAC (can be used as a control), no sheen, black pigment, white deposits, greyish black residue/ pigment, one layer of gypsum	x1	N 4.5/	Yes
East	A6	2	Original scratch coat		28					
East	C5	1	Layers of earthen mortar, lime mortar, and post 1949-repair material		29					
South	B1	3	Dado fragments		30					
West	B2	1	Finish plaster		31		Alligatoring, light tan pigment, evident brush strokes, gypsum wash on side, 1-2 layers of gypsum	x1	7.5YR 8/2	Yes
	A5	1	Gypsum finish		32					
West	E5	3	Edging type I with gypsum plaster finish		33					
			Pilaster nicho. Finish layer		34		Some tan pigment, cracking, soil build up, one layer of gypsum		7.5YR 8/2	Yes
			Pigmented plaster fragments (Red); SW corner cornice		35	Yes	Too small for hand sample analysis			Yes
South			Pigmented plaster chips; south wall top west corner		36	Yes	Too small for hand sample analysis		5YR 7/10	Yes
				Plaster	37					

Appendix 7: Bulk Sample Observations

SAMPLE - # 1
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: sheen, alligatoring, tannish brown pigment, soil deposits one layer of gypsum, 5YR 7/4

SAMPLE - # 4
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: Red spots, black and white splotches, soil deposits on the surface, fibers in the gypsum, 7.5 YR 9/2 & 7.5 YR 7/2

SAMPLE - # 5
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: Brush strokes, red, maybe black, two layers of gypsum, soil deposits, 7.5 YR 9/2, 7.5YR 7/2, 5YR 7/4

SAMPLE - # 7
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: Thin plaster coat, fibers, 5YR 9/1

SAMPLE - # 10
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: Very little sheen, brownish tan pigment, alligatoring, one layer of gypsum, brush strokes evident, thick gypsum on one side, 5YR 7/4

SAMPLE - # 13
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

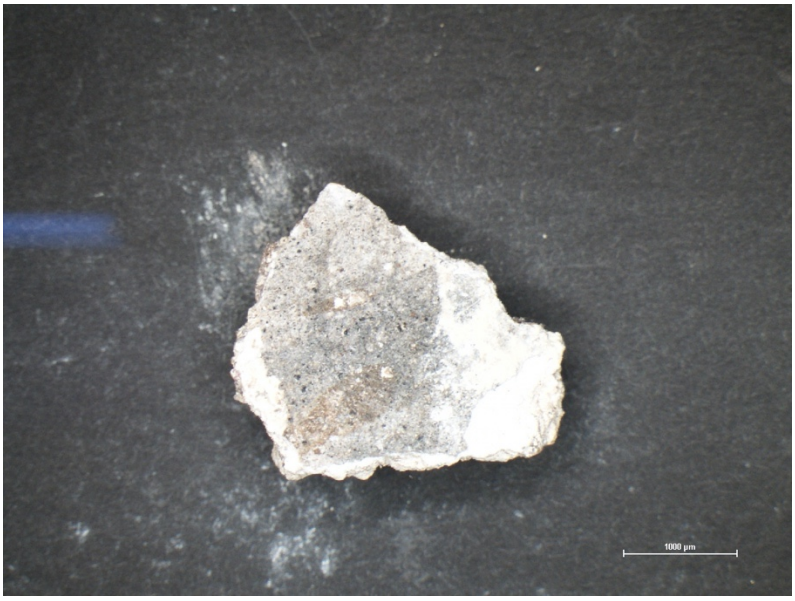
MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: 2 gypsum layers, alligator (?) cracking pattern, chalking



SAMPLE - # 15
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: dark bluish-gray pigment, dark brown residue (soil?), little chalking, 7.5YR 8/2

SAMPLE - # 16
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: brown pigment, two layers of gypsum, dark speck, 7.5YR 8/2 & 7.5YR 6/4

SAMPLE - # 17
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: tannish-brown pigment, two layers of gypsum

SAMPLE - # 18
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: Some brown pigment, gypsum on two sides of plaster, 10YR 7/1

SAMPLE - # 22
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

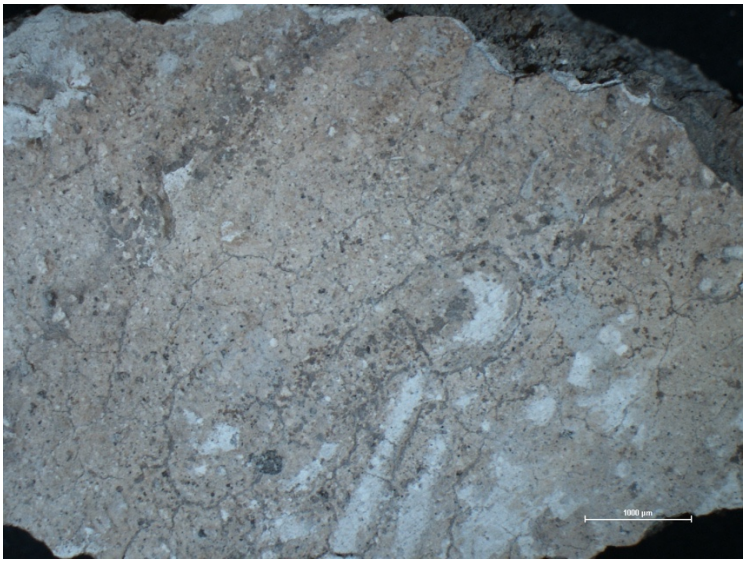
MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: Yellow pigment, alligatoring, one layer of gypsum, brown residue on edge (could be soil or PVA?), 7.5YR 9/2



SAMPLE - # 23
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

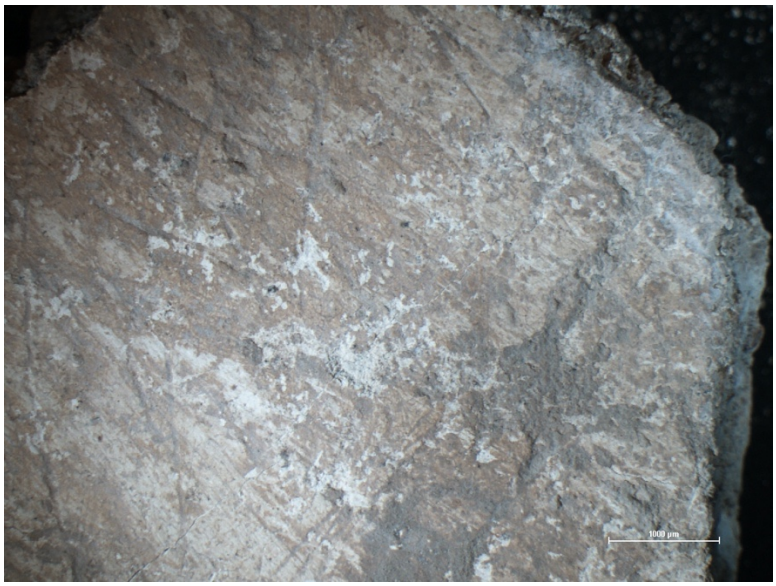
MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: uneven gypsum on surface, cracking on surface, soil deposits in divets, 2 layers of gypsum in some areas, one layer in others, brush strokes evident in raking light, gypsum exposed in areas where there is pigment (abrasion? Intentional?), 7.5YR 8/2



SAMPLE - # 25
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

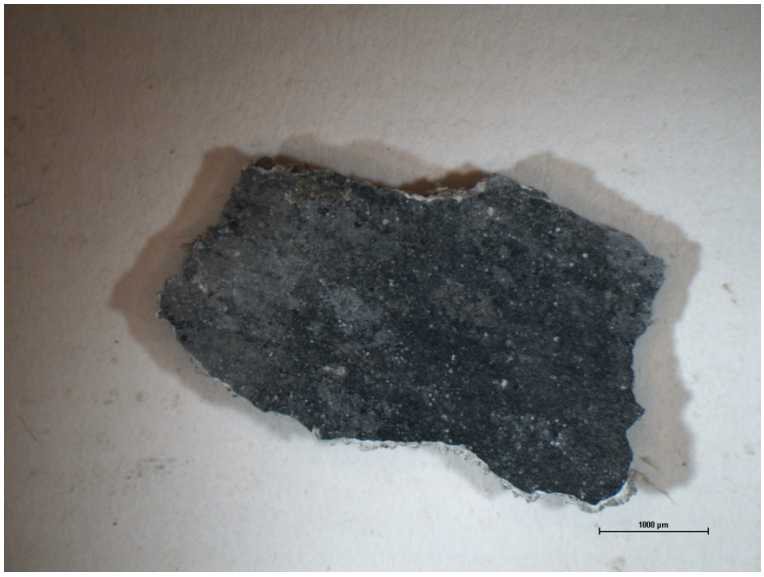
MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: Pigmented or soiled?, grayish white and brown reside along one side, cracking, brown deposits, brush strokes, one layer of gypsum, 5YR 9/1



SAMPLE - # 27
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: Likely untreated by PVAC (can be used as a control), no sheen, black pigment, white deposits, greyish black residue/ pigment, one layer of gypsum, N 4.5/

SAMPLE - # 31
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: Alligatoring, light tan pigment, evident brush strokes, gypsum wash on side, 1-2 layers of gypsum, 7.5YR 8/2

SAMPLE - # 34
HAND SAMPLE

ORIGIN: Tumacácori
RECEIVED:

IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Leica MZ16a
OCULAR MAG: 10 x

OBJECTIVE: 0.5 x
ZOOM: 1 x

TRINOCULAR MAG: 1 x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: 3000 °K

NOTES: Some tan pigment, cracking, soil build up, one layer of gypsum, 7.5YR 8/2

Appendix 8: Cross-Section Analysis of Samples and Facsimiles

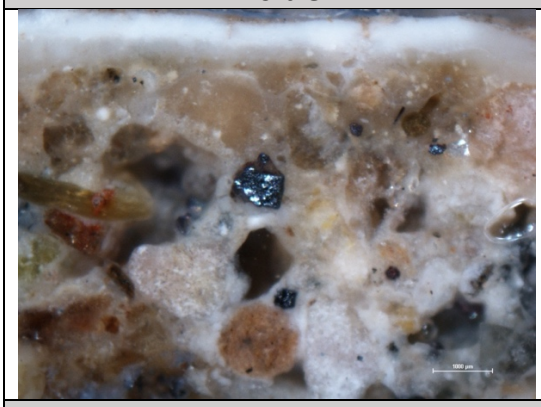
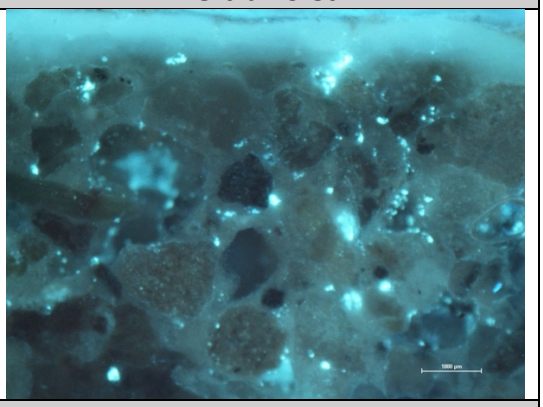
Table 1: Sample 1			
Visible		**Ultraviolet**	
			
Location	**Sampled By**	**Sampled On**	**Analyzed By**
West Nave		5/4/21	G. Goldstein
Microscope	**Light Source**	**Filters**	**Camera**
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular Mag	**Trinocular Mag**	**Objective Mag**	**Zoom**
10.0x	1.0x	4.0x	-
Notes:			
• Some auto-fluorescence but does not appear to be PVAC			

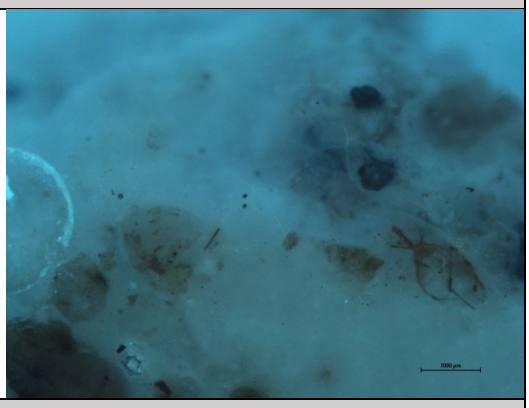
Table 2: Sample 25			
Visible		Ultraviolet	
			
Location	**Sampled By**	**Sampled On**	**Analyzed By**
East Nave		5/4/21	G. Goldstein
Microscope	**Light Source**	**Filters**	**Camera**
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular Mag	**Trinocular Mag**	**Objective Mag**	**Zoom**
10.0x	1.0x	4.0x	-
Notes:			
• No auto-fluorescence			

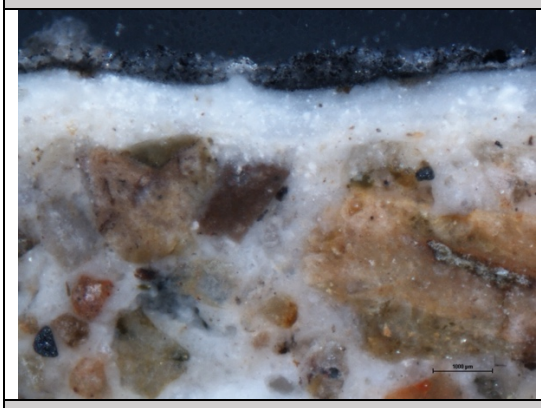
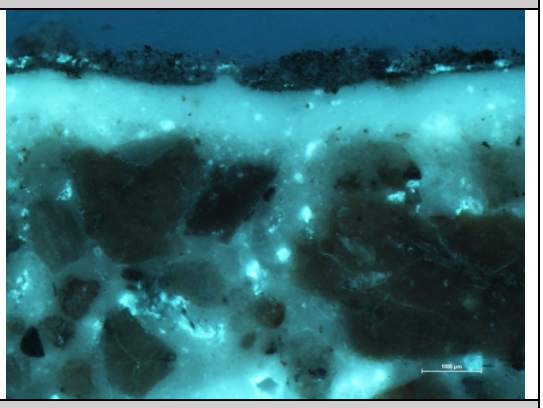
Table 3: Sample 27			
Visible		Ultraviolet	
			
Location	**Sampled By**	**Sampled On**	**Analyzed By**
East Nave		5/4/21	G. Goldstein
Microscope	**Light Source**	**Filters**	**Camera**
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular Mag	**Trinocular Mag**	**Objective Mag**	**Zoom**
10.0x	1.0x	4.0x	-
Notes:			
• Some auto-fluorescence but does not appear to be PVAC			

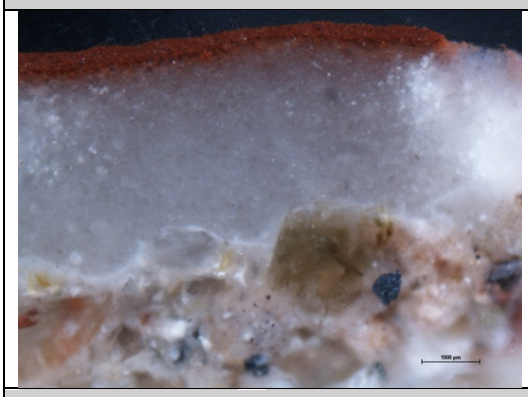
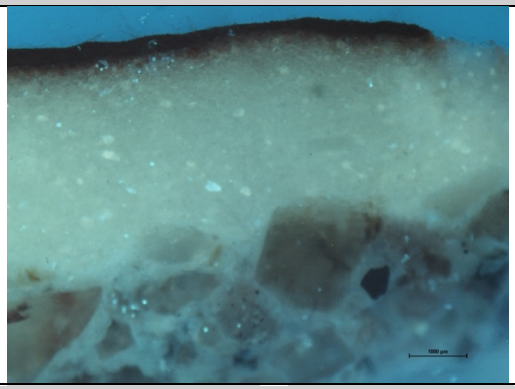
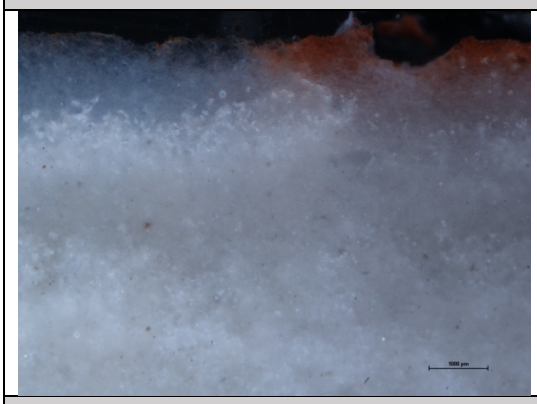
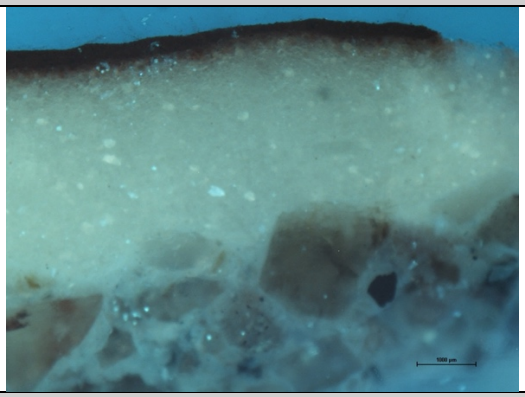
Table 4: Facsimile 1.1.4			
Visible		**Ultraviolet**	
			
Location	**Sampled By**	**Sampled On**	**Analyzed By**
-	G. Goldstein	5/6/21	G. Goldstein
Microscope	**Light Source**	**Filters**	**Camera**
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular Mag	**Trinocular Mag**	**Objective Mag**	**Zoom**
10.0x	1.0x	4.0x	-
Notes:			
• Both gypsum and hematite present • No evidence of autofluorescence from PVAC			

Table 5: Facsimile 1.1.5			
Visible		**Ultraviolet**	
			
Location	**Sampled By**	**Sampled On**	**Analyzed By**
-	G. Goldstein	5/6/21	G. Goldstein
Microscope	**Light Source**	**Filters**	**Camera**
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular Mag	**Trinocular Mag**	**Objective Mag**	**Zoom**
10.0x	1.0x	4.0x	-
Notes:			
• Both gypsum and hematite present • No evidence of autofluorescence from PVAC			

Appendix 9: Ultraviolet Analysis of PVAC Solution

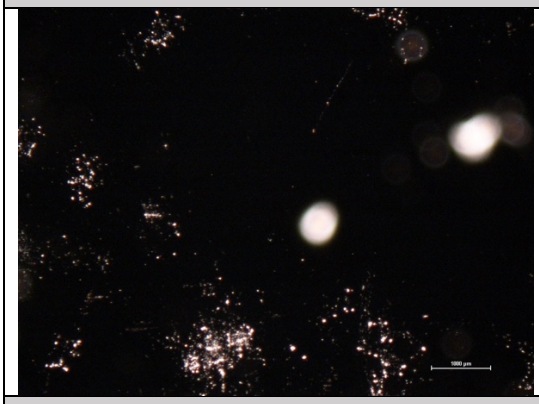
Table 1: Glass Slide			
Visible		**Ultraviolet**	
			
Location	**Sampled By**	**Sampled On**	**Analyzed By**
-	G. Goldstein	5/19/21	G. Goldstein
Microscope	**Light Source**	**Filters**	**Camera**
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular Mag	**Trinocular Mag**	**Objective Mag**	**Zoom**
10.0x	1.0x	4.0x	-
Notes:			
• No autofluorescence of glass			

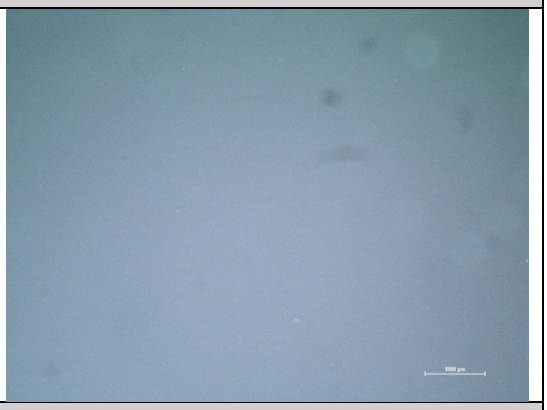
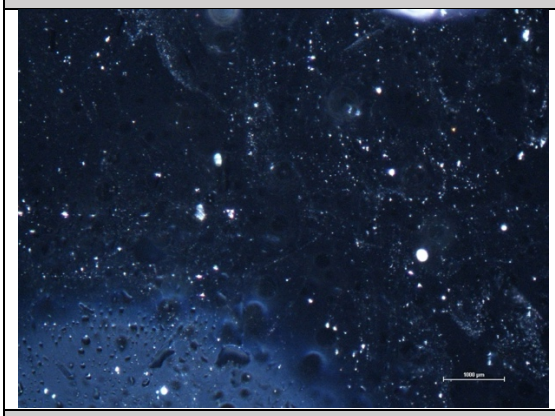
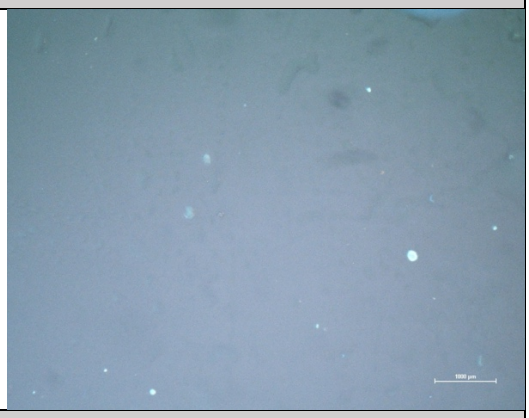
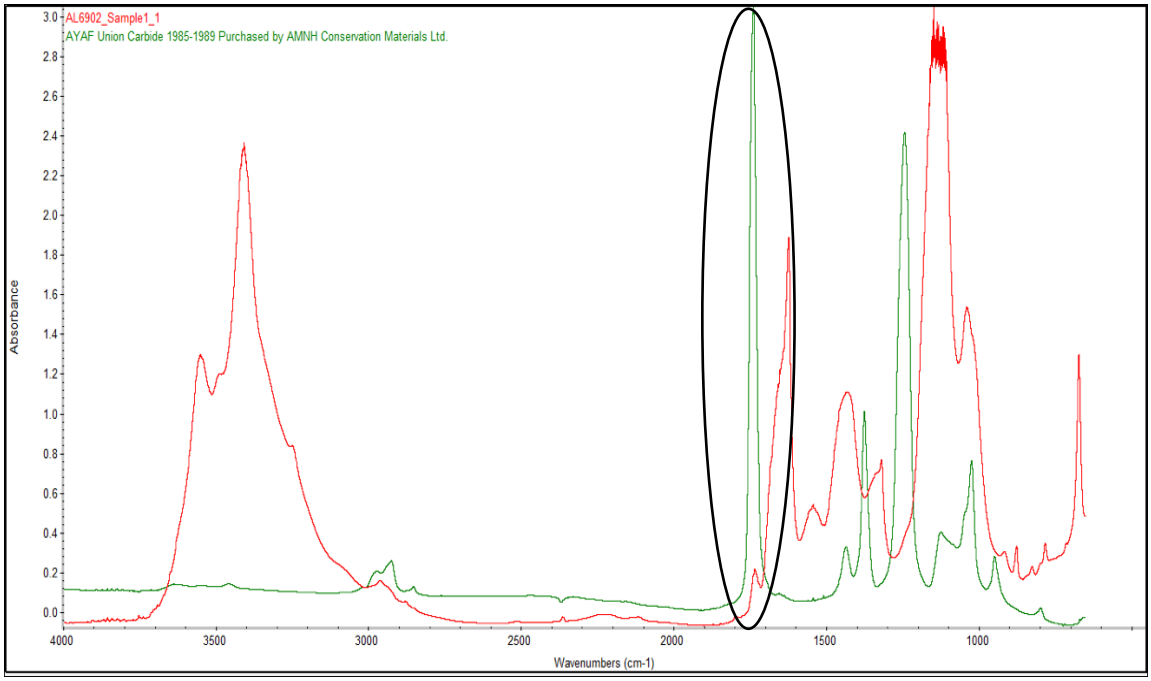
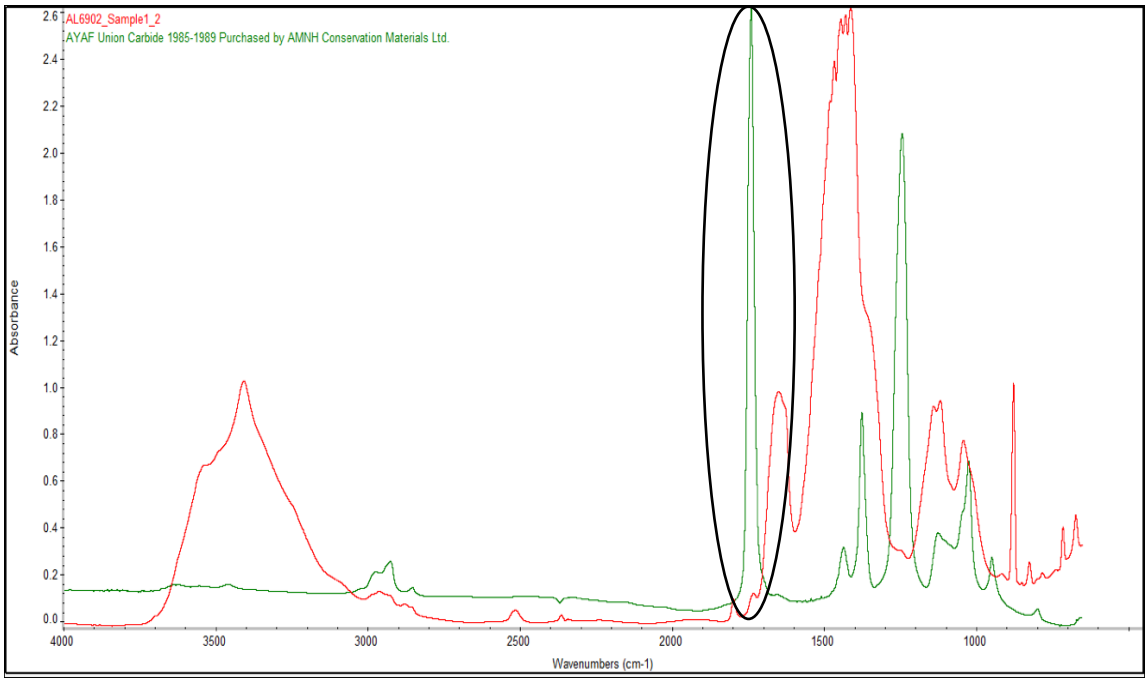
Table 2: PVAC Solution			
Visible		**Ultraviolet**	
			
Location	**Sampled By**	**Sampled On**	**Analyzed By**
-	G. Goldstein	5/19/21	G. Goldstein
Microscope	**Light Source**	**Filters**	**Camera**
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular Mag	**Trinocular Mag**	**Objective Mag**	**Zoom**
10.0x	1.0x	4.0x	-
Notes:			
• PVAC solution does not auto-fluoresce			

Table 3: Solvent Mixture			
Visible		**Ultraviolet**	
			
Location	**Sampled By**	**Sampled On**	**Analyzed By**
-	G. Goldstein	5/19/21	G. Goldstein
Microscope	**Light Source**	**Filters**	**Camera**
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular Mag	**Trinocular Mag**	**Objective Mag**	**Zoom**
10.0x	1.0x	4.0x	-
Notes:			
• Solvent mixture, without the PVAC, does not auto-fluoresce			

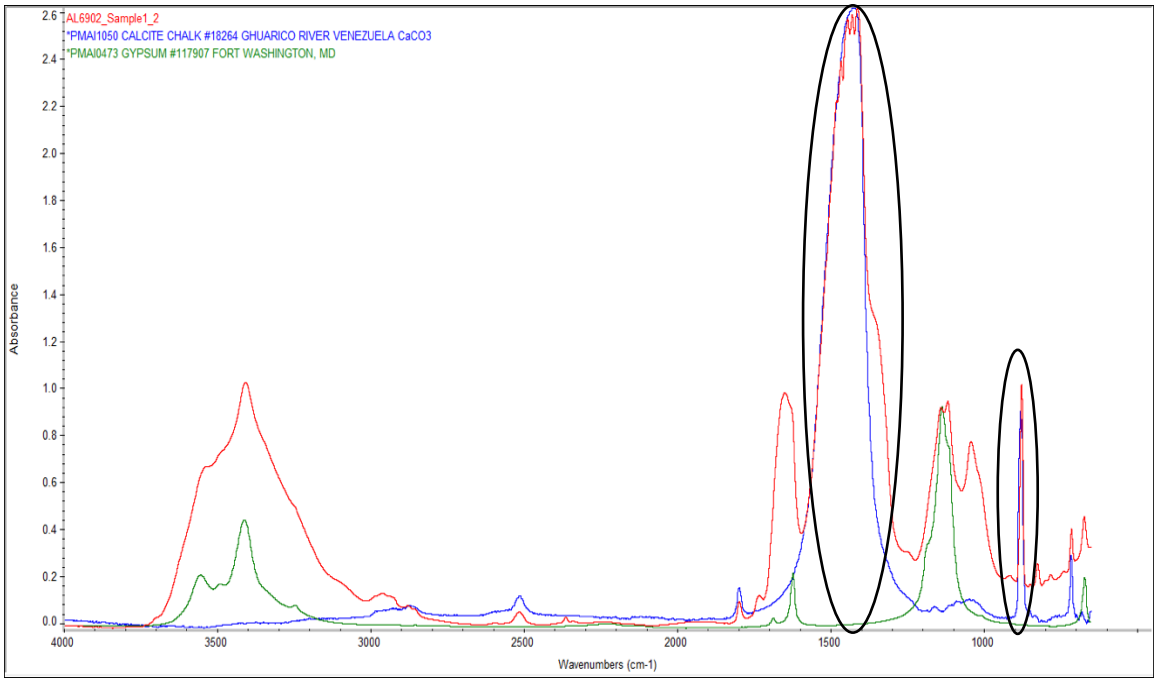
Appendix 10: FTIR Graphs



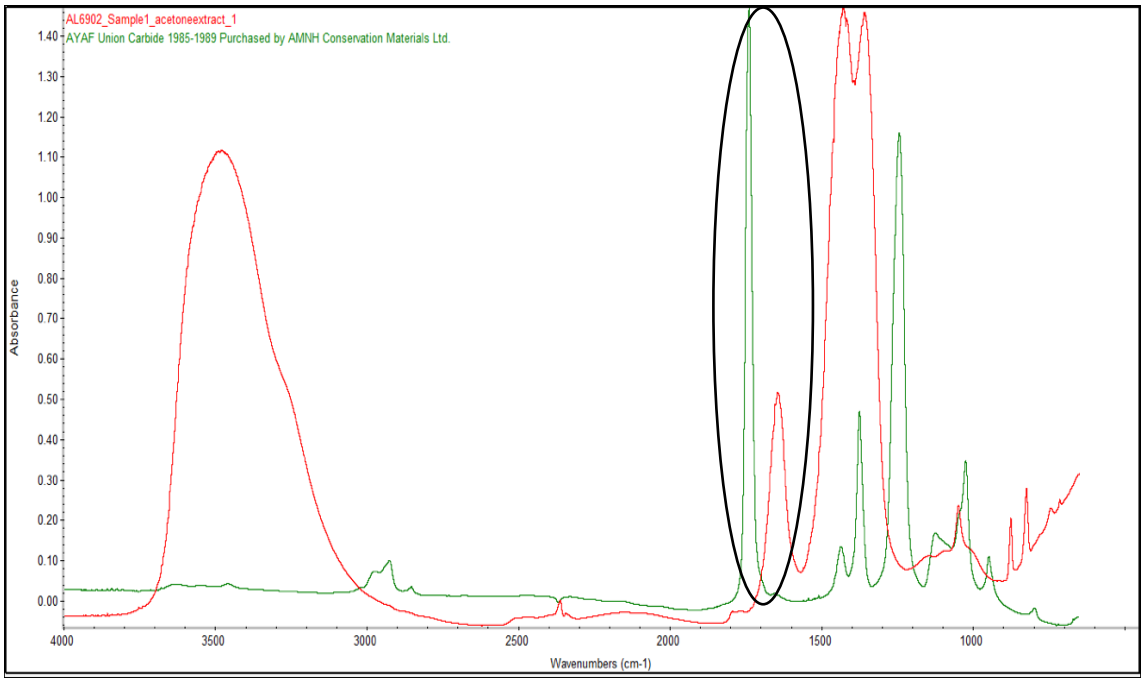
Graph 1- Sample 1 compared to known PVAC resin, with relevant peak highlighted.



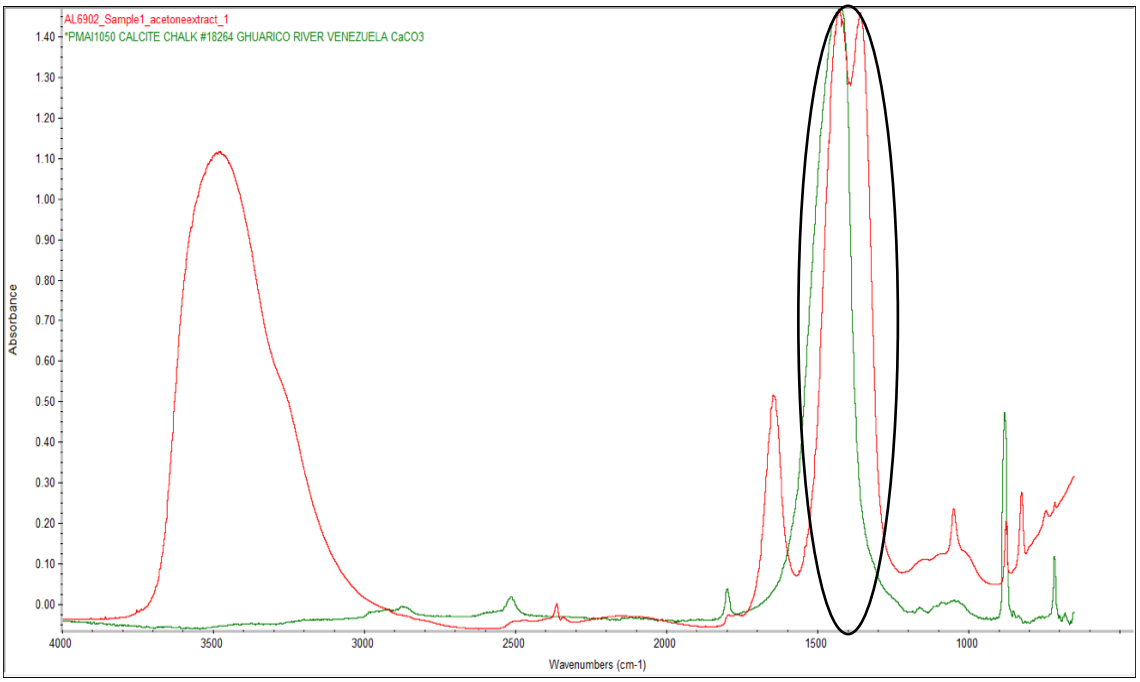
Graph 2- Sample 1 compared to known PVAC resin in a different location, with relevant peak highlighted.



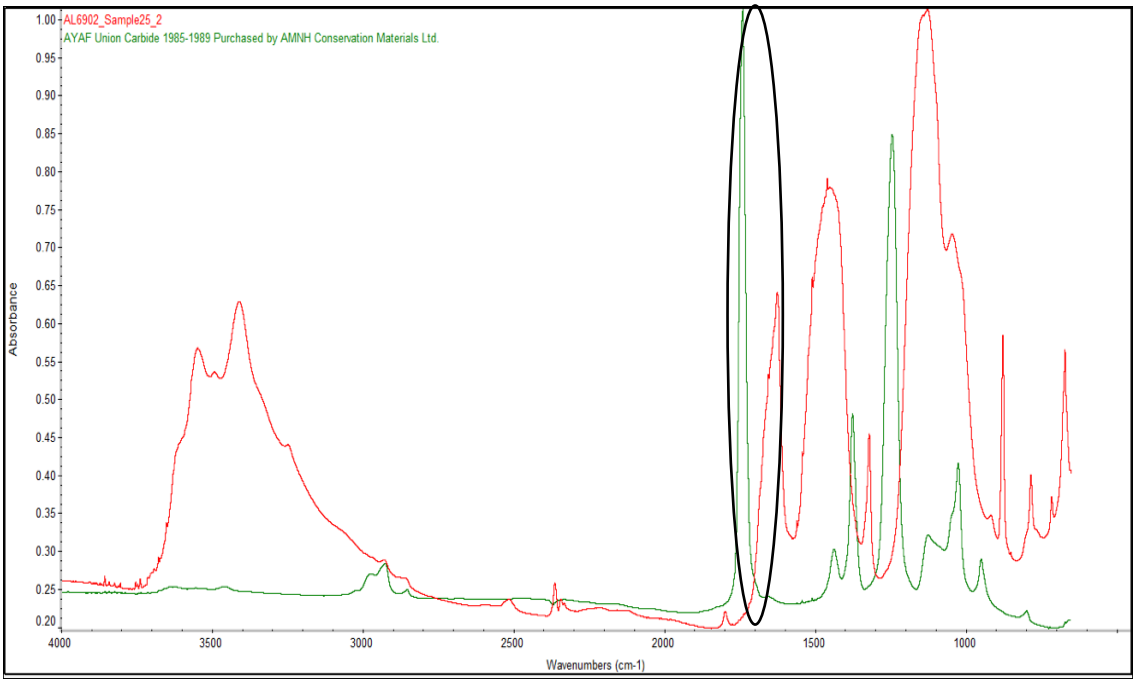
Graph 3- Sample 1 compared to known two different gypsum samples, indicating the gypsum is most similar to calcite chalk.



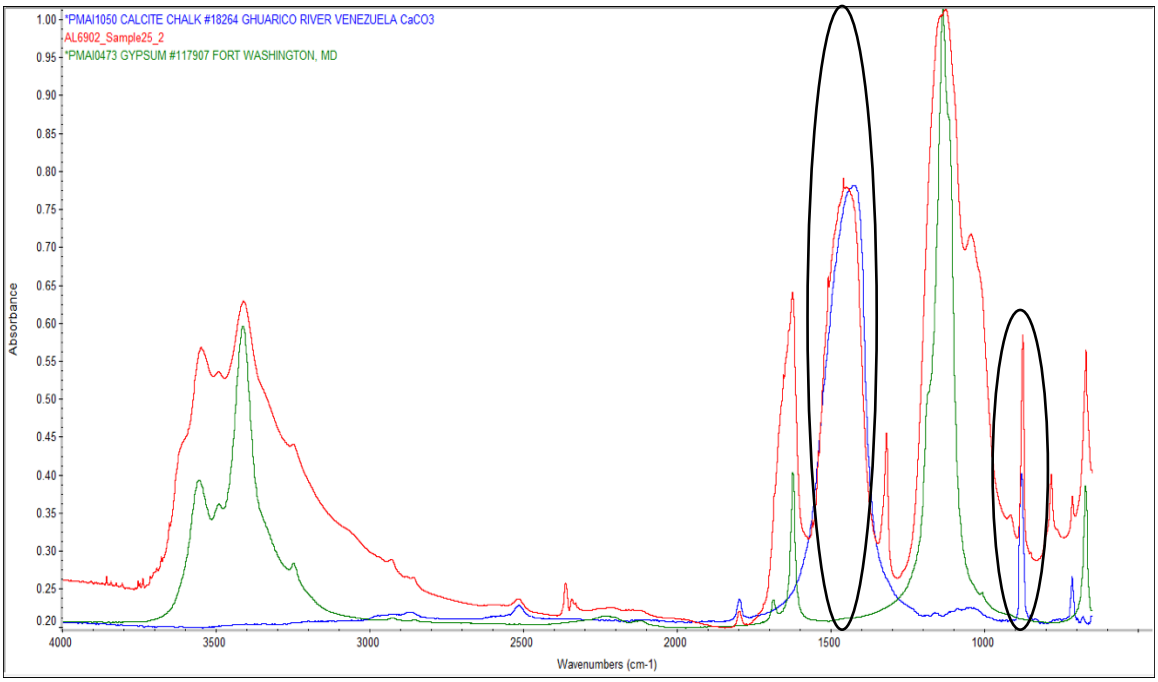
Graph 4- Sample 1 acetone extract compared to known PVAC resin, with relevant peak highlighted



Graph 5- Sample 1 acetone extract compared to calcite chalk.



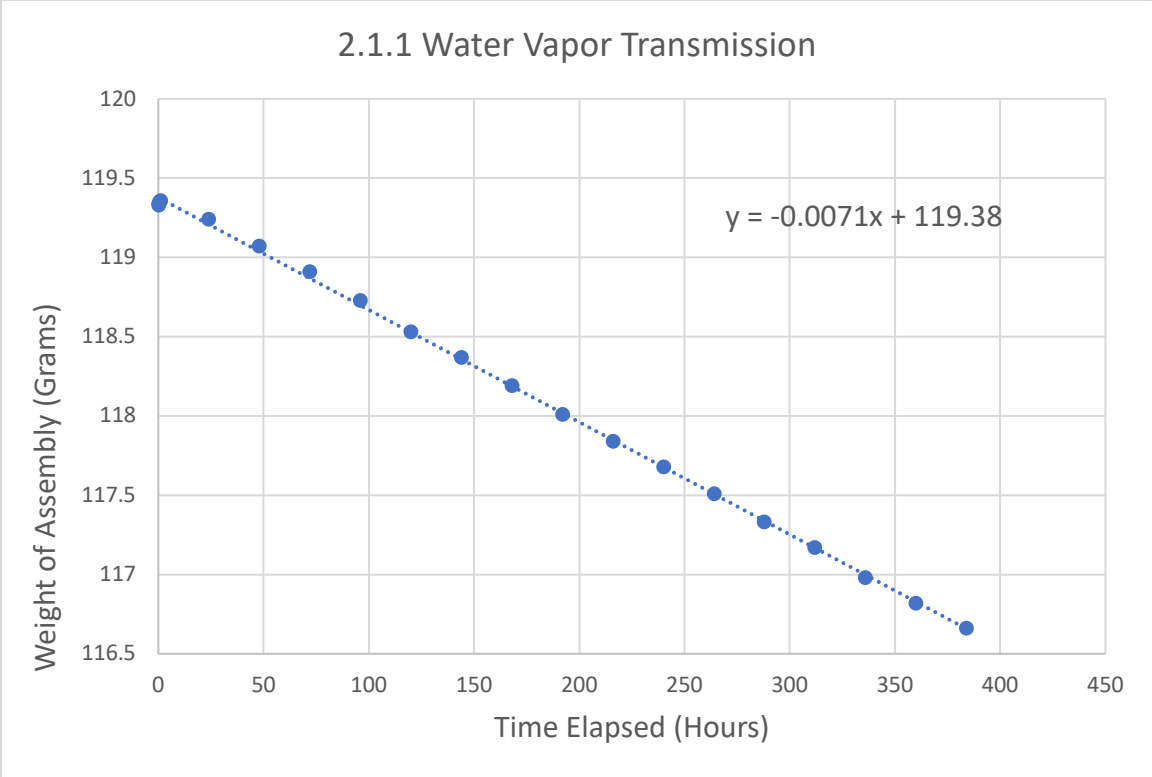
Graph 6- Sample 25 compared to known PVAC resin with relevant peak highlighted.

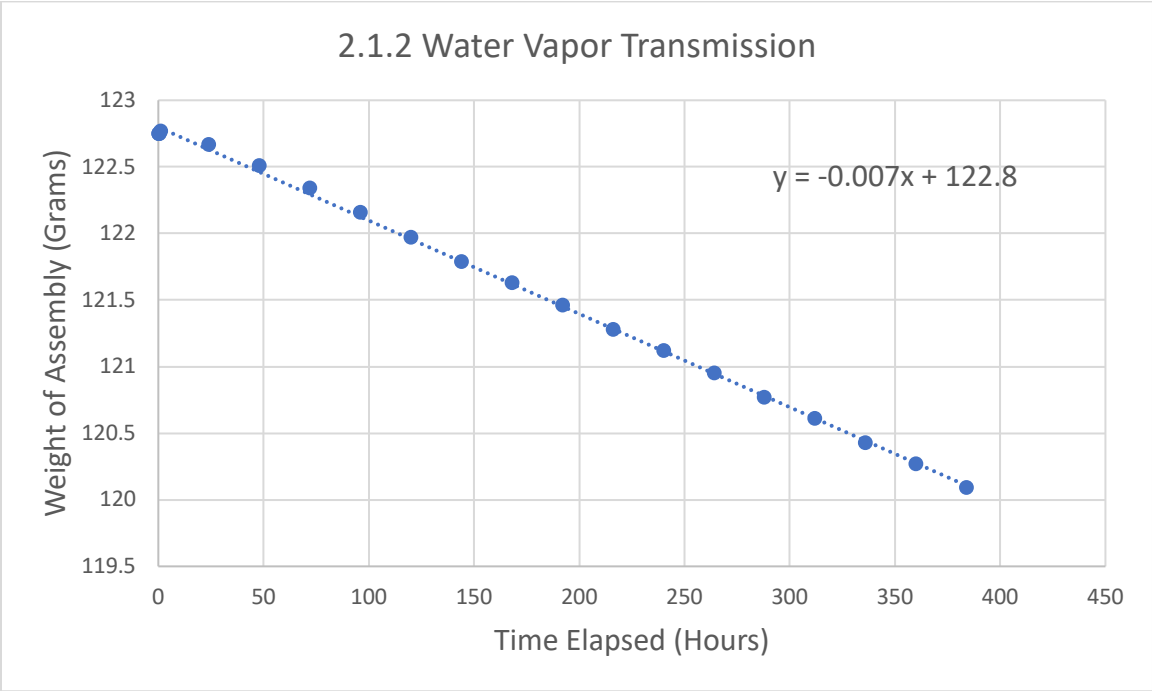


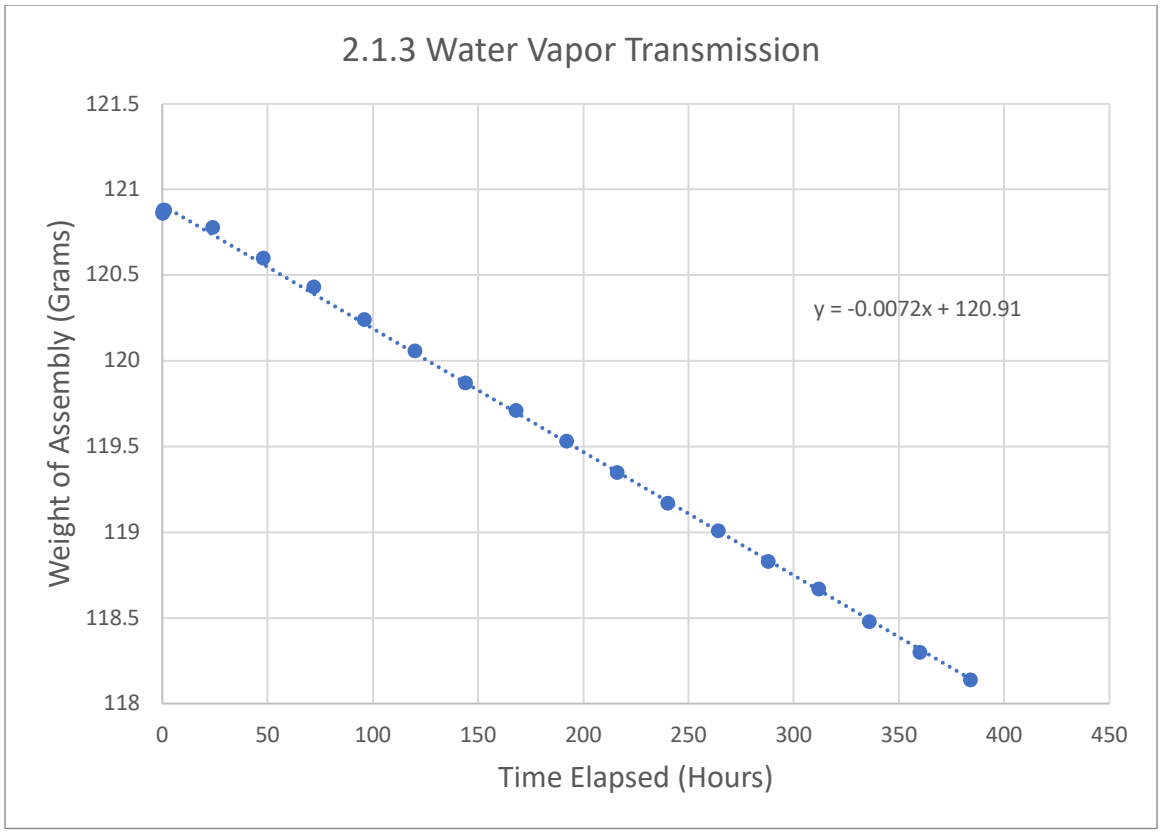
Graph 7- Sample 25 compared to two different gypsum samples, indicating the gypsum is most similar to calcite chalk.

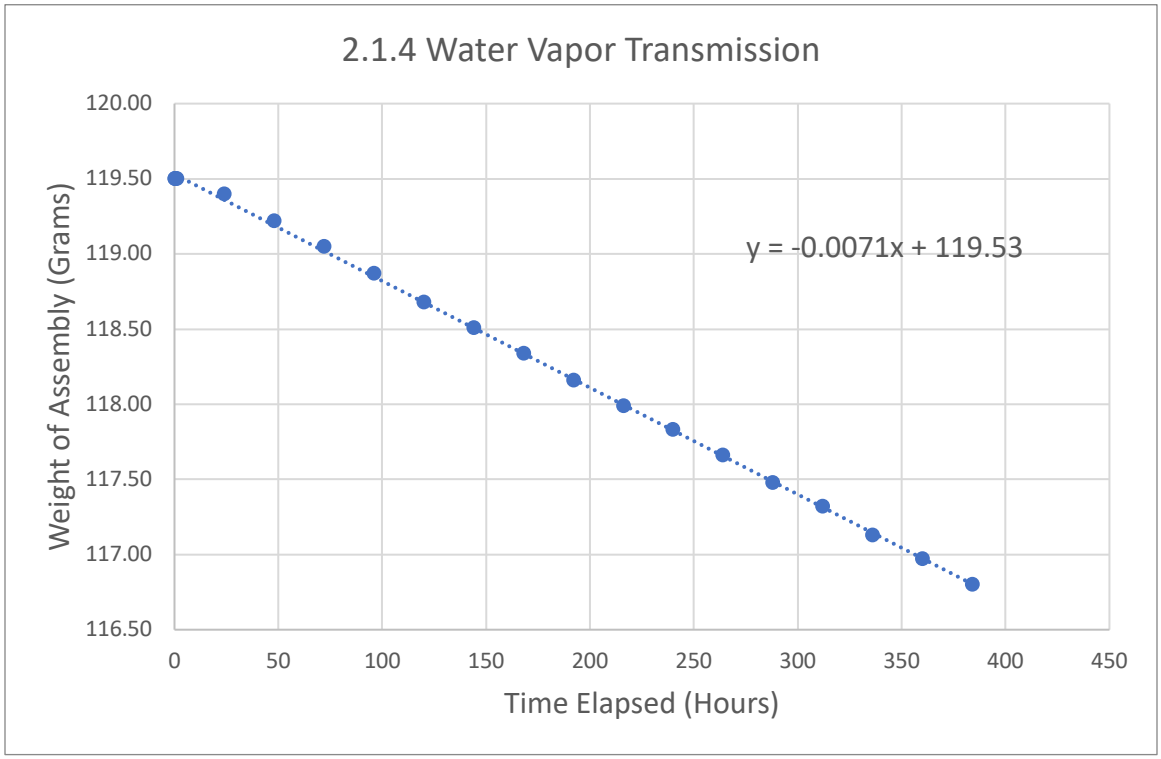
Appendix 11: Water Vapor Transmission Data and Graphs

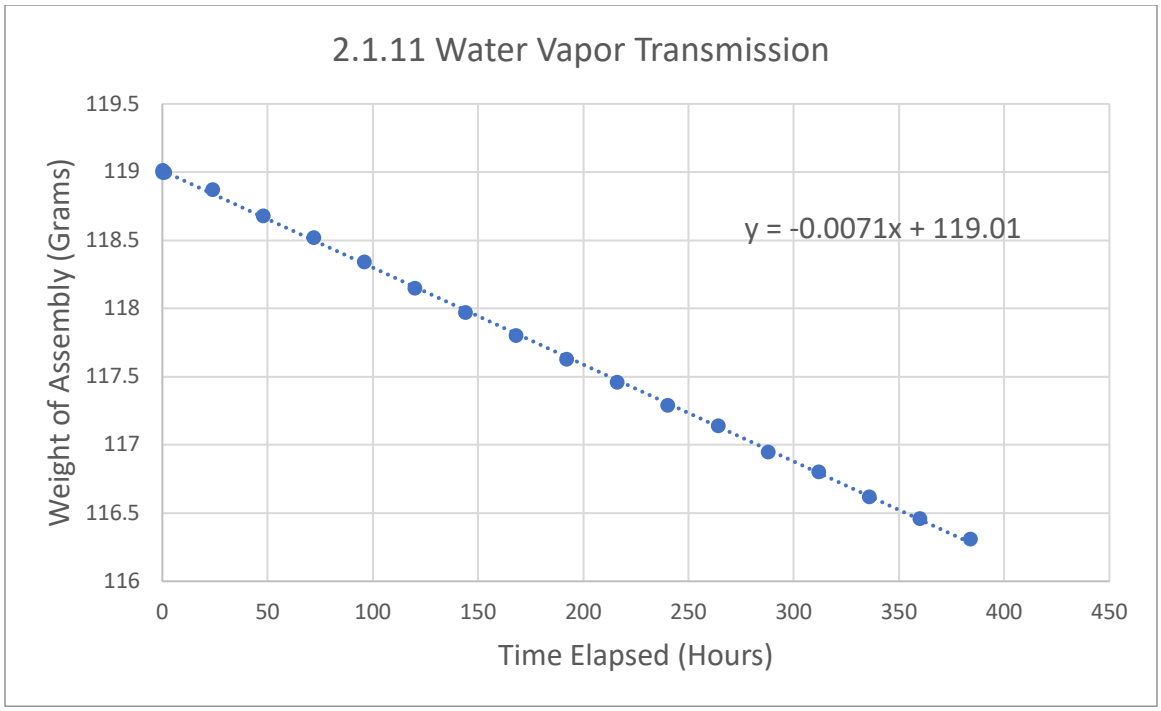
Painted Facsimiles										
	Consolidated					Unconsolidated				
	2.1.1	**2.1.2**	**2.1.3**	**2.1.4**	**2.1.11**	**2.2.6**	**2.2.7**	**2.2.8**	**2.2.9**	**2.2.10**
Md	76.03	79.02	76.79	76.37	71.7	78.51	74.96	76.08	78.2	75.09
Mb	10.24	10.45	10.47	10.33	10.24	10.35	10.35	10.47	10.27	10.25
Mbw	40.06	40.56	41.15	39.69	41.59	40.4	40.71	40.56	41.77	40.55
Ma	119.35	122.75	120.88	119.00	119.49	121.65	118.97	120.05	126.51	119.25
Time Elapsed (hours)	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**
0.083	119.33	122.75	120.87	119.50	119	121.63	118.95	120	126.53	119.23
0.25	119.34	122.75	120.86	119.50	119.01	121.7	118.96	120.01	126.52	119.25
0.5	119.35	122.75	120.88	119.50	119	121.68	118.96	120	126.52	119.25
1	119.36	122.77	120.88	119.50	119	121.69	118.96	120.01	126.52	119.26
24	119.24	122.67	120.78	119.40	118.87	121.55	118.79	119.86	126.38	119.11
48	119.07	122.51	120.6	119.22	118.68	121.35	118.56	119.66	126.17	118.9
72	118.91	122.34	120.43	119.05	118.52	121.15	118.32	119.46	125.95	118.69
96	118.73	122.16	120.24	118.87	118.34	120.93	118.08	119.24	125.76	118.47
120	118.53	121.97	120.06	118.68	118.15	120.7	117.81	119.01	125.51	118.22
144	118.37	121.79	119.87	118.51	117.97	120.51	117.57	118.8	125.31	118.02
168	118.19	121.63	119.71	118.34	117.8	120.3	117.34	118.61	125.1	117.8
192	118.01	121.46	119.53	118.16	117.63	120.1	117.09	118.4	124.9	117.59
216	117.84	121.28	119.35	117.99	117.46	119.89	116.85	118.21	124.69	117.38
240	117.68	121.12	119.17	117.83	117.29	119.68	116.6	118.01	124.47	117.16
264	117.51	120.95	119.01	117.66	117.14	119.5	116.4	117.83	124.29	116.98
288	117.33	120.77	118.83	117.48	116.95	119.27	116.14	117.61	124.06	116.74
312	117.17	120.61	118.67	117.32	116.8	119.07	115.91	117.41	123.88	116.53
336	116.98	120.43	118.48	117.13	116.62	118.84	115.65	117.17	123.63	116.3
360	116.82	120.27	118.3	116.97	116.46	118.63	115.42	116.98	123.43	116.1
384	116.66	120.09	118.14	116.80	116.31	118.45	115.2	116.79	123.24	115.91
WVT (g/(h/cm^2))	0.000359	0.000353	0.000363	0.000292	0.000422	0.000425	0.000502	0.000434	0.000436	0.000443

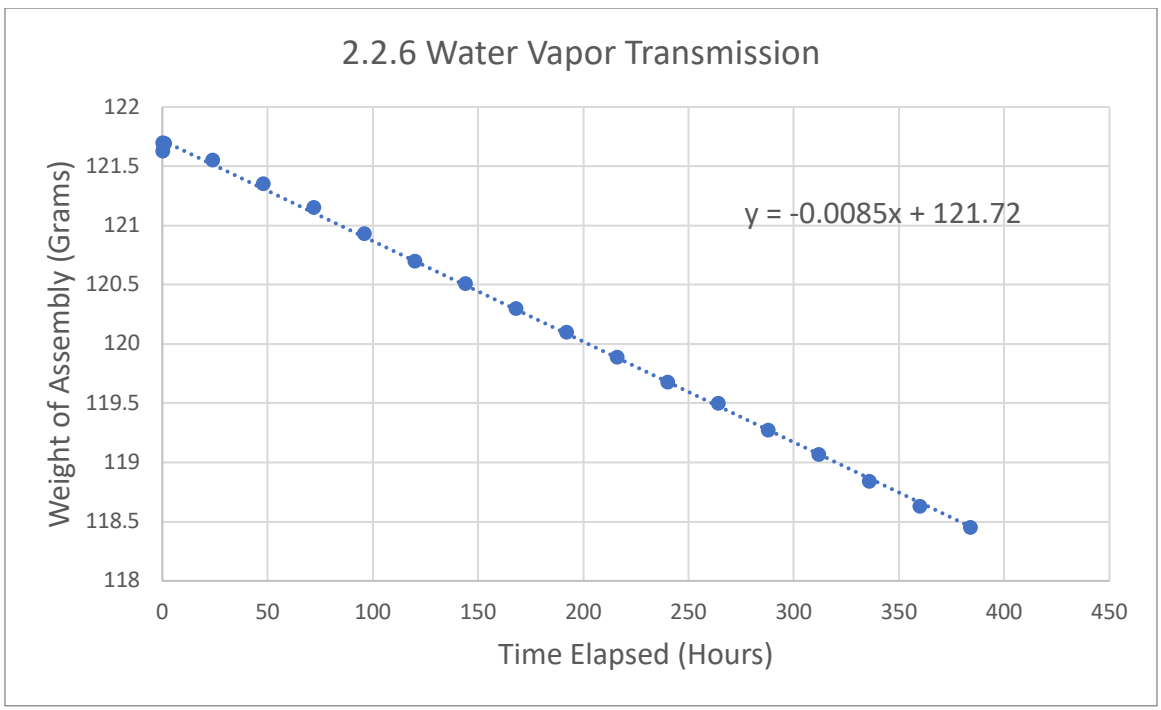

2.1.1 Water Vapor Transmission
y = -0.0071x + 119.38
Weight of Assembly (Grams)
120
119.5
119
118.5
118
117.5
117
116.5
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)

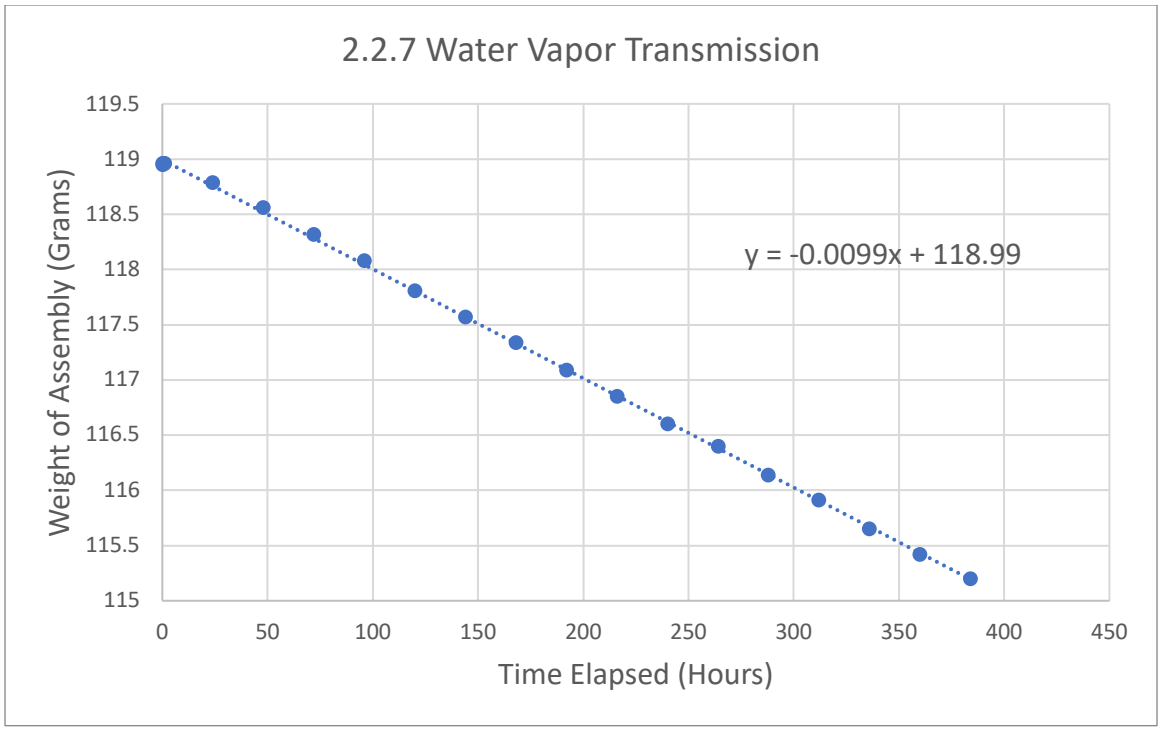

2.1.2 Water Vapor Transmission
y = -0.007x + 122.8
Weight of Assembly (Grams)
123
122.5
122
121.5
121
120.5
120
119.5
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)

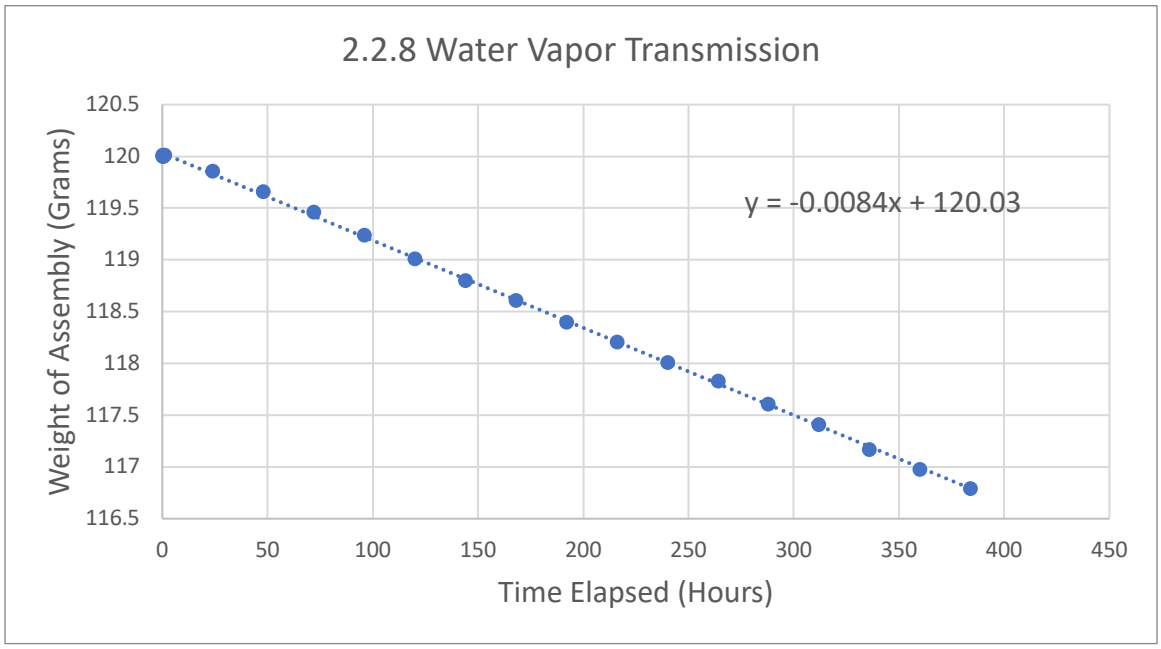

2.1.3 Water Vapor Transmission
Weight of Assembly (Grams)
121.5
121
120.5
120
119.5
119
118.5
118
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)
y = -0.0072x + 120.91

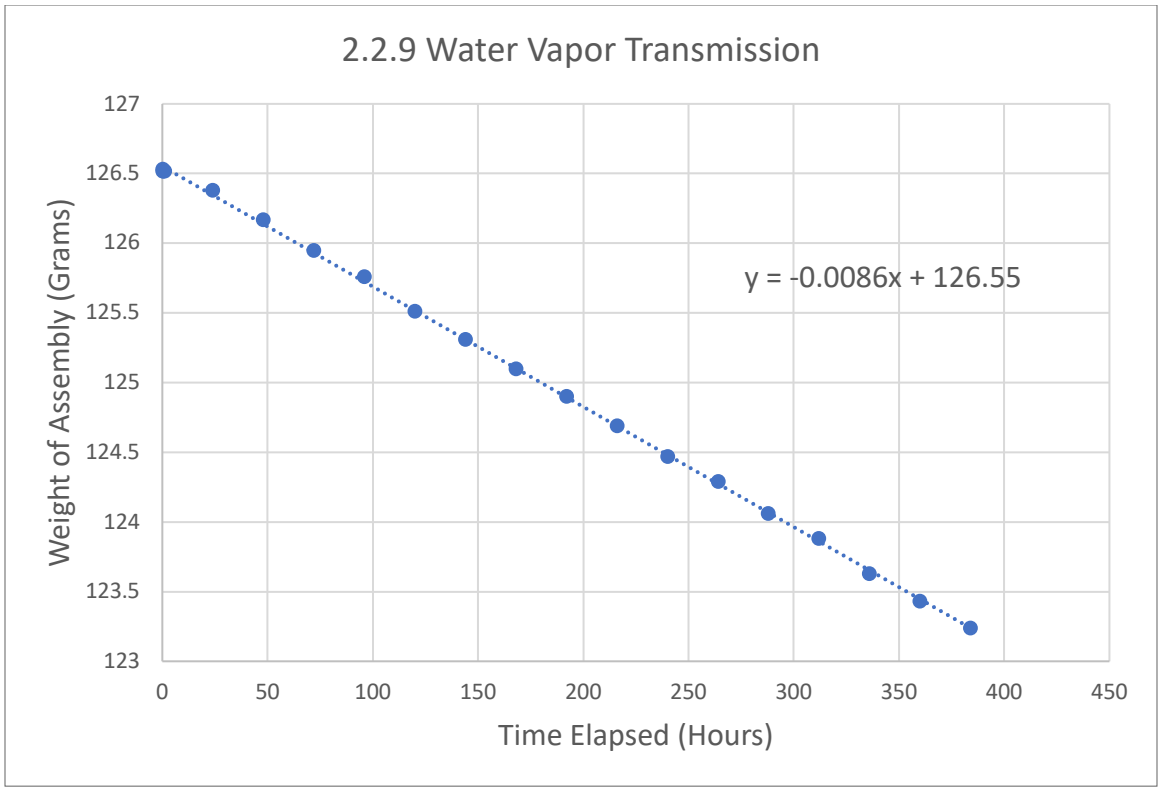

2.1.4 Water Vapor Transmission
Weight of Assembly (Grams)
120.00
119.50
119.00
118.50
118.00
117.50
117.00
116.50
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)
y = -0.0071x + 119.53

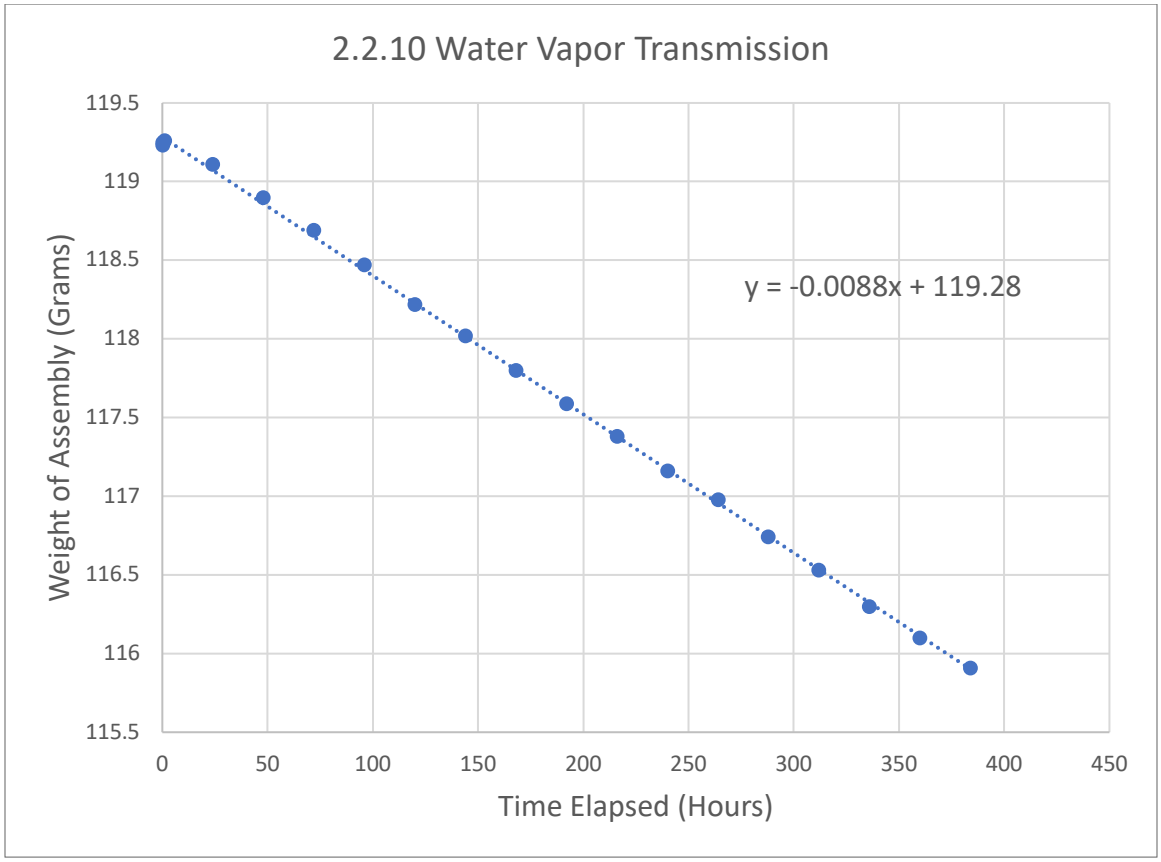

2.1.11 Water Vapor Transmission
y = -0.0071x + 119.01
Weight of Assembly (Grams)
119.5
119
118.5
118
117.5
117
116.5
116
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)


2.2.6 Water Vapor Transmission
y = -0.0085x + 121.72
Weight of Assembly (Grams)
122
121.5
121
120.5
120
119.5
119
118.5
118
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)

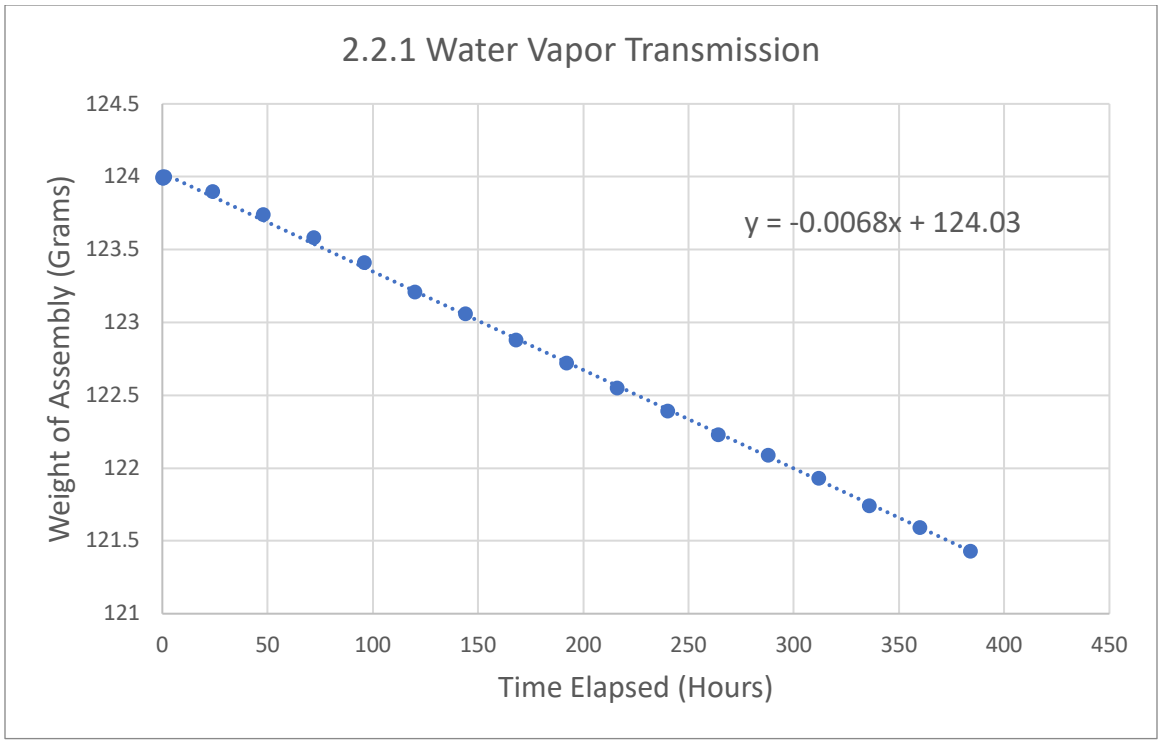

2.2.7 Water Vapor Transmission
Weight of Assembly (Grams)
119.5
119
118.5
118
117.5
117
116.5
116
115.5
115
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)
y = -0.0099x + 118.99

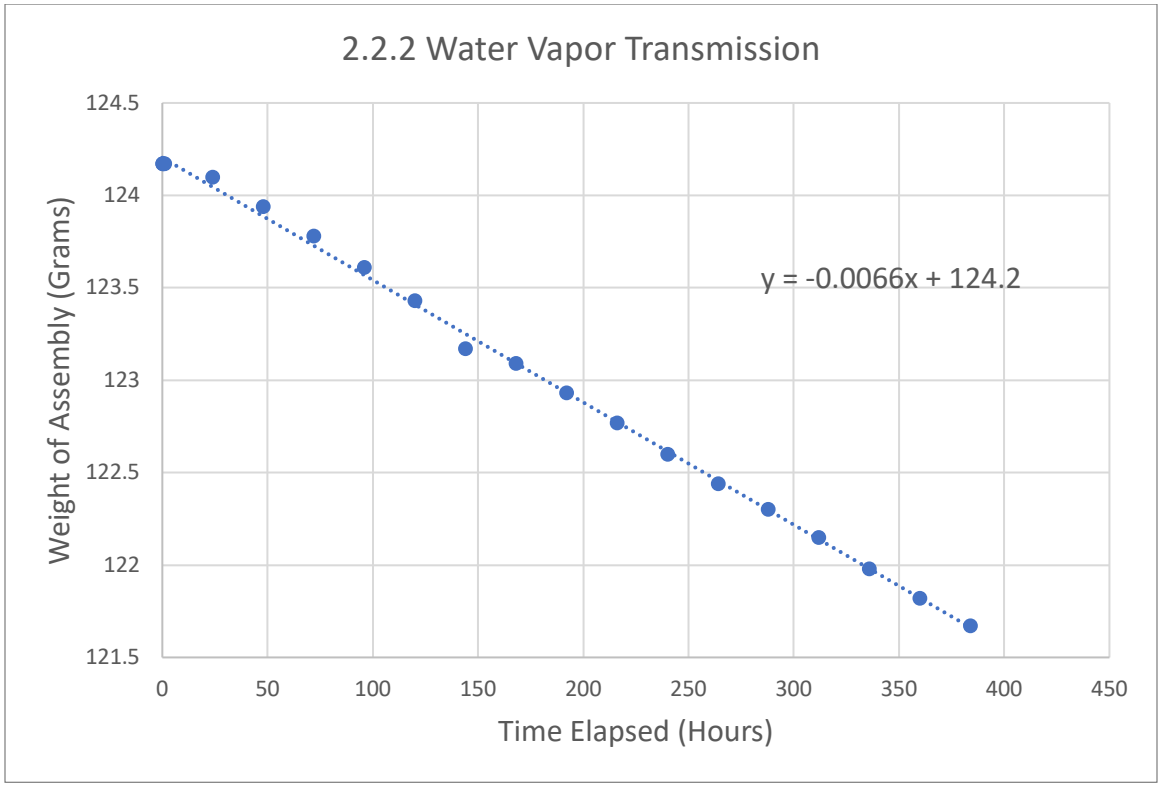

2.2.8 Water Vapor Transmission
Weight of Assembly (Grams)
120.5
120
119.5
119
118.5
118
117.5
117
116.5
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)
y = -0.0084x + 120.03

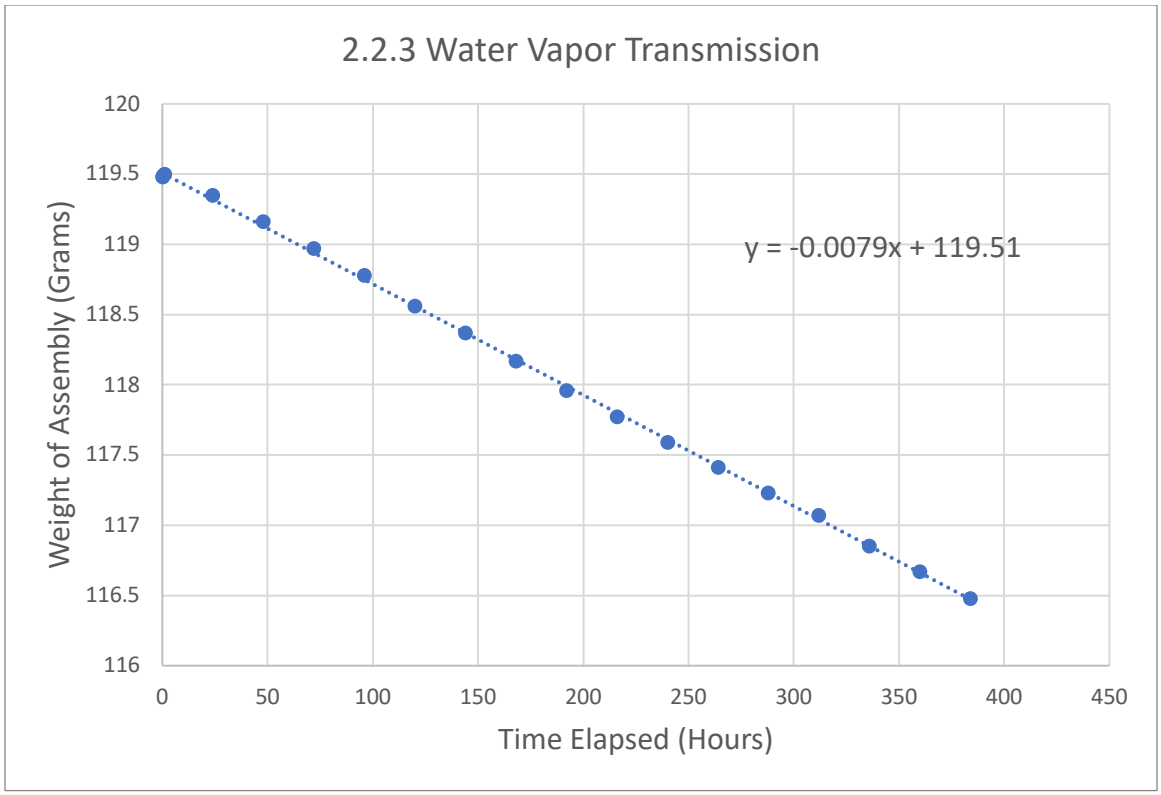

2.2.9 Water Vapor Transmission
Weight of Assembly (Grams)
127
126.5
126
125.5
125
124.5
124
123.5
123
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)
y = -0.0086x + 126.55

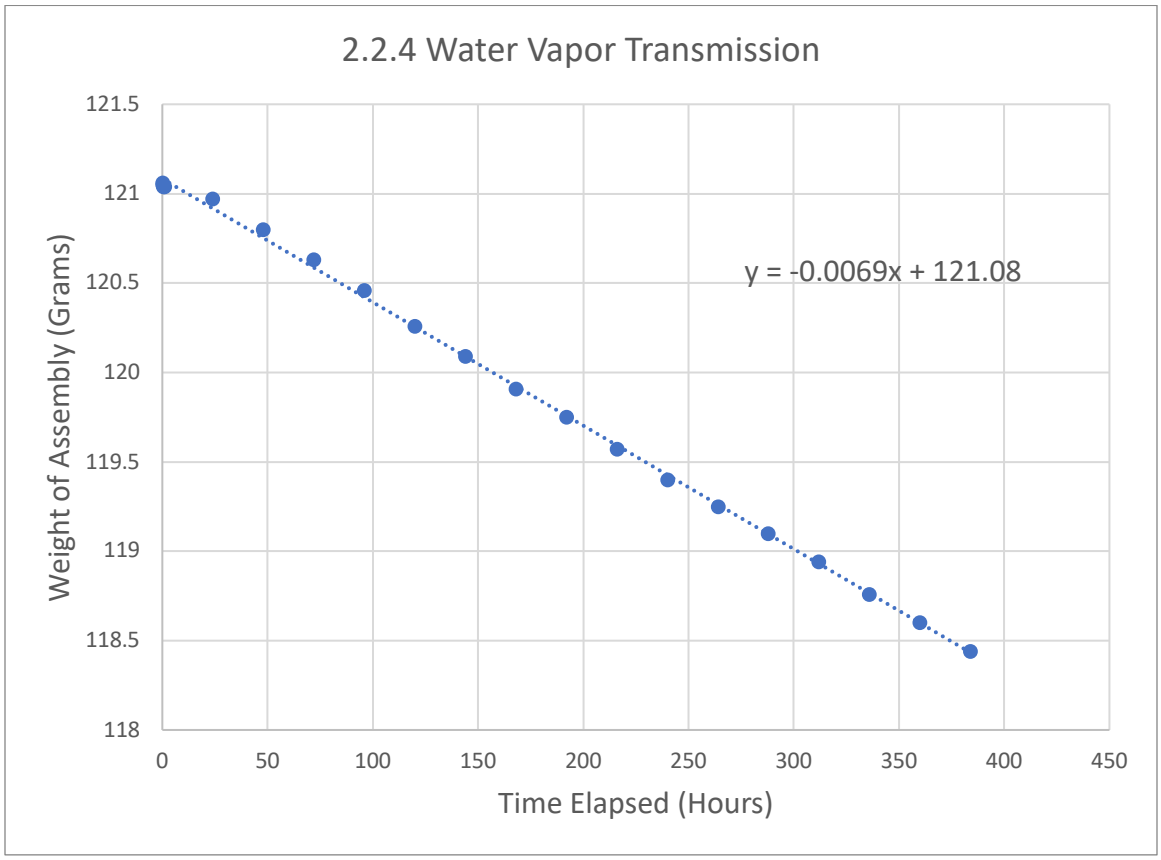

2.2.10 Water Vapor Transmission
Weight of Assembly (Grams)
119.5
119
118.5
118
117.5
117
116.5
116
115.5
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)
y = -0.0088x + 119.28

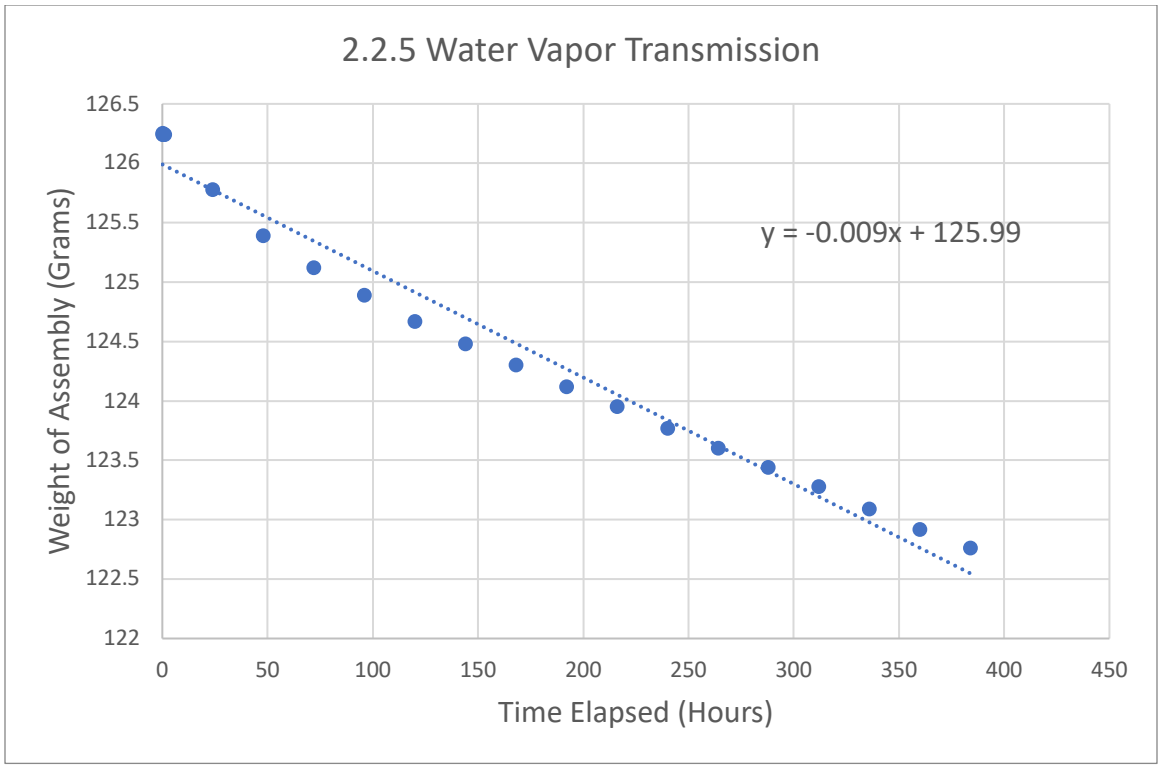
Unpainted Facsimiles										
	Consolidated					Unconsolidated				
	2.2.1	**2.2.2**	**2.2.3**	**2.2.4**	**2.2.5**	**2.2.11**	**2.2.12**	**2.2.13**	**2.2.14**	**2.2.15**
Md	79.95	80.98	72.42	78.05	80.26	77.05	72.43	81.52	78.52	80.7
Mb	10.46	10.48	10.35	10.33	10.25	10.34	10.34	10.34	10.46	10.23
Mbw	40.13	39.89	40.81	40.01	42.03	40.05	41.06	40.4	41	40.19
Ma	123.99	124.16	119.48	121.04	126.25	120.83	116.71	125.68	122.97	123.97
Time Elapsed (hours)	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**	**Weight (g)**
0.083	123.99	124.17	119.48	121.06	126.25	120.84	116.71	125.68	122.97	124
0.25	124	124.17	119.48	121.05	126.24	120.84	116.67	125.68	122.97	124
0.5	123.99	124.17	119.49	121.04	126.24	120.84	116.67	125.68	122.96	124.01
1	124	124.17	119.5	121.04	126.24	120.84	116.67	125.69	122.97	124.01
24	123.9	124.1	119.35	120.97	125.78	120.7	116.5	125.56	122.83	123.88
48	123.74	123.94	119.16	120.8	125.39	120.5	116.28	125.38	122.63	123.69
72	123.58	123.78	118.97	120.63	125.12	120.3	116.07	125.19	122.42	123.49
96	123.41	123.61	118.78	120.46	124.89	120.09	115.84	124.99	122.21	123.29
120	123.21	123.43	118.56	120.26	124.67	119.86	115.59	124.77	121.96	123.07
144	123.06	123.17	118.37	120.09	124.48	119.64	115.37	125.57	121.75	122.88
168	122.88	123.09	118.17	119.91	124.3	119.44	115.15	124.38	121.55	122.68
192	122.72	122.93	117.96	119.75	124.12	119.24	114.94	124.18	121.35	122.49
216	122.55	122.77	117.77	119.57	123.95	119.03	114.72	124	121.14	122.3
240	122.39	122.6	117.59	119.4	123.77	118.83	114.5	123.81	120.94	122.12
264	122.23	122.44	117.41	119.25	123.6	118.64	114.3	123.63	120.75	121.94
288	122.09	122.3	117.23	119.1	123.44	118.45	114.1	123.46	120.56	121.77
312	121.93	122.15	117.07	118.94	123.28	118.26	113.91	123.28	120.38	121.59
336	121.74	121.98	116.85	118.76	123.09	118.04	113.66	123.07	120.15	121.37
360	121.59	121.82	116.67	118.6	122.92	117.85	113.45	122.89	119.95	121.19
384	121.43	121.67	116.48	118.44	122.76	117.66	113.25	122.7	119.76	121.02
WVT (g/(h/cm^2))	0.000340	0.000330	0.000380	0.000345	0.000463	0.000421	0.000459	0.000395	0.000426	0.000391

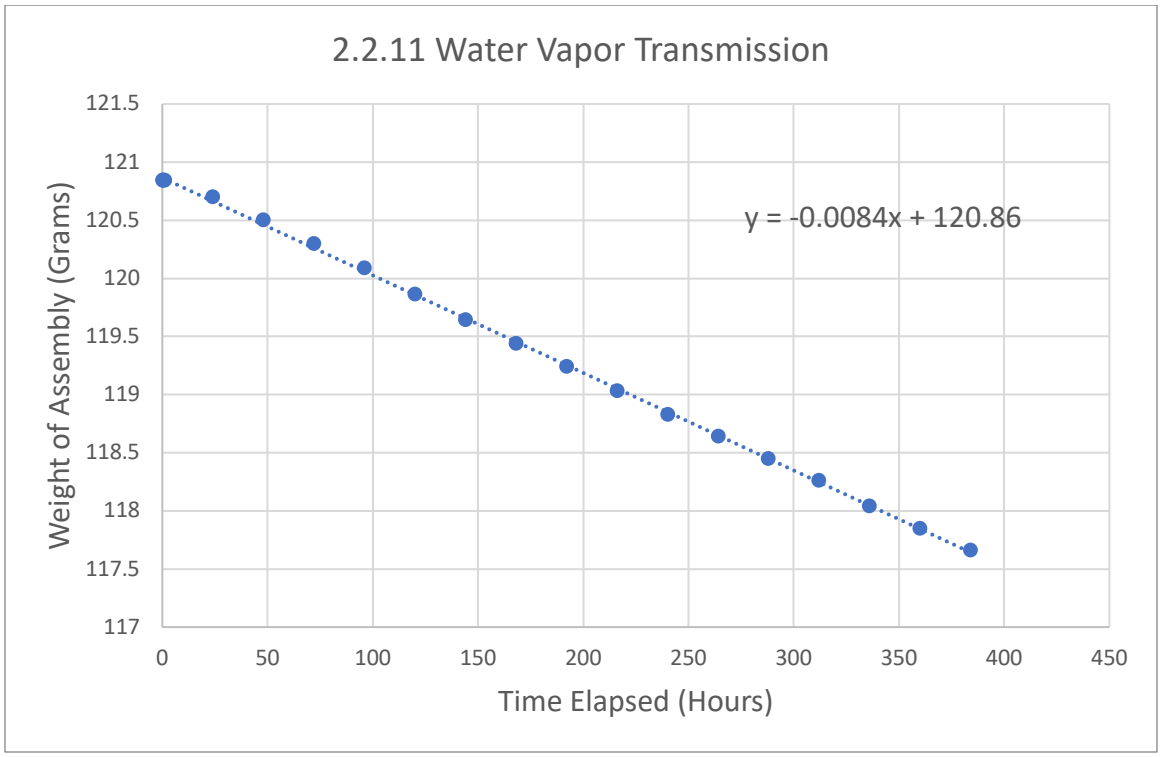

2.2.1 Water Vapor Transmission
y = -0.0068x + 124.03
Weight of Assembly (Grams)
124.5
124
123.5
123
122.5
122
121.5
121
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)

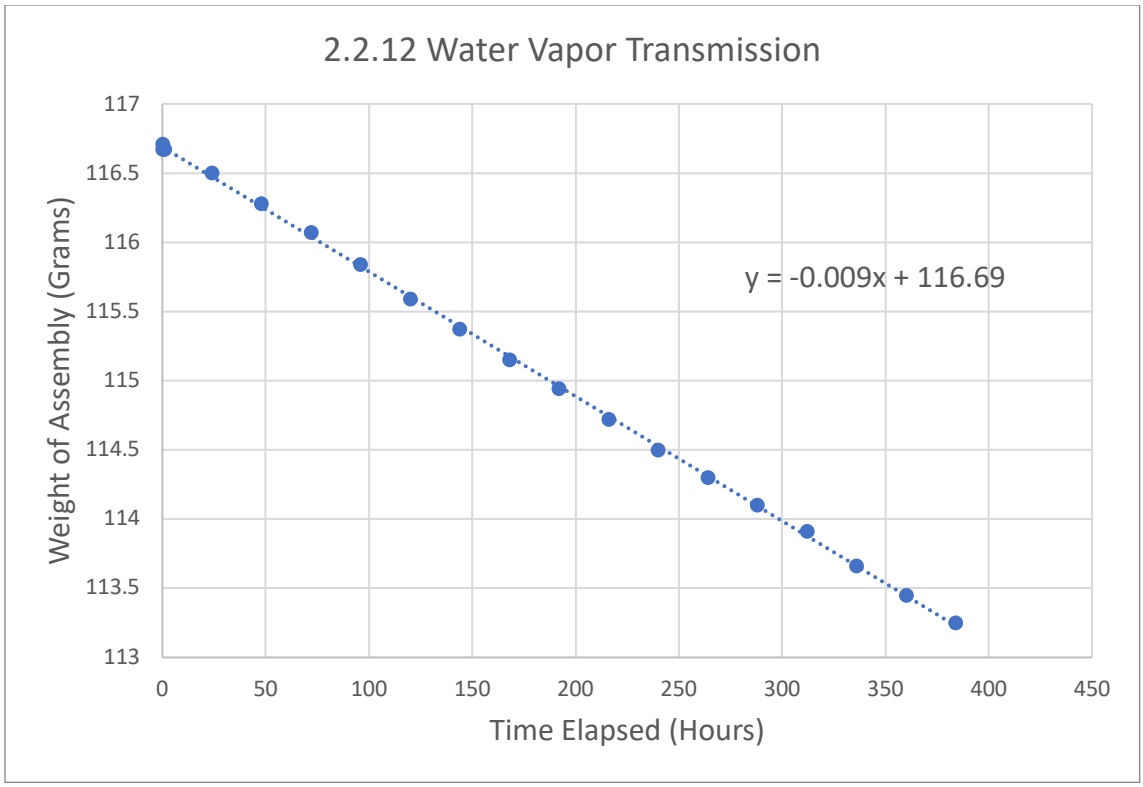

2.2.2 Water Vapor Transmission
y = -0.0066x + 124.2
Weight of Assembly (Grams)
124.5
124
123.5
123
122.5
122
121.5
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)

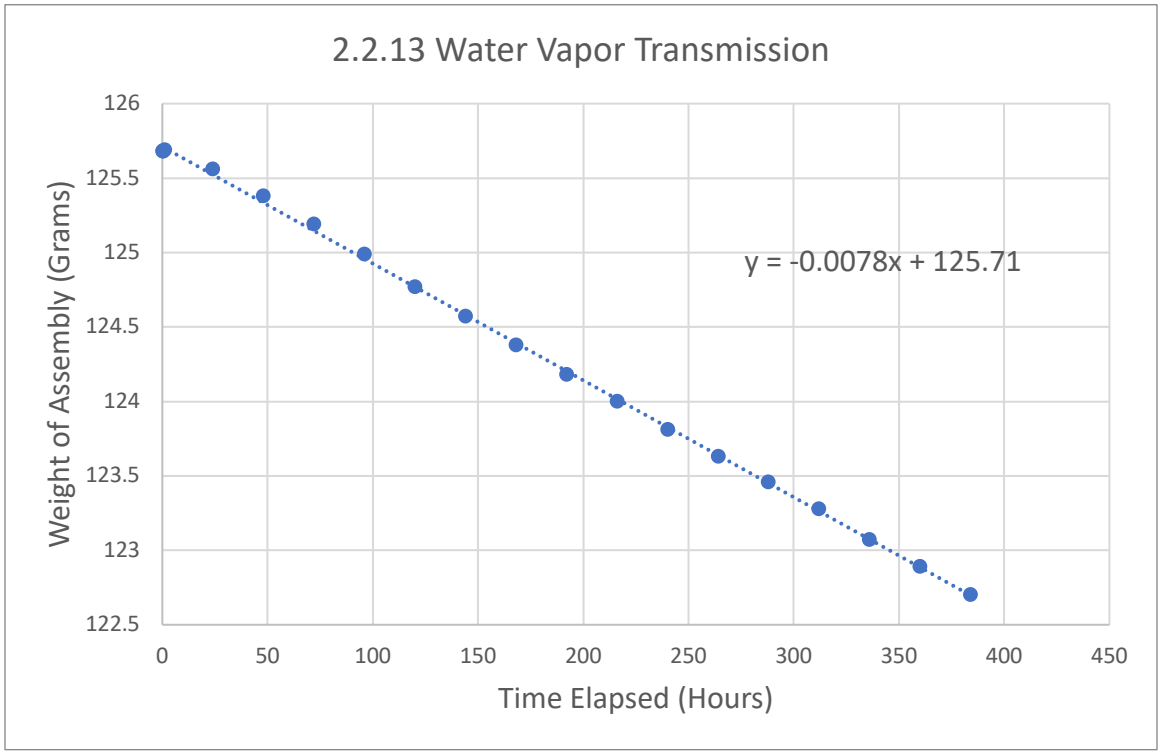

2.2.3 Water Vapor Transmission
y = -0.0079x + 119.51
Weight of Assembly (Grams)
Time Elapsed (Hours)
120
119.5
119
118.5
118
117.5
117
116.5
116
0
50
100
150
200
250
300
350
400
450

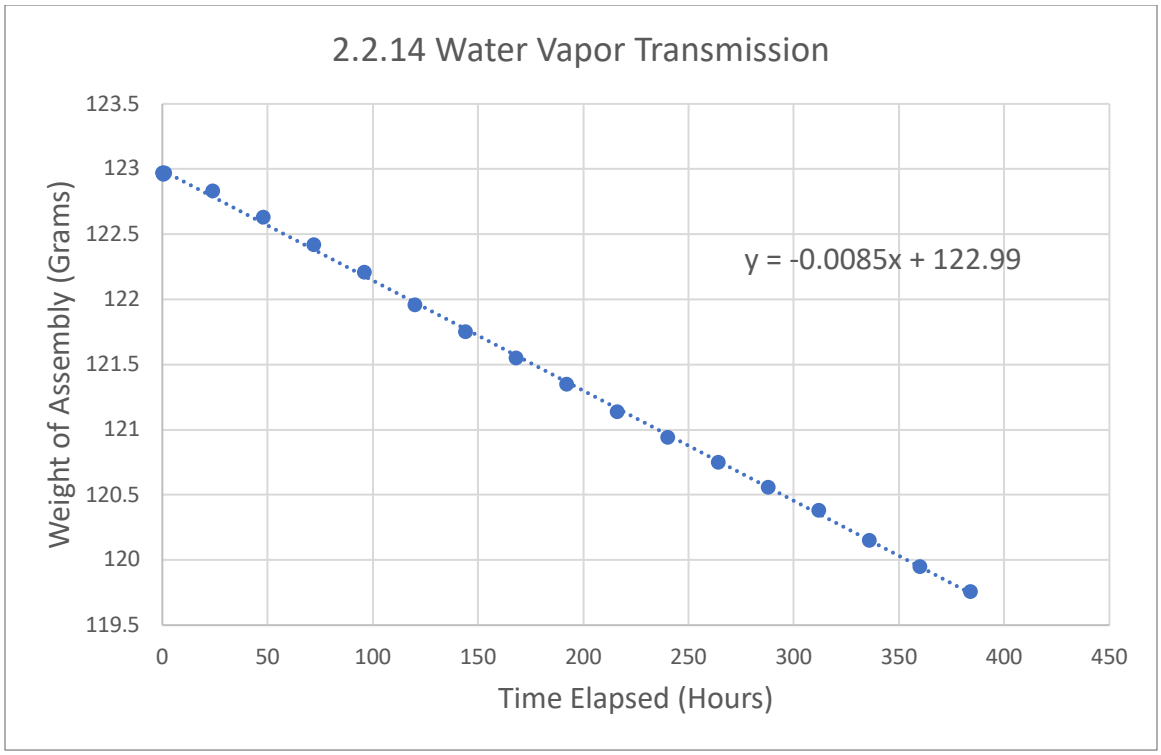

2.2.4 Water Vapor Transmission
y = -0.0069x + 121.08
Weight of Assembly (Grams)
Time Elapsed (Hours)
121.5
121
120.5
120
119.5
119
118.5
118
0
50
100
150
200
250
300
350
400
450

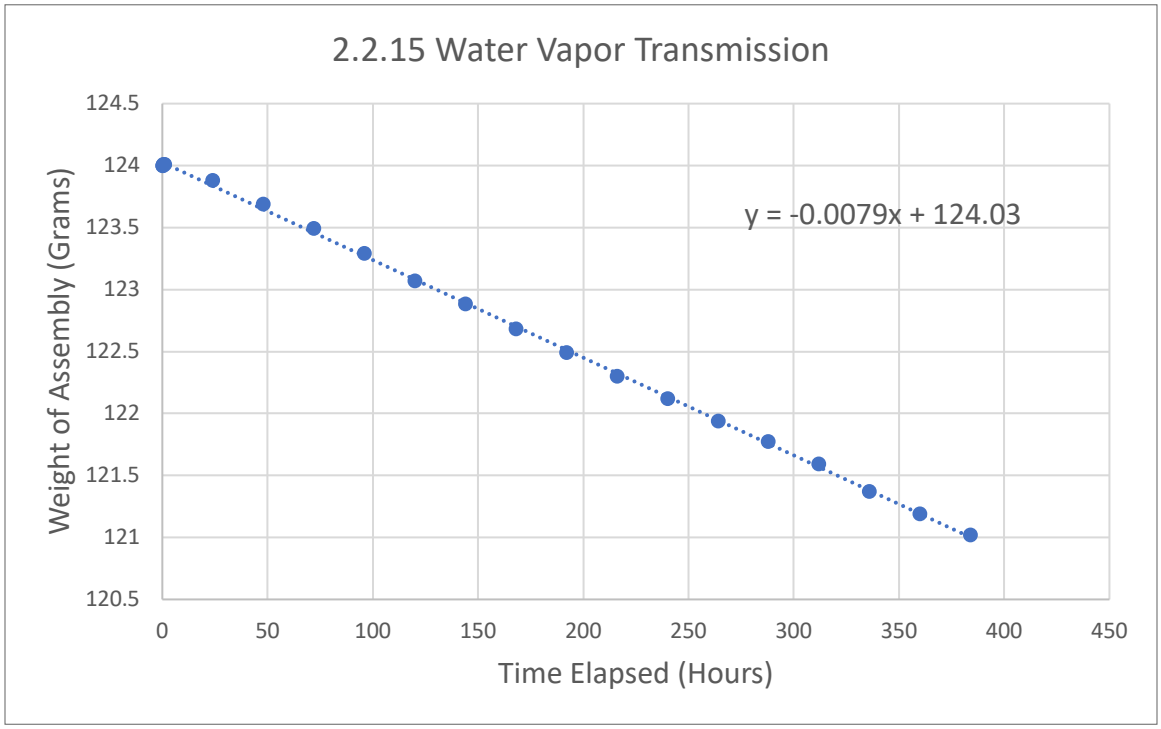

2.2.5 Water Vapor Transmission
y = -0.009x + 125.99
Weight of Assembly (Grams)
126.5
126
125.5
125
124.5
124
123.5
123
122.5
122
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)


2.2.11 Water Vapor Transmission
y = -0.0084x + 120.86
Weight of Assembly (Grams)
121.5
121
120.5
120
119.5
119
118.5
118
117.5
117
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)


2.2.12 Water Vapor Transmission
Weight of Assembly (Grams)
117
116.5
116
115.5
115
114.5
114
113.5
113
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)
y = -0.009x + 116.69


2.2.13 Water Vapor Transmission
Weight of Assembly (Grams)
126
125.5
125
124.5
124
123.5
123
122.5
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)
y = -0.0078x + 125.71


2.2.14 Water Vapor Transmission
Weight of Assembly (Grams)
123.5
123
122.5
122
121.5
121
120.5
120
119.5
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)
y = -0.0085x + 122.99


2.2.15 Water Vapor Transmission
Weight of Assembly (Grams)
124.5
124
123.5
123
122.5
122
121.5
121
120.5
0
50
100
150
200
250
300
350
400
450
Time Elapsed (Hours)
y = -0.0079x + 124.03

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