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An Investigation of the Painted Finishes of Mission San José de Tumacácori's Façade: At the Interface of Materials Analysis, Conservation, and Cultural Confluence

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Abstract

Located near Tucson, Arizona, the Mission San José de Tumacácori is a Spanish-Colonial mission and the primary landmark of significance within the Tumacácori National Historical Park. Begun around 1800 and acquired by the National Park Service as a half-completed ruin in 1916, successive campaigns of repair have stabilized but also obscured much of the original surfaces of its once brilliantly painted church façade.

There are comparatively very few mission structures that have not been repainted or replastered. Initial conservation methodologies at Tumacácori were experimental and would eventually give rise to the use of traditional building materials and methods. However in contrast, between the 1940s and 1970s, synthetic resins and non-traditional treatments were heavily employed. Tumacácori's façade can thus be read as a document in itself - by studying the application of these methods in succession, one can gain a perspective of nearly a century's worth of preservation thinking and insight into the development of architectural conservation in the United States.

This particular investigation of the original polychromatic painted surface finishes of Tumacácori's façade consisted of archival research, historic contextualization, comparative studies, in-situ investigation, and laboratory analysis – encompassing optical microscopy of the surface finish cross-sections and dispersed pigment layer particles, scanning electron microscopy with energy-dispersive X-ray spectroscopy, Raman microscopy, Fourier Transform Infrared Spectroscopy, microchemical testing, and petrographic analysis of the stucco substrate. Ultimately, the analytical findings of this thesis research will be used as the basis for a pilot conservation treatment to preserve these rare and fragile finishes for the future.

Keywords

limewash, polychromy, NPS, plaster, pigments

Disciplines

Architectural Technology | Historic Preservation and Conservation | Structural Materials

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AN INVESTIGATION OF THE PAINTED FINISHES OF MISSION SAN JOSÉ DE TUMACÁCORI'S FAÇADE: AT THE INTERFACE OF MATERIALS ANALYSIS, CONSERVATION, AND CULTURAL CONFLUENCE

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“Yo no estudio para saber más, sino para ignorar menos”
“I do not study to know more, but rather to ignore less”

- Sister Juana Inés de la Cruz, 1651-1695

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Chapter 1 – Introduction

Situated near the Santa Cruz River in Arizona amongst the mesquite trees, the Mission San José de Tumacácori stands proudly as a stabilized Spanish-Colonial mission and the primary landmark of significance within the Tumacácori National Historical Park. The current church configuration, located approximately an hour south of Tucson, was first built upon the lands of the Tohono O'odham (Pima) Native Americans in approximately 1800 and abandoned in 1848.[1] It holds the distinction of being one of the first two monuments of earthen architecture to be designated a National Monument through the 1906 Antiquities Act, and was acquired by the National Park Service as a partially restored ruin in 1916.[2]

Successive campaigns of repair have stabilized but also obscured much of the original surfaces of its once brilliantly painted church façade. With the support of the National Park Service and the Colorado Plateau Cooperative Ecosystems Studies Unit, the following thesis completed through the University of Pennsylvania's Architectural Conservation Laboratory is the result of an in-depth analysis of the original painted, polychromatic surface finishes of the mission façade. The scope of this work encompassed archival research, historic contextualization, comparative studies, in-situ investigation, and laboratory analysis. Technical investigations included optical microscopy of the surface finish cross-sections and isolated pigment layers, scanning electron microscopy with energy-dispersive X-ray spectroscopy, Raman microscopy, Fourier Transform Infrared Spectroscopy, microchemical testing, and petrographic analysis of the stucco substrate.

Through the construction of Spanish missions, the Jesuits, and later the Franciscans, were decidedly influential in shaping the expansion of New Spain during the colonial drive of the Spanish empire, thereby establishing missions through the Sonoran Desert, California, and Arizona.[3] After the Jesuits were expulsed by the Spanish King Carlos III in 1767, the missions were inherited by the Franciscans; however already by that time they were in a period of general decline from several factors including Apache hostility, competing settlers, lack of support from the Spanish government, discontent within the converts, and disease.[4] After 1848, Tumacácori entered a period of general abandonment until the newly created National Park Service accepted responsibility for the site and placed Frank Pinkley to begin a long tenure as site steward in 1918.[5] Pinkley's decision to preserve and interpret Tumácacori as "a stabilized ruin" thus began a long tradition of preservation that would later guide much of the philosophy and history of architectural conservation in the Southwest.[6]

Indeed, Tumacácori's façade can be read as a document in itself that communicates the development of American preservation philosophy for almost 100 years. Originally covered in polychromatic painted lime plaster, significant decorative finishes can be found in protected areas and approximately 155 square feet of historic plaster currently remains on the exterior.[7] Under Pinkley's stewardship, conservation methodologies were experimental and would eventually give rise to the use of traditional building materials and methods as a form of repair. In contrast, between the 1940s and 1970s, synthetic resins and non-traditional treatments of grouts, water repellents, and consolidants were heavily employed.[8] By studying the application of these methods in succession, one can gain a perspective of nearly a century's worth of preservation thinking and insight into the development of architectural conservation and historic preservation in the United States. This analytical work will inform the foundation for a pilot conservation program to conserve the fragile exterior finishes and develop new interpretive content on the design, construction and evolution of the exterior. Furthermore, the project will be highlighted in the National Park Service's centennial in 2016 by examining the conservation history of Tumacácori's celebrated church as an illustration of past and present preservation methodologies and site management.

Figure 1.1: View from the southeast taken February 1946[9]

Figure 1.2: View from the southeast taken during January 2015 field visit

Figure 1.3: 1934 HABS watercolor rendering of original polychromy scheme based upon observations by former Superintendent Frank Pinkley [10]

Thus the Mission San Jose de Tumacácori epitomizes this multifaceted tradition of adaptation and cultural amalgamation not just through its surviving architecture and landscape, but also in its reconfigured continuity through early preservation efforts. Tumacácori was the first example of Spanish-Colonial architecture to be designated a National Monument. As such, its inclusion and early preservation make it unique in the national narrative eventually interpreted and managed by the National Park Service for the general American public. As Trent Elwood Sanford remarked,

> [The Southwest] is a land where the selfless energies of the friars left an indelible impression and where American economic strides of the past hundred years have been amazing but still have not erased the earlier cultures. It is Indian America. It is Spanish America. And it is Anglo-America, with all that is implied by that unsatisfactory, limited term. All were builders of the Southwest.[11]

Indeed, the façade of the Mission San Jose de Tumacácori represents an exemplary case in which architecture, preservation, and conservation technology converge to reveal the complex history of the church and its present condition – ultimately representing the confluence of Native American, Spanish, Mexican, and Euro-American culture, religion, settlement, and politics.

Notes

[1] Jeremy Moss, "Of Adobe, Lime, and Cement: The Preservation History of the San José De Tumacácori Mission Church," *NPS Archeology Program: Research in the Parks*, National Parks Service: U.S. Department of the Interior (2008), Web.
[2] Ibid.
[3] Ibid.
[4] Ibid.
[5] Ibid.
[6] Angelyn Bass and Douglas Porter, "Preliminary Condition Assessment of the Architectural Finishes, South Façade Mission Church at Tumacácori National Historical Park 2013" National Parks Service. (2013).
[7] Bass and Porter, 4.
[8] Moss.
[9] Charlie R. Steen, "MEMORANDUM for the Associate Regional Director," Letter, 5 Mar. 1946, United States Department of the Interior: National Park Service - Region Three, Santa Fe, New Mexico.
[10] "San Jose de Tumacacori (Mission, Ruins)" Survey (photographs, measured drawings, written historical and descriptive data), Historic American Engineering Record, National Park Service, U.S. Department of the Interior, post 1933. From Prints and Photographs Division, Library of Congress (HABS ARIZ,12-TUBA.V,1-).
[11] Trent Elwood Sanford, *The Architecture of the Southwest: Indian, Spanish, American*, (New York: Norton, 1950) Print, pg 5.

Chapter 2 – Historical Context

2.1 – Spanish-Colonial Missions in North America

Keenly felt throughout portions of the United States and Mexico, the robust influence of the Spanish-Colonial empire in North America left an indelible mark upon the urban and cultural fabric of its former territories that is still visible today. Spanning approximately 1535 to 1821, the scope of the Spanish reign in Northern America is bounded by the Pacific Ocean to the west, between the 22^{nd} and 42^{nd} parallels, and generally the 100^{th} meridian and the Gulf of Mexico to the east.[1] While the southern boundary of Northern New Spain is subject to both cultural and political interpretation, it approximately skirts along the borders of the present-day Mexican states of Sinaloa and Nayarit, Durango, through Zacatecas and San Luis Potosí, and Tamaulipas to the Gulf of Mexico.[2] And finally, its northern reach includes portions of present-day California just south of Sonoma, all of Arizona and New Mexico, most of Texas and Florida, as well as parts of the Gulf States.[3]

1.1. Northern New Spain at its furthermost boundaries superimposed on the present Mexican and U.S. states.

Figure 2.1: Map depicting the western portion of the missions established in North America[4]

A variety of forces, encompassing economic, religious, and political, shaped and provided the impetus for the colonization of the New World and those who eventually established the area presented an equal diversity of background. While many originated from Spain and others from Mexico, there were other settlers from areas as far reaching as Ireland

and Italy who could be considered "missionaries, soldiers, explorers, sailors, engineers, bureaucrats, and people of wealth and influence."[5]

Indeed, the effects of Spanish-Colonial contact with the indigenous peoples of Northern American resulted in a unique cultural hybridity and gave rise to a new set of cultural circumstances. Regarding the American Southwest in Trent Elwood Sanford's The Architecture of the Southwest, he boldly remarks that

> No other part of the country has the same human background. Despite the near perfection of the climate and despite the overwhelming beauty of the scenery, it is not the work of nature that gives the Southwest its greatest distinction; it is the influence of man. Its greatest distinction lies then in how it is peopled, how it has been peopled for centuries, and in the marks left by that human occupation.[6]

However despite the incredible growth and impact that resulted from the far flung spread of the Spanish empire, the ripples of the Napoleonic invasion of Spain and concurrent rebellion against Spanish authority in Mexico after 1810 marked the beginning of the decline of the Spanish-Colonial missions.[7] Dispossessed of the royal support that provided the funding necessary to their operation, the remaining missions and communities in California, Arizona, New Mexico, and Texas struggled until finally after the independence of Mexico, in which overarching decrees of secularization effectively saw the age of Spanish-Colonial missions come to a close for most of the mission complexes.[8] Indeed, by 1846 when the United States absorbed these remains from Mexico, "little was left outside New Mexico of the tenuous and remarkable effort to extend Spanish civilization into the extreme north except a few dusty, struggling towns like San Antonio and Los Angeles and the already crumbling remnants of the architecture."[9]

And so despite the steadfast endurance of Spanish-Colonial architectural remnants in all former territories, prior to 1880s there was little interest in the role of the Spanish legacy in shaping the early identity of the United States.[10] It would later take the romantic revivals popularized by leading historians and literary and artistic figures in the late 19th century to shed a spotlight back upon the remarkable achievements wrought by the Spanish-Colonial empire. Indeed, this cultural confluence would find admirers such as Walt Whitman, who upon the 33rd anniversary of the founding of Santa Fe in 1833 noted that "'Spanish character will supply some of the most needed parts' of the future composite national identity based no longer entirely on English origins 'as America, from its many far back sources…entwines [and] faithfully identifies its own.'"[11]

2.2 – The Case of Sonora and Arizona

While Florida, Louisiana, Texas, and New Mexico were all considered distinct jurisdictions of Spain, Spanish Arizona was considered an ancillary portion of Sonora, a colonial administrative unit that composes about two-thirds of the present day Mexican state of the same name.[12] The upper stretch of Sonora was deemed by the founding Jesuit missionary Father Eusebio Kino as the Pimería Alta in 1687, named for the land of the upper Tohono O'odham (Pima) Native Americans; this is the geographic area in which the Tumacácori National Historical Park resides within.[13]

Father Eusebio Kino was "a man of great energy and great hopefulness, an eager evangelist, baptizer of close to four thousand Indians, and a tireless explorer."[14] From the center of Sonora, Jesuit missionaries slowly penetrated northward and around 1686 Father

Kino was sent as the new rector of the Pimería Alta following two years of exploratory work in California.[15] He would spend about 24 years within the Pimería Alta and embark upon over forty expeditions to lay foundations for a string of missions within the Pima area including those now within the Tumacácori National Historical Park and San Xavier del Bac about forty miles away.[16] In one 1691 expedition accompanied by Father Juan María Salvatierra under an arbor constructed by the local Pima tribesmen, Father Kino held the first Christian service to be held in southern Arizona at Tumacácori.[17] Following Father Kino's death in 1711, for twenty years there was only one Jesuit in the whole of the the Santa Cruz Valley who consistently remained in the area, Agustín de Campos, and the missions of Pimería Alta suffered the disadvantages of their remote location from an indeterminate Spanish government and the nearest city center of Mexico City.[18]

Further focus will be devoted upon the subsequent development specific to Tumacácori under the stewardship of the following Franciscan period that lasted until approximately 1820 in "Chapter 3.0 – Development of Mission San José de Tumacácori." Following the second wave of missionary activity and subsequent Franciscan decline, through the Gadsden Purchase of 1853 the northernmost portion of Sonora was annexed and the two aforementioned Arizona missions– "one of the very finest and most complete of all Spanish missions [San Xavier del Bac], and the picturesque ruins of another [Mission San José de Tumacácori]" – became a part of the United States.[19]

Thus in considering the case of the Arizona-Sonora chain of missions, this stands as virtually the only area, save for Baja California, in which the Jesuits had worked.[20] Despite every mission in Arizona to have been plagued by destruction more than twice, the fact that less than half of the recorded twenty missions and *visitas* can be located, and the moniker the "Way of the Martyrs," Prentice Duell in "The Arizona-Sonora Chain of Missions" maintains that in considering this chain "we are considering the finest examples in mission architecture."[21]

2.3 – Spanish-Colonial Mission Architecture

Thus the development of Spanish-Colonial mission complexes between the 15th and 17th centuries serves as an architectural testament to the confluence of cultures wrought by this period of Spanish colonialism and imperialism. Drawing from a diverse foundation of stylistic influences that were imported and then shaped by the new American situation, mission churches are an expression of cultural and geographic diversity spread along Florida, Latin America, and California. Thus while comparisons can be drawn between the collection of architectural remains that comprise the Spanish mission oeuvre, each set is quite characteristic of its specific regional and temporal contexts. According to Trent Elwood,

> It is the only part of the United States where the life and the work, the arts and the crafts, and particularly the architecture – because it is the *only* part that had a permanent, indigenous architecture – of the Indians have left any permanent impression. It is the only part of the country, with the exception of certain remnants in Florida and occasional faint wafts in the French atmospheric breezes of New Orleans, where the effect of Spanish occupation is felt. And in that part of the country the best work of the Americans of today is not without the influence of one or the other, or both, of the two earlier cultures.[22]

Due to the frontier nature of these settlements and use of fugitive materials such as wood and adobe that renders the present remains of Spanish North America as a mere fraction of the mission and urban churches, houses, and forts that once stood, it underscores both the fragility and the importance of that what does survive. The padres did not have a specific architectural program to follow, and the design of these mission buildings were a symbiotic process of their own rich Spanish architectural heritage while also continually adapting and revising to suit the abilities of the Native American laborers.[23] While chronologically within the same construction period of the Spanish-Colonial settlements, the stylistic vogues of Spanish art and architecture within Europe that were seen within more urban centers of Spain and Mexico such as the early Plateresque, Churrigueresque, and Baroque, were not hugely influential in mission architecture.[24] At the core, these structures were frontier buildings, and in most cases the priests were the builders, having "not received the necessary professional training to make them good architects and in attempting to raise to the Glory of God houses of worship in the wilderness they fell into many difficulties."[25]

Despite being crafted of similar materials, resultant architectural variations throughout the missions of the United States and Mexico indicate differing attitudes and treatments of technology, knowledge, and construction corresponding to a mission chain's context. For the purposes of this thesis, some conclusions about regional variations specific to general construction, materials primarily used in wall treatment, and building technology as proposed by James Early in Presidio, Mission, and Pueblo: Spanish Architecture and Urbanism in the Untied States, are transcribed as follows. These conclusions provide the basis for narrowing the field of potential candidates that could pair well with Tumacácori as further, more sustained comparative studies.

Table 2.1: Regional Variations of Mission Construction From *Presidio, Mission, and Pueblo: Spanish Architecture and Urbanism in the United States* (James Early, 2004)				
Region	**Construction**	**Wall Materials**	**Technology**	**Citation**
Florida	-Frameworks of poles filled in with lesser vertical elements -Interwoven with horizontals of willow branches, vines, twigs	-Plastered with clayey earth mixed with Spanish moss -Tabby (concrete from oyster shells) in use in 1580s, known for roofs and a church floor -Concrete roofs as early as late 17th c.	-Quarry of *coquina* stone, poverty and lack of masons delayed its use -Military engineering -Subject to Council of Indies rather than viceroy of New Spain	Early, pg. 9, pg. 212
New Mexico	-Timbers used to support flat earthen roofs -Adobe earthen construction (bricks) -In a few areas unshaped ledge stone, embedded in mud mortar used	-Adobe earthen construction -Mud mortars	-Adobe bricks -Remote, materials and construction was adapted to existing Pueblo techniques -Hardly any artisans available	Early, pg. 8, pg. 212
Texas	-Wooden construction more characteristic in heavily wooded eastern Texas -Shelters (*jacales)* using vertical logs with gaps filled with brush or stones common in central area -Adobe used in more substantial houses -Stone for most luxurious buildings	-Adobe earthen construction -Mud plaster	-Craftsmen from central New Spain brought to region by friars to design and oversee construction of several vaulted stone churches	Early, pg. 9
California & Arizona	-*Jacales* for more common buildings -Adobe for larger houses and most churches -Stone and fired brick rarely used -A few California missions had and have stone facades and walls -San Xavier del Bac is Moorish-looking, decorated oval vaults, fired brick in lime mortar with stone rubble core	-Adobe earthen construction -Stone -Fired brick -Lime plaster -Painted decoration mentioned	-18th c. masons essential for design and construction of vaulted and domed stone churches -Masons in Arizona for Tumacácori and San Xavier del Bac -Major churches in California directed by masons (San Carlos, San Gabriel, San Juan Capistrano, San Luis Rey, Santa Barbara)	Early, pg. 9, pg. 212

2.4 – Comparable Case Study Missions

The stretch and diversity of the Spanish-Colonial mission complexes has been emphasized thus far, which necessitated further research and distillation of a proposed sampling of comparable case study missions. While by no means fully exhaustive, comparative studies offer several lenses in which to begin to situate the polychromatic surface finishes and exterior decoration of the Mission San José de Tumacácori amongst its most appropriate contextual relatives.

Perhaps the most obvious and readily appropriate comparison is that of San Xavier del Bac, the other major mission structure that remains left in Arizona along with Mission San José de Tumacácori. Located approximately forty miles from Tumacácori, San Xavier del Bac was probably begun about 1781 and is a still functioning church whose construction and ornamentation is a decadent contrast to that of Tumacácori.[26] In 1804, Captain José de Zúñiga admiringly describes the church construction of “fired bricks and lime mortar. The ceiling is a series of domes. The interior is adorned with thirty-eight full-figure statues, plus three ‘frame’ statues dressed in cloth garments, and innumerable angels and seraphim. The façade is quite ornate, boasting two towers, one of which is unfinished.”[27] Like Tumacácori, the façade is constructed of fired brick with a stone rubble core and the exterior brick surfaces were all covered in layers of lime plaster.[28] All written descriptive documents, such as that of Captain Zúñiga and Fray Francisco Iturralde, stress the overall sense of effusive decoration and dense ornamentation.[29]

Figure 2.2: Exterior view of San Xavier del Bac, Arizona

Figure 2.2: Detail of San Xavier del Bac façade

Exterior decoration was generally confined to the façade with an interior containing painted and sculptural elements like in Tumacácori. The elaborately sculptural façade's central frontispiece was known to be once multicolored and is now described as being nearly monochromatically brown, while at one time the interior of the dome was painted to resemble Moorish tile.[30] Indeed, "tradition relates that they were done by an artistic monk of the college of Queretáro, who was the pupil of Francisco Eduardo de Tresfuérras, the 'Michael Angelo of Mexico'."[31] Captain José de Zúñiga's 1804 account was particularly extensive, as he was filled with amazement at the prospect that such an intricate building could have existed in such a remote place so that "salaries of the artisans had to be doubled."[32]

Correspondingly, it is known that the Gaona (also spelled Gauna) brothers, a pair of master mason brothers, were responsible for not only San Xavier del Bac's construction and design but also the Mission San José de Tumacácori.[33] While a 1797 inscription of "Pedro Bojorquez" on the door of San Xavier del Bac has led several sources to believe that Bojorquez was the principal architect, Bernard L. Fontana has posited this inscription as mere graffiti in his article "Who Were The Builders and Decorators of Mission San Xavier del Bac?"[34] This is supported by a 1880 document by Bishop Jean B. Salpointe that presented "the principal builders of this church were two brothers by the name of Gauna, who were subsequently employed by the missionaries to build the Church of Tumacácori…" based upon their designation as *maestro albañil* as well as potentially the builders of the mission at Caborca.[35] Indeed, both the Gaona brothers, as well as other artisans employed at San Xavier and potentially Tumacácori, are likely from the present-day region of Querétaro, Mexico; this state's archives could thus be a fertile source of further information regarding the builders, decorators, materials and techniques of those who worked on the Arizona missions.[36]

Other than the trained builders and artisans, the principal laborers were the Pima Native Americans, whose labor was not forced but paid through grain, sugar, and cigarettes.[37] Through this relationship between Spanish artisans and Native American laborers, Father Antonio Barbastro, at one time the Father President of the Pimería Alta missions, remarked in 1793 that,

> During the time that my college [of Holy Cross of Querétaro] has governed these missions they introduced the use of lime mortar and brick with which the Indians were previously unacquainted, and with these materials they raised from the foundations the churches of Pitiqui[to], San Ignacio, Sáric, and Tubutama, always keeping the sword in one hand to fight the enemy and the trowel in the other…[San Xavier del Bac] is the northernmost pueblo of the Christian world and everyone thinks it rivals the most beautiful churches in Mexico. In this country it should be rightly termed 'astounding'.[38]

According to Captain José de Zúñiga's 1804 report, the raw lime referenced may have likely been sourced from "an outcropping of lime which supplies us with all we need whenever we need it for construction" approximately twenty miles from Tucson.[39] This is hypothesized to be the very same place near the northern end of the Tucson Mountains in which the Arizona Portland Cement Company continues to mine lime.[40]

Even in addition to original materials, design, and construction, San Xavier del Bac further provides a rich comparison study to the Mission San José de Tumacácori when considering specific interventions to the exterior painted ornamentation. Indeed, the same earthquakes that severely destabilized Tumacácori also damaged San Xavier del Bac, and in 1906 Bishop Henry Granjon of Tucson replastered the exterior of the church while also making extensive alterations and additions.[41] 1870s photographs of Carleton E. Watkins show the exterior as an almost uniformly reddish-brown with the unfinished east belfry left unplastered, leaving James Early to remark, "the present whiteness and the strong contrast of colors on the façade create an effect never intended by San Xavier's builders, whatever the original colors may have been."[42] This would not be the first time that original painted surface finishes have been completely obscured in the name of preservation, and perhaps the most astonishing alteration made by Bishop Granjon was his choice to subsequently paint the exterior of San Xavier del Bac a dazzling white.[43] This single action emphasizes with urgency that the fact that Tumacácori has never been repainted is utterly remarkable.

Final notable conservation efforts at San Xavier that can be correlated and compared to actions taken at Tumacácori included the application of Daracone to exterior surfaces in 1958 as well as an interior restoration campaign undertaken between 1989 and 1992. An international assemblage of conservators headed by Paul Schwartzbaum, then chief curator of the Guggenhiem Museum in New York, worked at San Xavier for three winter months each year and recruited four Tohono O'odham apprentices to learn conservation practices.[44] Pigments were identified as local earth reds and greens, as well as some imported vermillion and Prussian Blue.[45] With this transmission of knowledge acting as a thread of continuity through history, it was the goal to leave the apprentices with the skills to revive their own cultural heritage.[46]

While San Xavier del Bac clearly makes a compellingly rich point of comparison, other Sonoran missions can also be considered, as some in Mexico may have fared better over the years. In Prentice Duell's multi-installment article, "The Arizona-Sonora Chain of Missions," she notes that generally, the eastern Sonoran group were not rebuilt by Franciscans, while the central and western groups are of the greatest architectural interest.[47] Two in particular, La Misión de Nuestra Señora del Pilar y Santiago de Cocóspera and La Purísima Concepción de Caborca, stand as excellent missions for potential comparative research as both Cocóspera and Caborca exhibit evidence that it was constructed and decorated by the same men who erected San Xavier del Bac.[48] Indeed, La Purísima Concepción de Caborca is considered by Duell as the prototype for San Xavier del Bac and likely done by the same men, however unfortunately the interior decoration has been since whitewashed and completely obscures whatever original decorative finish fabric that could have remained.[49] Furthermore, the village of Caborca boasts as one of their own citizens the great-great grandson of one of the two Gaona brothers as Duell laments, "one cannot help but wonder if the plans of missions themselves are not mouldering behind the dusty tomes in a library of some Mexican cathedral. A story goes that copies of the plans were retained in Mexico, probably with the Vicar-General or at the colleges from which the various groups of padres emanated."[50] All of the aforementioned Mexican sources of archival material could provide further clues as to the construction and corresponding context of the building technology, materials, and surface finish techniques found at Mission San José de Tumacácori.

Some monuments of comparison that could be further explored are presented for the stabilization actions taken after having been absorbed into the National Park Service system, echoing the same post-NPS history of Tumacácori. It would be remiss to not mention Casa Grande Ruins National Monument in Arizona, for while it is not a mission site, it and Tumacácori were designated National Monuments to be under the stewardship of

Superintendent Frank Pinkley at about the same time – the first two monuments of earthen architecture to be designated. Accordingly, written evidence confirm that much of what was tried in terms of stabilization efforts at Casa Grande would later be attempted at Tumacácori.[51] Thus a comparative study of NPS preservation efforts, successes, and missteps taken at both sites, such as those for the Hohokam Murals wall art at the Clan House of Casa Grande alongside the Tumacácori exterior painted finishes, may prove fruitful.[52]

Final monuments of appropriate comparison that follow this similar logic of correlating their post-NPS treatment are the mission complexes of San Estevan del Rey at Acoma Pueblo in New Mexico, as well as Missions San Miguel and Santa Inés in California. San Estevan del Rey at Acoma stands as a structure that is, like Tumacácori, substantially intact as well as substantially rebuilt. As Kate Wingert-Playdon notes, "these conditions can coexist in a structure, both contributing fully to its authenticity."[53] The extensive preservation and restoration work that was undertaken in the 1920s as a collaboration with the Pueblo of Acoma and Society for Preservation and Restoration of New Mexico Mission Churches was sensitively considered as an active process with both the materials and treatment as a living testament to community participation.[54] Like Tumacácori, this shaping of the mission as a place of collective memory is similarly illustrated by its exterior plasterwork as "time is marked through preference for materials, reuse at different moments, and more generally an approach that would indicate experimentation."[55]

Consequently, the interface of cultural collaboration and the influence of the Native Americans cannot be underestimated in any of these sites, as Edith Webb proposes that in the Missions of San Miguel and Santa Inés sufficient finishes for a study of the pigments used by the California mission Native Americans may still be found.[56] Furthermore, she remarks that apart from the considerable degree of exterior ornamentation at Missions Santa Clara, La Purísma Concepción, Santa Inés, and San Fernando, that the Fathers' residences were similarly adorned with color.[57] These observations provide yet another avenue of potential research to try to further determine the original polychromy scheme of Tumacácori, as Webb concludes that, "indeed the Padres' house at San Fernando was so gaily decorated on the exterior that one visitor thought that the work had been done in preparation for a fiesta. And who knows? Perhaps it had. The Indians loved color and they used it lavishly."[58]

Notes

[1] Gloria Fraser Giffords, *Sanctuaries of Earth, Stone, and Light: The Churches of Northern New Spain, 1530-1821* (Tucson: U of Arizona, 2007) Print, pg 1.
[2] Giffords, 1.
[3] Rexford Newcomb, *Spanish-Colonial Architecture in the United States*, (New York City: J.J. Augustin, 1937) Print.
[4] Giffords, 1.
[5] James Early, *Presidio, Mission, and Pueblo: Spanish Architecture and Urbanism in the United States* (Dallas: Southern Methodist UP, 2004) Print, pg 1.
[6] Trent Elwood Sanford, *The Architecture of the Southwest: Indian, Spanish, American*, (New York: Norton, 1950) Print, pg 3.
[7] Early, 10.
[8] Ibid.
[9] Ibid.
[10] Early, 1.
[11] Ibid.
[12] Early, 137.
[13] Ibid.
[14] Ibid.
[15] Sanford, 174.
[16] Early, 137.
[17] Sanford, 175.
[18] Early, 138.
[19] Sanford, 172.

[20] Prentice Duell, "The Arizona-Sonora Chain of Missions" *Architect and Engineer* 64-67 (1921): Web, pg 63.
[21] Duell, 63.
[22] Sanford, 3.
[23] Duell, 63.
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[27] Early, 144.
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[29] Ibid.
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[31] Duell, 71.
[32] Early, 145.
[33] Bernard Fontana, "Who Were The Builders and Decorators of Mission San Xavier del Bac?" *Kiva* Vol. 61, No. 4, Maney Publishing (Summer, 1996): Web, pg 381.
[34] Fontana, 381.
[35] Ibid.
[36] Ibid.
[37] Fontana, 370.
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[40] Ibid.
[41] Early, 152.
[42] Ibid.
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[44] Early, 153.
[45] Ibid.
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[48] Duell, 68.
[49] Duell, 74.
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[51] A. Berle Clemensen, *A Centennial History of the First Prehistoric Reserve, 1892-1992: Administrative History, Casa Grande Ruins National Monument, Arizona*, (Denver, CO: U.S. Dept. of the Interior/National Park Service, 1992) Print.
[52] John M. Andresen, "Hohokam Murals at the Clan House, Casa Grande Ruins National Monument" *Kiva* Vol. 48, No. 4, Maney Publishing (Summer, 1983): Web.
[53] Kate Wingert-Playdon, *John Gaw Meem at Acoma: The Restoration of San Esteban Del Rey Mission* (Albuquerque: U of New Mexico, 2012) Print, pg 2
[54] Wingert-Playdon, 4.
[55] Wingert-Playdon, 6.
[56] Edith Webb, "Pigments Used by the Mission Indians of California" *The Americas* Vol. 2, No. 2, Academy of American Franciscan History (Oct., 1945): Web, pg 144.
[57] Ibid.
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Chapter 3 – Development of Mission San José de Tumacácori

3.1 – Site Description

The site of Mission San José de Tumacácori is within the boundaries of Tumacácori National Historical Park in Arizona. Located approximately 52 miles south of Tucson and just 20 miles north of Nogales, Mexico, it includes the mission sites of Mission San José de Tumacácori, Mission San Cayetano de Calabazas, and Mission Los Santos Ángeles de Guevavi. The entire park complex spans 360 acres of a one mile stretch of the Santa Cruz River Valley upon the lands of the Tohono O'odham indigenous peoples (named the Pima by the Spanish) whose geographic reach was subsequently dubbed the Pimería Alta, or upper land of the Pimas.[1]

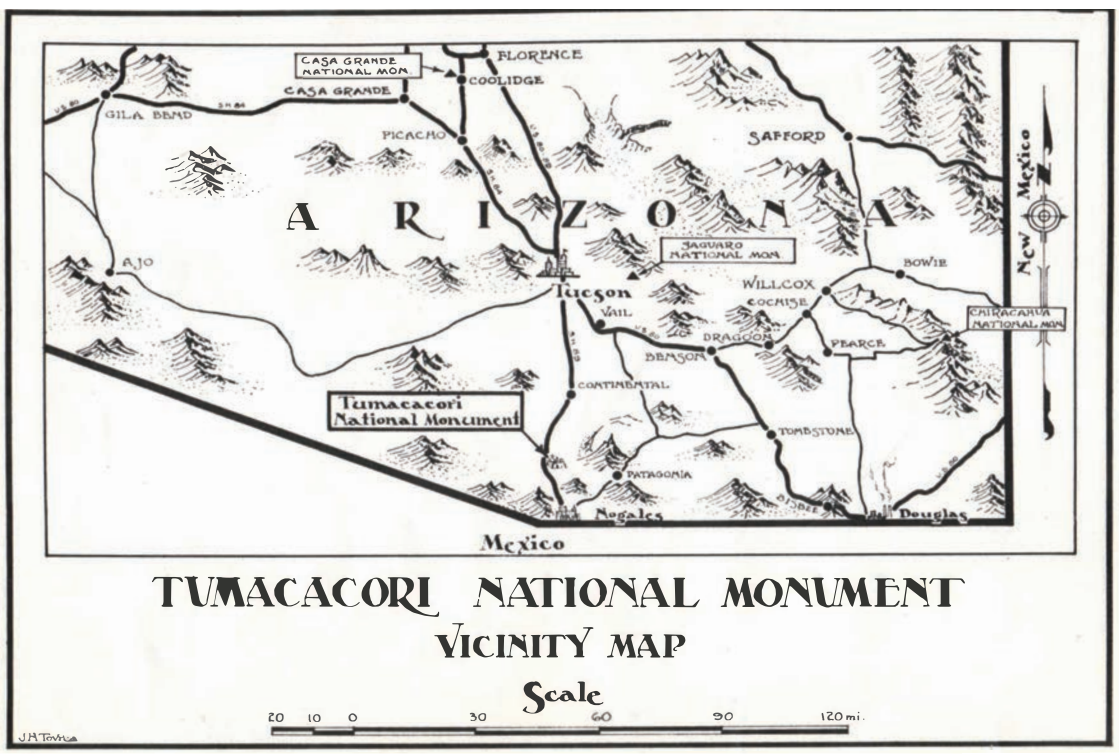

Figure 3.1: Hand drawn map by Tovrea depicting vicinity of Tumacácori[2]

The area is characterized under ASHRAE Climate Zone 3B (Dry).[3] The following climate data benefits from the presence of a weather station (Network ID: GHCND: USC00028865) located at the site itself, with a latitude of 31.5677°, longitude of -111.0497°, and elevation of 995.8 meters[4]

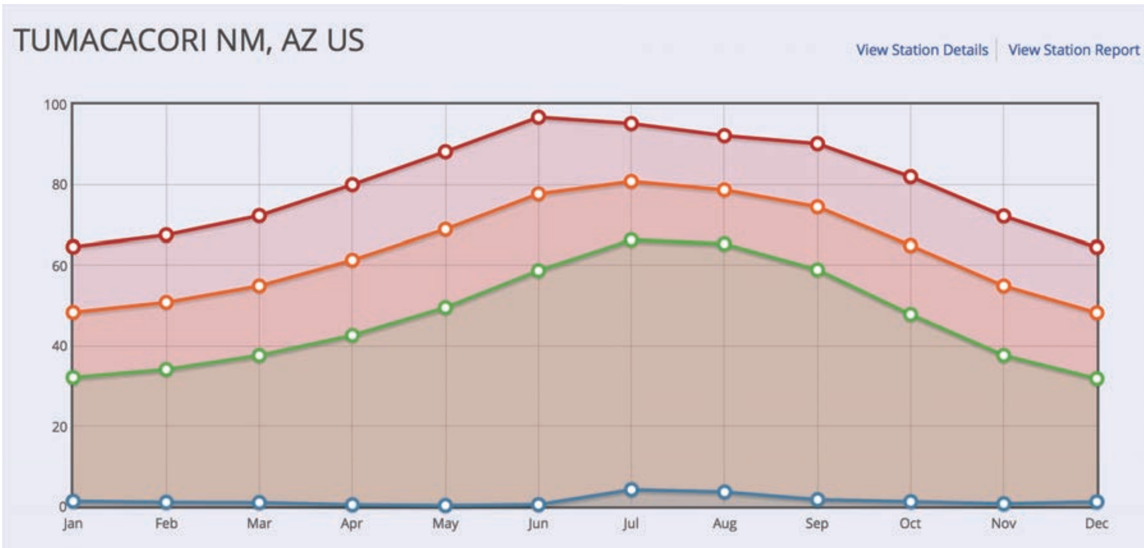

Figure 3.2: ASHRAE climate data graph depicting monthly averages[5]

MONTH	PRECIP (IN)	MIN TMP (°F)	AVG TMP (°F)	MAX TMP (°F)
01	1.27	32.1	48.3	64.6
02	1.01	34.1	50.8	67.5
03	0.94	37.6	54.9	72.3
04	0.39	42.6	61.3	80.0
05	0.23	49.5	68.9	88.2
06	0.43	58.7	77.7	96.8
07	4.14	66.3	80.8	95.2
08	3.56	65.3	78.7	92.2
09	1.66	58.9	74.5	90.2
10	1.16	47.8	64.9	82.0
11	0.65	37.6	54.9	72.2
12	1.12	31.8	48.2	64.5

Figure 3.3: ASHRAE climate data depicting monthly averages[6]

TUMACACORI NM, AZ US

View Station Details | View Station Report

SEASON	PRECIP (IN)	MIN TMP (°F)	AVG TMP (°F)	MAX TMP (°F)
Annual	16.56	46.9	63.7	80.5
Winter	3.40	32.6	49.0	65.5
Summer	8.13	63.5	79.1	94.7
Spring	1.56	43.2	61.7	80.2
Autumn	3.47	48.1	64.8	81.5

Figure 3.4: ASHRAE climate data depicting annual averages

Apart from the basic logistical data of Tumacácori's geography and climate, what subsequently follows is a brief discussion of the development of Tumacácori as a site with particular attention given to any construction details that highlight the exterior walls, plaster, and painted finishes. The following history is therefore by no means fully exhaustive, as several versions of Historic Structures Reports have previously detailed the storied legacy of Tumacácori's history. Particularly salient documents include Frank Pinkley's "Tumacacori National Monument: Visitors Handbook" (1928), James Ivey's "Historic Structure Report: Tumacácori, Calabazas, and Guevavi Units, Tumacácori National Historical Park, Arizona – History Data Section", H.E. Rensch's Chronology for Tumacacori National Monument With Bibliography, and successive drafts of the Tumacacori Historic Structures Report.

3.2 – 1691-1767: The Initial Jesuit Period

While the mission churches of Arizona and northern Sonora that lie along the 75 mile chain of the Pimería Alta are Franciscan constructions of a later time period, the Jesuit missionary Father Eusebio Kino was the one who initially paved the way with his first visit and establishment of Mission San Cayetano de Tumacácori in 1691.[7] The other structures, Mission

San Cayetano de Calabazas and Mission Los Santos Ángeles de Guevavi, were the first two mission buildings and two oldest missions in Arizona on the land now known as Tumacácori National Historical Park.[8]

Ignaz Pfefferkorn described the Jesuit churches as sun-dried adobe constructions with ceilings which "were not arched but instead were flat, constructed with logs. In contrast to this simplicity of construction…[they] were decorated with beautiful altars, [carved] images, paintings, and other ornaments."[9] Over the decades, the church furnishings increased although they were still comparatively quite modest, as 1737 inventories indicate only one painting for each church.[10] Francisco or "El Pintor," a Native American artisan from the Baja Pimería is documented to have worked for Father Kino. [11]

When the Tubac presidio was established in 1753 in response to a Pima revolt two years prior, Mission San Cayetano de Tumacácori was moved to the west side of the Santa Cruz River and reestablished as Mission San José de Tumacácori.[12] The modestly built church measuring approximately sixty by twenty feet was overseen by the Jesuit Francisco Xavier Paner (originally Bauer) and constructed of adobe with a viga-supported flat earthen roof; this mission would be used for 65 years.[13] However, soon thereafter in 1767 the Jesuits were unceremoniously expelled from New Spain and Franciscan missionaries were subsequently assigned as replacements for the Jesuits.[14]

3.3 – 1767-1848: The Franciscan Period of Reconstruction

The first Franciscans present in Arizona were Juan Crisóstoma Gil de Bernabé at Guevavi and Francisco Garcés at San Xavier del Bac.[15] As with many other mission sites in the

Sonoran desert, the Franciscans inherited the Jesuit lands and often rebuilt larger, more elaborate churches upon the Jesuit foundations.[16] Sometime within three years of Father Gil's arrival in 1768, he decided to shift mission headquarters from Guevavi to Tumacácori.[17] By 1773, both the villages of Sonoita and Guevavi were left abandoned and Franciscans found their missionary work while constantly under threat by Apaches equally as difficult as the Jesuits.[18] Fray Bartolemé Ximenez, wearily lamented, "As long as the government fails to provide more, prompt, active, and efficacious methods to contain the Apaches not only will the missions not be advanced…but…even what is already conquered will be lost…All that will be said is here, was Troy, over there once stood a mission called Tumacácori."[19]

Between 1783 and 1797 the Franciscan effort saw the rebuilding of San Xavier del Bac upon the foundations of Father Kino's simple 1700 adobe church.[20] At Tumacácori, construction for a grand new mission church nearly twice the size of the existing one began in 1801 with Fray Narcisco Gutiérrez's hiring of a stonemason, likely the Gaona brothers, to design a church to be the replacement for Mission San Cayetano de Tumacácori.[21] The original plans of Mission San José de Tumacácori were meant to be much more grandiose and inspired by San Xavier del Bac, with a dome of fired bricks over its crossing and barrel vaults of fired bricks over the nave, transepts, sanctuary, and sacristy.[22] However funds ran out in just a year when the foundations had only been completed to a height of two feet, and before passing away in 1820 Father Gutiérrez left the constructed foundations of Mission San José de Tumacácori at a height of seven feet.[23]

In 1821 Bishop Bernardo del Espíritu Santo of Sonora visited the half-constructed church and Fray Juan Bautista Estelric signed a contract to acquire the funding necessary for construction completion.[24] The original 1801 plans were reduced in order to allow for completion within the newly bolstered budget and Father Estelric hired Maestro Félix Antonio Bustamente of Sombrerete, Zacatecas.[25] Six months of construction by Bustamente and his crew successfully completed a dome over the baptistery in the bell tower alongside the façade, closed the transepts, and built the walls up to a height of fourteen feet.[26] Additional *pesos* were required for over 150 workdays of the crew, scoped to encompass building scaffolding, producing 7,000 sun-dried adobe bricks and 3,100 fired adobe bricks, and making lime for mortar.[27] After Fray Ramón Liberos decided upon further reductions in design such as the replacement of the nave barrel vault with a flat roof and removing the crossing dome, the Mission San José de Tumacácori was nearly taken to completion until the 1848 Apache raid on Tubac.

Just two months before the Apache invasion an American soldier documented his surprise upon discovering the nearly completed Mission San José de Tumacácori, as “a very large and fine church standing in the midst of a few common conical Indian huts, made of bushes [and] thatched with grass” where “no priest has been in attendance for many years, though all its images, pictures, figures remain unmolested, and in good keeping”[28] However after the attack, the parisioners of Tumacácori removed the *santo*s and paintings, stripping the church of anything easily transported and of value, and stashed them at San Xavier del Bac; by December of 1848, the last of the residents and workers that had remained at Tumacácori abandoned the unfinished mission.[29]

Besides the mission church proper, the remainder of the abandoned Franciscan mission complex at Tumacácori include preserved *convento* rooms, buried room block, *campo* *santo* (cemetery), mortuary chapel, *acequia madre* and other irrigation features, lime kiln, 4.6 acres of former orchards and gardens, and potentially other buried structures.[30]

3.4 – Neglect and Decline

While the Mission San José de Tumacácori lay abandoned, the church was utilized as quarries for building materials, stables, and barracks.[31] By 1849, damage to the roof was noted although much of the interior remained intact, but by 1858 the roof had collapsed.[32] Between 1886 and 1889 the final roof beams fell, and in 1887 there was a registered 7.4 magnitude earthquake that did significant damage to the already incredibly destabilized structure, including damage to the weakened pediment, choir loft, and west wall.[33] However despite the collapse of the roof and intense weathering by rain and wind, perhaps the most damaging to the structure was the persistence of treasure hunters and vandals from the late 19th century to mid 20th century.[34]

3.5 – The Role of Federal Funding and the Establishment of a National Monument

A modicum of relief finally came to Mission San José de Tumacácori in the passage of the seminal 1906 piece of legislation "An Act for Preservation of American Antiquities", more commonly known as the Antiquities Act of 1906.[35] While modern attitudes towards the remains of these Spanish-Colonial missions are now affectionate and meticulous, the attitude was markedly different in the middle of the 19th century when the United States absorbed nearly one hundred decaying and already abandoned mission churches.[36] However, with the passage of the Antiquities Act, national monuments could thereby be designated by executive proclamation – in effect, allowing for the designation of historically significant structures in an entirely different manner.[37] This piece of legislation would become a cornerstone in preservation, and without it many areas of cultural significance would have likely been destroyed if they had to slog through the previously existing lengthy bureaucratic process.[38]

Thus in 1908, President Theodore Roosevelt leveraged the power of the Antiquities Act to elevate Mission San José de Tumacácori to a National Monument, joining Casa Grande National Monument as the first structures of the notoriously fragile earthen architecture to be designated.[39] Citing the "local awareness of the church's significance, interest in old buildings, and concerns over the looting of antiquities," Tumacácori's designation found support with James Wilson, Secretary of the Department of Agriculture, who wrote in 1908 that, "the old Tumacácori is of sufficient historical interest to warrant its protection from all unseemly exploitation by the creation of a National Monument."[40]

The remarkable beginnings of the National Park Service system demonstrate the changing values of American preservation and the propagation of the tenets of preservation from a mere few to a more commonly accepted social objective.[41] When considering the archaeological sites in the Southwest, the importance placed upon them are very much a product of the given time period. In contrast to other regional approaches to preservation – New England was home to stringent private organizations, the middle Atlantic considered slightly broader categorizations, and the South tended toward designating based upon associations with famous individuals[42] – the interest in the Southwestern sites was of the following as presented by Hal Rothman:

> the awakening to the idea that Americans could exhaust the natural attributes of the continent, xenophobia that held that the American West had natural and cultural attributes as spectacular as those of Europe, and the Progressive-

> era desire for scientific management and centralized authority over the resources of the nation.[43]

This provided a highly appropriate illustration of the changing values of preservation within the United States. The fact that sites such as the Mission San José de Tumacácori, a highly diverse site of cultural interplay between Native Americans, Spaniards, and Mexicans, were considered as a worthy part of the narrative of what constitutes American significance exemplifies how the establishment of these Southwestern monuments allowed for the consideration of a multifaceted view of a richly diverse American past.[44]

However, despite this momentous shift towards an advocacy for historic preservation, challenges remained – particularly at sites like Tumacácori – for the fledgling National Park Service, whose priority with limited resources and a massive area of administration was upon the national parks rather than the national monuments.[45] Indeed, "during the late 1910s and early 1920s, political realities and the views of the leaders of the NPS made national monuments into second-class areas," necessitating the leadership of someone with unique vision, gumption, and passion.[46]

3.6 – The Influence of Superintendent Frank Pinkley

Upon the National Park Service acquiring Mission San José de Tumacácori in 1918, funding toward the necessary stabilization of the ruins that had been left mid-construction was severely limited.[47] Frank Pinkley, the first Custodian of Casa Grande Ruins, would eventually absorb responsibility for not just Casa Grande and Tumacácori, but all of the Southwestern National Monuments as future Superintendent.[48]

A legend within the National Park Service, Superintendent Pinkley fervently advocated for the preservation and stabilization of Southwestern sites. Working within a disproportionally limited budget, "protection, development, and publicity were Pinkley's main concern."[49] Indeed, in the shadow of the attempts to draw tourists to the national parks, there were many obstacles to provide consistent and quality maintenance and stabilization to the national monuments – while most custodial attention was adequate to good, there was no one who could match Pinkley's degree of care on a full-time basis.[50]

Superintendent Pinkley's level of advocacy was unmatched, and his efforts that began at Casa Grande and Tumacácori were absolutely essential in making the American public aware of not only the history and culture of the Southwest but also the necessity for its maintained preservation.[51] He had no qualms about alerting those in Washington D.C., to the dire state of the decaying ruins of national monuments as he pointedly wrote in 1920 "it makes me sad to see a prehistoric monument…gradually distintegrating and to know that many other of our 24 monuments are in like condition, all for a lack of a few thousand dollars a year."[52] By 1923 the need for a more localized regional authority was growing increasingly apparent – Washington, D.C. was simply too far to effectively administer and care for the breadth and quantity of national monuments when they were considered slightly anomalous annoyances in comparison to their vision of grandiose parks.[53]

As a known innovator who did not shy from a challenge, he was the natural candidate to take on the role and in October of 1923 Frank Pinkley became the Superintendent of the fourteen Southwestern national monuments within the Park Service's jurisdiction.[54] Pinkley's vision for the monuments saw them as one day working together as a cohesive system, rather than as discrete, isolated entities.[55]

Remarkably, Pinkley's efforts, infectious enthusiasm, and invested professionalism were able to gradually improve the state of the Southwestern group of national monuments after their subjection to institutionalized neglect.[56] Time-honored tenets of historic preservation such as the preference for locally sourced materials and community involvement are considered purposeful objectives nowadays, however Pinkley had to utilize these values out of necessity as his requests for funding often went unfulfilled.[57] The vast discrepancy between administrative funding and challenges that Pinkley regularly faced were starkly apparent: for example, in 1927 the budget of Mount McKinley National Park in Alaska was approximately equivalent to the budget of the entire Southwestern monuments category.[58] Indeed, for less amount than the $18,700 spent at McKinley for 651 visitors, Superintendent Pinkley was intended to grapple with a total of 270,000 visitors at eighteen different Southwestern sites.[59]

The battle for budget and development at sites such as Tumacácori would continue until his death. A leading proponent of educational dissemination, Pinkley spearheaded some of the first curated, interpretive efforts of the National Park Service at these Southwestern sites. What seems like a vital objective in today's national parks and monuments, he alone saw it as a primary goal and was often contested when attempting to advocate funding for educating visitors so that they comprehended the building fragments in front of them.[60] His affable nature and recognition that the Southwestern public responded more fully to a colloquial style drove him to strongly campaign for the propagation of using the Southwestern monuments as a tool for teaching. Indeed in 1920 he cautioned that, "future generations will censure us greatly for our lack of interest and for not properly caring for and preserving for them these great relics of a long vanished race."[61]

Pinkley's final impacts at the Southwestern sites were in seeing his dreams of a school to prepare future park rangers and custodians come to fruition in 1938.[62] As Hal Rothman notes regarding the Southwestern national monuments, of which Casa Grande and Tumacácori led the way for earthen architecture,

> Evolving into an integral part of the federal preservation of the natural and human past on this continent, the national monuments are truly monuments; their existence reminds Americans of the need to remember the past as well as of the necessity of preparing for a long-term future. Of aesthetic and cultural value, the national monuments are testimony to a vision of social responsibility shared by American leaders of an earlier time.[63]

3.7 – Mission San José de Tumacácori Today

In 1990, the Tumacácori National Historical Park was designated in tribute to the significant historic mission elements within the park. The legacy of Pinkley's goals of gently curating and interpreting these relics for the diversity of the modern American public stands today.

A particularly appropriate representation of these aims is in the case of the Tumacácori museum building, and the care that was devoted to its complementary design. In a lengthy, personalized correspondence from Frank Pinkley to architectural student Miss Mildred Burrage on January 27, 1939, he proudly explains how elements of the museum building are direct homages to other Sonora-Arizona missions such as doors modeled after those of San Ignacio, motifs patterned after Cocóspera, and grilled windows to echo typical mission architecture.[64] But perhaps to this particular investigation of painted surface finishes, the most appropriate demonstration of Pinkley's interpretive design came in the bemused, fervent explication of the choice of museum color:

> The reason the museum is painted a bright yellow is that bright yellow is one of the most common colors used in the old days in Tumacacori and her chain of sister missions. Other authentic colors from which could choose include a blue, an orange, a red, a pink, and a white. The yellow museum is startling to our eyes because we fail to realize that the building is one of the northernmost expressions of a distinct and different type of architecture which extends almost the whole length of the continent to the south. But since the design of the building was so carefully executed that it is authentic not only in detail but in toto, its impact on the unitiated visitor surely has an educational effect, do you not think? You see, a competent museum guide will say something like this, "The brilliantly colored museum building may have startled you when you came in. But REMEMBER THAT IT LOOKS LIKE ALL OF TUMACACORI'S BUILDINGS ONCE LOOKED. If you will glance at the museum and then the mission, you can re-create in your minds eye what a magnificent scene the Tumacacori mission buildings once must have presented…To you as an artist and an architectural student, I wish to make assurance that we do not intend to keep the museum building in as spick-and-span condition as when you saw it. We want the building to tone down through the passage of months and years to the condition of a normally well maintained public building of the Spanish era. Thus, when this coat of calcimine has faded and peeled almost to the point of dilapidation, the next coat will probably be white. (Imagine the visitors' reactions if we calcimined the building the 1800 Spanish-Mexican shade of blue, or pink. We like to think that we have exercised some restraint in choosing one of the least amazing of the authentic tints, and have utilized their favorite blue in a fairly inconspicuous position under the arcades, which is a common trick of theirs.) When this white has commenced to peel, and a flake or two of yellow shows through, when a small piece of cornice falls off and the doors are weathered down to a natural gray-brown, then the museum will be even more authentic, and more what we are striving for.[65]

Notes

[1] Jeremy Moss, "Of Adobe, Lime, and Cement: The Preservation History of the San José De Tumacácori Mission Church," *NPS Archeology Program: Research in the Parks*, National Parks Service: U.S. Department of the Interior (2008), Web.

[2] Water G. Attwell, Gene H. Gordon, "Report on Proposed Ruins Stabilization, Mission San Jose de Tumacacori," *NPS Archeology Program: Research in the Parks* (San Francisco, Branch of Engineering - National Parks Service: U.S. Department of the Interior, 2008), WAAC: TUMA_4553_Attwell_1935.
[3] "Data Tools: 1981-2010 Normals Tumacacori NM, AZ." *1981-2010 Normals Tumacacori NM, AZ.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Web.
[4] Ibid.
[5] Ibid.
[6] Ibid.
[7] Trent Elwood Sanford, *The Architecture of the Southwest: Indian, Spanish, American*, (New York: Norton, 1950) Print, pg 176.
[8] James Early, *Presidio, Mission, and Pueblo: Spanish Architecture and Urbanism in the United States* (Dallas: Southern Methodist UP, 2004) Print, pg 139.
[9] Ibid.
[10] Ibid.
[11] Ibid.
[12] Early, 140.
[13] Ibid.
[14] Early, 139.
[15] Early, 140.
[16] Of adobe.
[17] Early, 140
[18] Ibid.
[19] Ibid.
[20] Moss.
[21] Early, 141.
[22] Ibid.
[23] Ibid.
[24] Ibid.
[25] Ibid.
[26] Ibid.
[27] Ibid.
[28] Early, 142.
[29] Ibid.
[30] Moss.
[31] Early, 209.
[32] Moss.
[33] Ibid.
[34] Ibid.
[35] Hal Rothman, *Preserving Different Pasts: The American National Monuments* (Urbana: U of Illinois, 1989. Print).
[36] Early, 209.
[37] Rothman, xi.
[38] Ibid.
[39] Moss.
[40] Ibid.
[41] Rothamn, xi.
[42] Rothamn, 9.

[43] Rothman, xiii.
[44] Ibid.
[45] Rothman, 89.
[46] Ibid.
[47] Moss.
[48] Rothman, 108.
[49] Rothman, 109.
[50] Rothman, 116.
[51] Rothman, 184.
[52] Rothman, 112.
[53] Rothman, 119.
[54] Rothman, 121.
[55] Rothman, 120.
[56] Rothman, 126.
[57] Ibid.
[58] Rothman, 128.
[59] Ibid.
[60] Rothman, 137.
[61] Rothman, 120.
[62] Rothman, 184.
[63] Rothman, 230.
[64] Frank Pinkley, Letter to Miss Mildred Burrage, 27 Jan. 1939 (United States Department of the Interior: National Park Service - Headquarters, Southwestern Monuments: Coolidge, Arizona) pg 4.
[65] Pinkley, pg 5.

Chapter 4 – Traditions of Spanish-Colonial Architectural Façade Polychromy

4.1 – Cultural Contexts

While describing the current state of the painted surface finishes at the Mission San José de Tumacácori, Superintendent Frank Pinkley remarked,

> We must remember the architecture in the Jesuit and Franciscan periods was NOT unplastered adobe, but adobe walls neatly lime plastered and coated with bright colors. As you know, the oriental architectural influence was highly developed in Spain and Mexico at the time, and this same influence came up here almost unadulterated. Witness San Xavier today, and innumerable other examples just across the line in Mexico. Such an unplastered adobe bulding (and our ranger residence in their present state, for that matter) would have been scoffed at by any decent-minded Spaniard in Tumacacori's heyday as being newly unfinished. We would have built a building that imitated nothing except the decadent backwoods Arizona Mexican style of today – regressive because of our failure to appreciate the beautiful, environmentally adapted Spanish and Mexican earlier styles.[1]

Indeed, an understanding of the stylistic, artistic, and technological traditions of architectural polychromy is necessary in order to contextualize the painted surface finishes of Tumacácori. The influence of Spanish imperialism that left its traces across North America was not a matter of simple cultural dissemination through the mission system. As there was a great diversity of local and imported influences, there resulted distinct variations of stylistic and contextual expression – even within the same geographic area or time period.

During this period, Spain was composed of a unique blend of Christian, Jewish, and Muslim influences still visible in the variety of cultures found through its seventeen autonomous regions today. Regional associations tended to predominate, even within the religious orders. The Franciscan order was established in the 13th century prior to the rise of

European nationalism, while the Jesuits were proponents of the Counter Reformation.[2] Therefore, as

> heirs to North African culture, [the Spanish] were also the frontiersmen of Catholic Europe and custodians of the even older decorative traditions of the Celtic north, which were as important in Galicia as in Ireland or Wales or Brittany. This composite they shipped to America.[3]

Thus, even after the elite class of Spain was replaced by a Christian one, the same craftspeople who drew from Muslim traditions continued to work through the Carolingian Renaissance, Ottoman Renaissance, proto-Renaissance, and the Romanesque and Gothic eras while many went on to America.[4] Overall, many of the first Spanish built churches in the now continental United States appear in the same vein as some of the small mosques of Algeria and Morocco.[5]

This overall diversity is significant as it then filtered into the types of architectural traditions that were imported to the northern frontier of New Spain, providing a wide spectrum of building typologies within the genre of mission building and decoration. In the case of Arizona for example, "Spanish" Arizona was created by settlers who prioritized the lead of the pope first and the Hapsburg dynasty secondly.[6] From an administrative and military standpoint, Arizona was more of an extension of the Basque province from the 18th to 20th centuries, lending an important distinction as Basques were "in appearance, language, and custom, the ultimate expression of Spanish diversity."[7] Indeed,

> in Arizona, Argentina, or their own homeland on the northeastern coast of Spain, traditional Basques do not call themselves by that name. They are Euskadi. Their language (Euskera) bears some relationship to Finnish and Hungarian and none at all to Spanish or French. Their earliest inscriptions made use of letter-forms like those of the Levant, though the people were said by the twelfth-century Codex Calixtinus to be fairer in complexion than the neighboring Navarrese. [8]

This sense of diversity from the originating culture is then paramount in understanding how architectural traditions, such as the treatment of a mission church exterior, were to be expressed and how they differed from area to area.

All of these reasons give rise to the manner of ornamental treatment and façade decoration in North American mission architecture. For example, in the region where Tumacácori lies between northern Sonora and southern Arizona, the first divergence in materials came between the Jesuits and Franciscans as the Jesuits typically used sun-dried adobes and mud mortar, while the Franciscans generally favored kiln-dried brick and lime mortar.[9]

> These builders were practical people meeting problems of construction and serving symbolic needs; they were not builders of theme parks, so we should not look to the missions for "tags" or "labels" to lead us back to prototypes. What we will find, instead, is the accumulation of a millennium of experience, transported and altered by circumstance. It is of crucial importance, however, that we not limit our expectations of what that experience produced to what we might find in northern European or in Christian Europe alone.[10]

Furthermore, upon arrival in America, these "Afro-European eclectics" synthesized new ideas about the decoration, engineering, and construction from the Native Americans.[11] The Spanish and Mexican precedents saw how painted decoration was sometimes enhanced by the addition of glazed and colored tiles, while Arabic influence demonstrated ornamental stucco work that later found echoes within the geometric decoration of the Anasazi murals in Colorado or Texas mission churches.[12]

So despite some cases of stark or severely whitewashed mission facades today, "when they were new they must have been celebratory enough to please a Moor or a Spaniard or an Indian."[13] Indeed, while a strict black-and-white mural campaign that was perhaps indicative of a sentiment of "anti-barbarism" was instituted at some Mexican settlements such as Acolman, Actopan, and Huejotzingo, by the end of the 16th century, vibrant colors returned, particularly in the missions constructed within the continental United States.[14] A profusion of decorative exterior painting was evident in missions such as La Purisma Concepción in San Antonio, Texas with its "red and blue quatrefoil crosses and with yellow and orange squares" or San Jose y San Miguel (also in Texas) and its brilliant polychromatic façade of yellow, red, blue, and black.[15] In California, noted art historian Norman Neuerburg has suggested that despite the current coral and whitewashed appearance of many mission buildings, the original schemes once exhibited an exuberance of color.

4.2 – Technical Treatises of the Spanish New World

Evidence suggests that during the spread of the Spanish empire, some engineers, architects (*alarifes*), and craft masters (*maestros de obra*) travelled alongside the *conquistadores* and clergy through the New World.[16] However perhaps equally or even more commonly occurring would be the architectural attempts on the part of the friars, or others who were not craftspeople by trade.[17] Indeed, while Spanish guild regulations were quite stringent – distinguishing between sculpture and polychromy but not between painter and polychromer – the newfound settlers came from all types of occupations. [18] And once they found themselves in the Spanish New World, published treatises became a point of reliance for those hoping to decorate their freshly constructed mission complexes. For example inventories and transactional records from the Mission San Gabriel in California detail a request for a dozen paintbrushes and the book entitled "Painting without an Instructor" (*"un libro intitulado 'Pintar sin Maestro', o cosa semjante*")[19]

A previously completed thesis entitled "Architectural Exterior Finishes in the Spanish Caribbean. Case Studies: San Geronimo and Santa Elena Powder Magazines" by Almyr M. Alba provides an in-depth review of the various treatises in circulation through Spain as well as those sent to the Americas based upon trade invoices, wills, and library inventories.[20] Treatises that are contemporaneous to the general time period of Tumacácori's Franciscan construction (1800-1848) are presented as follows:

Table 4.1: Architectural Treatises in Spain (1800-1848)				
Period	**Year**	**Title**	**Author**	**Notes**
16th c.	1552	Tercero y Quarto Libro de Architectura	Sebastian Serlio	One of most frequently published, year of first Spanish translation
	1564	Medidas del Romano	Diego de Sagredo	One of most frequently published
	1564	Diez Libros de Architectura	Marcus Vitruvius	Most significant work, year of first Spanish translation
	1582	Diez Libros de Architectura	Leon Bautistca Alberti	Year of first Spanish translation
	1585	Conmensuración para Escultura y la Architectura	Juan de Arfe y Villafane	-
	1593	Regla de las Cinco Ordenes de Architectura	Giacomo Vignola	Year of first Spanish translation
	1598	Teoria y Practica de la Fortificacion	Cristobal de Rojas	-
17th c.	1616	Libro Primero de la Arquitectura	Andrea Palladio	Year of first Spanish translation
	1633	Arte y Uso de la Arquitectura	Lorenzo de San Nicolas	-
	1638	Arte de la Pintura	Francisco Pacheco	Artist's paint essay
	1687	El Architecto Perfecto Militar	Sebastian Fernandez de Medrano	Military treatise
18th c.	1724	El Museo Pictorico y la Esacal Optica	Palomino de Castro y Velazquez	"Painting and Proportions" practical handbook
	1734	Secretos de las Arte Liberales y Mecanicas	Bernardo Monton	"Secrets of Liberal and Mechanicals Arts" practical handbook
	1738	Escuela de Architectura Civil	Brizguz y Bru	-
	1740	Critica y Compendio de la Architectura Civil	Manuel Losada	-
	1776	Disertacion sobre las Argamasa que Gastaban los Romanos	Lloriot	"Discourse on the Roman Mortars" practical handbook
	1781	Principios de Fortificacion	Pedro de Lucuze	Military treatise
	1785	Arte de hacer el Estuco Jaspeado	Ramon Pascual Diez	"The Art of Marbleizing" practical handbook
19th c.	1814	Secreto de Artes Liberales y Mecanicas	Bernardo Monton	"Secrets of Liberal and Mechanical Arts" paint preparation and painting technique
	1827	Arte de Albanileria	Villanueva	"The Art of Masonry and Plaster Work"
	1840	Manual del Albanil-yesero	Ignacio Boux	"Mason and Plasterer's Manual"
	1841	Observaciones de la Practica de Edificar	Manuel Fornes y Gurea	Observations and Edification Practices

4.3 – Materials and Techniques of Spanish-Colonial Exterior Surface Finishes

Generally, a greater amount of the scholarship dedicated to the materials and techniques of Spanish mission architectural polychromy has focused on that of interior decorative painting rather than the inherently more fugitive exterior architectural finishes. Any European born craftsmen in New Spain would have been trained through the guild system common in Spain and Portugal; however Native Americans most likely did the majority of mission painting and possibly other crafts as early as the 17^{th} and 18^{th} centuries.[21]

Materials and techniques related to plastering and painting were already highly developed in Spain by the time of building in the Americas. Lime plaster was already manufactured and used throughout the northern frontier from the 17^{th} century onwards except in New Mexico. Lime was burned for quicklime (*cal vive*) and then soaked for several months in a process known as slaking; the subsequent slaked lime (*cal apagada)* was either then mixed with sand and water to make lime plaster or mortar, or with more water for whitewash. In contrast, gypsum plaster was more predominantly used in the area of New Mexico prior to 1680.[22] In some cases when lime mortar was not readily available, indigenous traditions of using mixtures of clay and charcoal ash were used.[23]

Stucco composition is highly variable depending on the regional tradition and availability of local materials. The dry mixture often contained large amounts of clay or brick dust, while additives to contribute to the strength and durability of the stucco range from animal blood or urine, to eggs, keratin or gluesize (animal hooves and horns), varnish, wheat paste, sugar, salt, sodium silicate, alum, tallow, linseed oil, beeswax, and wine, beer, or rye whiskey.[24] Additives to enhance performance and workability, such as waxes, fats, and oils to introduce water-repellency, sugary materials to retard setting time, and alcohol to promote air entrainment have also all been documented as methods in which to improve the plaster mixture.[25]

The aggregate – sand or sometimes burnt clay - often provided a foundational color, however the mixture was often either tinted with pigments or colorwashed following stuccoing.[26] Stucco was also sometimes stained, such as by the use of iron vitriol (ferrous sulfate) with a mixture of yellow ochre – further exploration of this technique is detailed in section "5.4 – Case Study: The Use of Ferrous Sulfate in Limewash Staining."[27]

Stucco was primarily applied first by hand or paddle (later by trowel), and consisted of mud that sometimes had ash or plant fiber added, or lime or gypsum that was mixed with sand.[28] A three coat process is typical as those applying the stucco would typically scratch or cut grooves into the adobe wall or plaster undercoat then would dampen it to prevent moisture from being absorbed, thereby avoiding cracking.[29] "Keys" in the form of small wooden pegs or thin sharp rocks that were level to the surface of the wall would help the plaster attach to the wall better. The preliminary coat, a rough or scratch coat, was generally composed of lime, sand, and gravel as needed.[30] The second scratch coat is often called either the "floating" or "brown" coat, while the final layer a "finishing" coat.[31] Ultimately, this provided a slick surface that could be burnished to the point in which it would be quite effective at conducting water away from a building. Sometimes elements as mundane as drainage channels were decorated as well; indeed, at the San Xavier del Bac and Tumacácori mission churches, the original drainage channels were colored red or yellow, possibly from brick dust in the mortars.[32]

Exterior polychromy at the mission complexes was generally achieved by the use of ground inorganic pigments. In the late thirteenth-century "Pórtico de la Majestad" of the Collegiate Church of Toro in central Spain, professional guild painters utilized twelve pigments to create fourteen colors; these pigments include lead white, chalk white, carbon black, azurite, indigo, copper green, yellow ochre, yellow orpiment, vermillion, red lead, red ochre, and earth pigments.[33] Similar pigments were utilized in the Spanish New World.

Blacks were primarily produced from carbonaceous material such as charcoal, bone black, and in some California mission cases, by manganese oxides.[34] Common natural pigments to provide deep, earthy hues such as ochres, umbers, and siennas were purified then roasted, as various shades from brownish-red to yellow and violet tinted colors could be produced depending on the processing treatment. Reds were derived from hematite, iron oxides in earth, clay, and stone, as well as cinnabar, an expensive and imported natural mercury oxide.[35] Blues were generally produced by copper based minerals, organic indigo, and colored clays, although San Xavier del Bac has shown traces of both imported Prussian Blue and smalt; greens were created from copper carbonates as well as malachite and from native clays that contained iron silicates.[36] Lastly, whites were generally derived from gypsum or anhydrite and kaolin clays, while yellows such as yellow ochre were extracted from ferrous minerals, such as the yellow types of limonite or goethite, or arsenic trisulfide, known as orpiment.[37]

Edith Webb notes that there are many erroneous legends and beliefs claiming the use of organic paints by the indigenous peoples who labored at the California missions.[38] Apart from indigo and charcoal, there is no evidence to suggest that there were any vegetable pigments that were utilized at the mission sites for exterior painting purposes.[39] Thus far, the only other posited organic colorant that has been noted through review of published literature was the use of gamboge, a resin, in the Spanish Caribbean.[40]

Native American artisans who worked on mission buildings used a variety of binding additives such as the fruit and juice of the yucca plant or prickly pear cactus, human and animal blood, chewed seeds, pine and mesquite resins, gums, and egg whites to improve working properties.[41] The Spanish then added to this indigenous knowledge the use of drying oils from seeds and nuts as well as fig juice as a binder.[42] Other materials such as pitch, milk, blood, egg white, or grain gluten was also added to lime mortar to make the stucco easier to manipulate and to retard drying for burnishing and modeling purposes.[43] In New Mexico, common floor sealers in 19th century mission buildings included domestic animal blood mixed with fine clay or earth as well as gelatin, hide glue, pine pitch, and sap.[44]

These traditional materials and techniques show merit for considering future historically and materially sensitive conservation treatments. In many areas in northern Mexico and the American Southwest, the fermented juice of the prickly pear cactus (*nopal*) is still added to lime plaster and whitewash by native builders in order to create a smoother, more durable finish.[45] The same practice was applied at La Purisma Concepción church in Caborca as well as at San Xavier del Bac, Tumacácori's contemporary both geographically and contextually.[46] In the case of San Xavier del Bac, previously applied synthetic paints and restorations were removed from the exterior surfaces of the domes and vault in the spring of 1989.[47] While the coatings had only been applied a few years before, their impermeable nature had promoted the degradation of the soft underlying brickwork.[48] Thus, under the direction of architect Robert Vint and historian Jorge Olvera, conservators replastered the surfaces using a traditional *nopal* juice, followed by burnishing the new plaster to a smooth, shiny finish.[49] Since then, internal reports have confirmed that the cactus juice treatment was a superior choice as a sealer as it allowed for a level of permeability while also resisting weathering.[50]

Interior painting was prevalent as well, although when plaster murals were painted (most notably at San Xavier del Bac), the fresco secco technique was typically used.[51] The paints were then applied to areas freehand, by inscribing areas with a compass, or areas that were "pounced" or stenciled with the aid of charcoal or pencil stencils made from parchment, paper and strips of leather.[52] While exterior painted finishes degrade over time, traces can be found in typically sheltered areas; notable examples include the stone arches of the Convento de San Francisco de Asis in Zacatecas, on volutes at the San Juan de Dios in Durango, the façade of the Cathedral de Chihuahua, on cornices, figures, and the door frame of Santa Eulalia de Merida in Chihuaha, and on the figures and façade of San Xavier del Bac in Arizona.[53]

4.4 – Case Study: Use of Ferrous Sulfate in Staining Limewash

After examination of several cross sections from the Mission San José de Tumacácori, the stratigraphy of some yellow samples did not suggest that the color was applied as a separate layer upon the surface, but rather that the visible color appeared integral to the limewash itself. This prompted further research into methods of limewash staining and provides an excellent area of continued inquiry.

In 2002, Marita Jonsson and E. Blaine Cliver published the article "Coloring Historic Stucco: The Revival of a Past Technique in San Juan, Puerto Rico," which detailed the use of ferrous sulfate (also known as copperas or iron vitriol) in order to stain limewashes a yellowish hue.[54] Basing their work upon the thesis of a Swedish pharmacist, Johan Julius Salberg, in 1743, the recipe for such an application of ferrous sulfate to color limewash is detailed below:

> The common practise of colouring stone houses yellow is to mix light ochre or Ochra lutea with lime-wash, more or less depending whether a light or dark covering is needed; the pigment however is a little expensive and also costs labour to handle and sift; therefore I will, after having used this myself, suggest a less expensive way for colouring stone houses yellow, giving them better durability and standing than when coloured the other way. Ordinary vitriol is melted in hot water, 2 skålpunds to ever kanna of water; the mixture is kept in a bowl. Then white sifted lime from Gotland, as much as is needed to paint a house, is taken and the lime is mixed with water to a thick paste in another bowl; in this lime putty as much vitriol mix is poured as is needed for making the mixture thin for painting. This so called lime-wash, *gröt*, has a bluish-green colouring and the wall itself when painted will not get the yellow colouring until the wall is dried. The more vitriol mix needed to make the lime-putty thin enough for painting, the darker the colouring of the wall an vice-versa; therefore it is possible to make the lime-putty thicker or thinner so that more or less vitriol-lime s needed…This method I have found adheres well to the plastering; the colour does not rub off on the hands when the wall is dry, it looks even better than when coloured with *ochre* and is of so little cost that 1 *lispund* of vitriol, which costs 7 to 8 mark *kopparmynt* can be used for more than 2 *lispunds* of *ochre* to the same cost.[55]

This discovery of ferrous sulfate to stain limewashes a pleasing yellow color and as a substitute for an application of more traditional ochre pigment was popularized through Europe, as ferrous sulfate was a generally more cost-effective and easily handled material than ochre pigments.[56] This technique tended to impart a greater durability to the plaster and Salberg's innovation was referred to in encyclopedias, journals of science, and books on building construction.[57] However, upon the introduction of cement stucco in 1920s, the use of ferrous sulfate to stain limewash lost favor until recent modern times, when a steady revival in the use of traditional techniques in architectural conservation has sustained further scholarly interest.[58]

Indeed, Jonsson and Cliver published this article in reference to researching and testing this method at the Spanish-Colonial fortifications of the San Juan National Historical Site. They found under microscopic examination of sample cross-sections that the limewashes similarly did not appear as a discrete layer, but rather as incorporated into the stucco surface that covered a large swath of wall.[59] Furthermore, it was noted that the color of the walls had seemed to turn a rust-red, suggesting the decomposition products of the ferrous sulfate staining method.[60] Colorant tests to assess the use of ferrous sulfate staining and appropriate recipes for pilot conservation purposes at the San Juan National Historical Site were conducted in 1999, with their detailed findings of each recipe tested outlined in their article.[61] While it was hypothesized that the actual reaction mechanisms are more complex, a proposed set of chemical reactions are proposed as follows:

- $FeSO_4 + Ca(OH)_2 \rightarrow CaSO_4 + FeO + H_2O$
    - $2FeO + O_2 \rightarrow Fe_2O_3$
    - FeO is unstable and whiteish and oxidizes to become Fe_2O_3
- $FeSO_4 + CaCO_3 \rightarrow CaSO_4 + FeCO_3$
    - $2FeCO_3 + O_2 \rightarrow Fe_2O_3 + CO_2$
    - $FeCO_3$ is brownish to white (siderite) and oxidizes to Fe_2O_3

This traditional method of applying colorant as a stain could provide potential avenues for a future conservation campaign to return the Mission San José de Tumacácori to a more historically accurate polychromatic scheme. Should this be pursued, test panels following the example set forth by Jonsson and Cliver should be created and evaluated to determine its efficacy and appropriateness to the site. Having been touted for its ease of application that removes the necessity of a trained paint specialist as well as the much lower cost of coloration, the use of ferrous sulfate to stain limewashes possesses a historically contemporaneous solution that could prove to be an extremely worthwhile area of study for the restoration of the painted surface finishes at Mission San José de Tumacácori.

Notes

[1] Frank Pinkley, Letter to Miss Mildred Burrage, 27 Jan. 1939 (United States Department of the Interior: National Park Service - Headquarters, Southwestern Monuments: Coolidge, Arizona) pg 4.
[2] Roger Kennedy, *Mission: The History and Architecture of the Missions of North America* (Houghton Mifflin, 1993) Print, 49.
[3] Kennedy, 56.
[4] Kennedy, 55.
[5] Kennedy, 56.
[6] Kennedy, 48.
[7] Kennedy, 49.
[8] Ibid.
[9] Kennedy, 24.
[10] Kennedy, 56.
[11] Ibid.
[12] Kennedy, 75.
[13] Ibid.
[14] Ibid.
[15] Ibid.
[16] Almyr M. Alba, *Architectural Exterior Finishes in the Spanish Caribbean. Case Studies: San Geronimo and Santa Elena Powder Magazines*. Thesis, (University of Pennsylvania, 1995. *ScholarlyCommons - Penn Libraries University of Pennsylvania*) Web.
[17] Edith Webb, "Pigments Used by the Mission Indians of California" *The Americas* Vol. 2, No. 2, Academy of American Franciscan History (2002): Web, pg 139.
[18] Melissa R. Katz, "Architectural Polychromy and the Painters' Trade in Medieval Spain" *Gesta* Vol. 41, No. 1, International Center of Medieval Art (Summer, 1996): Web, pg 381.
[19] Webb, 138.
[20] Alba.
[21] Gloria Fraser Giffords, *Sanctuaries of Earth, Stone, and Light: The Churches of Northern New Spain, 1530-1821* (Tucson: U of Arizona, 2007) Print, 74.
[22] Giffords, 81.

[23] Ibid.
[24] Anne Grimmer, *Preservation Briefs 22: The Preservation and Repair of Historic Stucco* (Washington: U.S. Dept. of the Interior, National Park Service, Preservation Assistance Division, 1990) Print, pg 4.
[25] Ibid.
[26] Ibid.
[27] Ibid.
[28] Giffords, 81.
[29] Giffords, 105.
[30] Giffords, 106.
[31] Grimmer, 5.
[32] Giffords, 106. .
[33] Katz, 5.
[34] Giffords, 94.
[35] Ibid.
[36] Ibid.
[37] Ibid.
[38] Webb, 146.
[39] Webb, 146.
[40] Alba.
[41] Giffords, 94.
[42] Giffords, 95.
[43] Ibid.
[44] Ibid.
[45] Giffords, 412.
[46] Ibid.
[47] Ibid.
[48] Ibid.
[49] Ibid.
[50] Ibid.
[51] Giffords, 121.
[52] Ibid.
[53] Ibid.
[54] Marita Jonsson, E. Blaine Cliver, "Coloring Historic Stucco: The Revival of a Past Technique in San Juan, Puerto Rico" *APT Bulletin* Vol. 33, No. 4, Association for Preservation Technology International (APT) (2002): Web.
[55] Jonsson and Cliver, 31.
[56] Jonsson and Cliver, 32.
[57] Ibid.
[58] Ibid.
[59] Ibid.
[60] Ibid.
[61] Ibid.

Chapter 5 – Conservation Efforts on Exterior Surfaces Finishes at Tumacácori

5.1 – Summary of Overall Conservation History

The mission at Tumacácori can consequently be read as a document in itself that communicates the development of preservation philosophies and approaches at the site. In the early 1900s, historic preservation was still in its infancy, lacking a clear vision based on a common methodology and understood range of treatment options rather than preservation or restoration. The 1906 Antiquities Act thus set the stage for Tumacácori and Casa Grande National Monuments, the first two monuments of earthen architecture to be designated and therefore considered for intervention and interpretation.[1]

Under the stewardship of Frank "Boss" Pinkley, conservation methodologies were experimental and would provide the basis of the development of the field as Pinkley used traditional building materials, methods of construction, and workers – often as a means to creatively circumvent budgetary restrictions by the National Park Service.[2] Pinkley inherited a site that had been plagued by the damages of time, institutionalized neglect, and looters.[3] In 1930 Charles E. Petersen, the founder of the Historic American Buildings Survey, visited Tumacácori and seven years later the first set of measured HABS drawings for Tumacácori was completed.[4] Concerns about decaying and destabilized structures such as Tumacácori were paramount, and a policy of restoration was pursued for historic, non-archaeological sites.[5] Indeed, J.H. Tovrea, the first historical architect at Tumacácori remarked in 1935 that

> since the buildings were designed to impart a feeling of mystery and sanctity, so should such a feeling be recreated in Tumacácori, as nearly as would be practiceable…At the present time, the interior of Tumacácori could be mistaken for the interior of an old banquet hall, a fortress, or even a storage

> room. A little restoration here and there would make it impress the visitor that it was the interior of a place of worship and he would be getting a truer picture of the mission.[6]

By the 1940s restoration through rebuilding had generally lost favor, though the next three decades would see an experimentation in synthetic and non-traditional materials such as ethyl silicates, polyvinyl acetate sprays for plaster, as well as Portland cement.[7] However the use of these materials that often present incompatible properties created new issues, and in 1977 George Chambers stripped away all non-historic materials used in prior preservation attempts.[8] Sporadic archaeology and documentation, such as a second set of photogrammetric HABS drawings in 1970s, continued through 1950 to 1990s.[9]

Modern preservation efforts at Tumacácori are undertaken by using traditional materials and techniques, such as adobe, lime, and earthen mortar, when possible.[10] In essence, by studying the successes and failures of these various treatments, one can gain a perspective of nearly a century's worth of experimentation in preservation methodology thereby offering insight into the development of architectural conservation in the United States. The façade and structure of the mission seen today is a testament to the continued relationship between maintenance and testing, evolved through trial and error and an understanding of the tradition of local construction.[11]

5.2 – Analyses and Interventions Specific to Façade and Surface Finishes

Owing to the relative rarity of a mission church whose exterior has never been extensively repainted, the architectural finishes of Mission San Jose de Tumacácori's façade thus merit a closer investigation in order to propose sensitive conservation treatments that promote their longevity and improve legibility. While not as ornate as some of its mission church counterparts, Tumacácori stands as a tribute to not only the diversity of influence found within the painted finish practices that fused Spanish and Native American traditions, but perhaps more significantly, to the development of historic preservation and architectural conservation as practiced during the early years of federal protection. Work specific to the façade finishes seems to have often taken a secondary position to other preservation work done at Tumacácori. Indeed, in order to consider the possibilities of what may have been undertaken on the façade, what follows is a conservation history of documented façade and polychrome descriptions, treatments on exterior church wall plasterwork, and analyses done upon interior painted decoration.

Superintendent Frank Pinkley's 1928 "A Handbook For the Use of the Visitors at Tumacácori National Monument" provides one of the earliest in-depth descriptions of the façade following the acquisition of the monument by the NPS; he admiringly describes the painted decoration for the education of visitors as follows[12]

> Let us now approach within a few paces of the entrance for a closer examination of the façade before entering the church. From this point it may be seen that the whole front of the façade was painted. The general background seems to have been a yellow tending toward pink. This color, somewhat faded by a century of time, can be seen on the under side of what remains of the original entrance arch. The columns were painted red as can be seen by a study of the two to the right of the doorway where they are attached to the wall. Their capitals were yellow and all show, especially next to the wall, black markings. It may surprise you to find Egyptian architecture here in southern Arizona, but these are undoubtedly imitations of Egyptian capitals and the explanation of them is that they were introduced into Spain by the Moors and are here copied from some Spanish structure by the person who designed this façade. The columns were painted to resemble stones; you may see a dim white band around the columns to the right and left of the entrance about two feet below their capitals. The second band may be traced on the right hand column

> at the foot of the little projecting shelf of the niche. In this connection, notice the imitation of stones in what remains of the original entrance arch. The imitation of stone construction was entirely unnecessary for the benefit of the people for the pleasure of the designer himself who had probably seen the stone constructions of Mexico and Europe and imitated them here to the best of his ability. The two lower niches in the façade have round tops while the two upper ones have pointed ones. These niches were painted blue; traces of the color can still be seen at the top where it has been protected from the weather. The little corbels or projecting shelves are quite characteristic with their spearhead decorations at the bottom and will be noticed elsewhere about the church. As well as being a decorative motif, these corbels served to bring the statue forward so it might be seen from a wider angle than if it sat back entirely within the niche.[13]

Apart from the façade proper, the downspouts or *canales* were also purposefully colored a bright red.[14] Other exterior decoration of interest is that of the church back wall, in which the remains of ornamentation created by pressing crushed brick and black slag into damp plaster is still visible today – indicating, "the influence of the Moor is again felt, recalling his abstract decoration in glazed tile."[15]

Multiple conservation campaigns have been documented; however it seems likely that there have been a number of smaller, undocumented treatment repairs over time. Superintendent Pinkley made exterior plaster stabilization a priority, although he generally focused primarily on the non-façade walls and requests for plaster repair are proposed consistently in the earliest maintenance request correspondences through 1919 to 1950.[16] In 1934 the Civil Works Administration began an exhaustive project at Tumacácori in attempts to stabilize the adobe walls, and in 1935 a solution of vinyl resin in acetone and toluene given the moniker "NPSX" was applied to the exterior mission wall on the south entrance's east side.[17] At 60 pounds per square inch of pressure, two coats of the 3% solution were applied to approximately the entrance arch's spring line, as well as to the interior nave at the first pilaster and base in the southernmost corner of the wall.[18] Dust was removed from interior painted frescoes and exposed adobe at a pressure of 60 psi and the interior frescoes were sprayed with the same application of "NPSX."[19] Other cocktails of proprietary synthetic compounds to stabilize exterior walls were considered in the early 20th century, including LUMINO water repellent and in 1946 Stabinol was applied to the eastern walls.[20]

Damage to the original plaster at Tumacácori continued steadily. Heavy rainfall in 1944 destabilized the lower pilaster on the mission façade, causing it to collapse as reported in August 1944 by acting custodian Ted C. Sowers – while it was noted that "all material was picked up by Ranger Brewer so that it can be restored in the immediate future," not much more was expounded upon this small project in later documentation.[21]

Figure 5.1: Photograph indicating damage from 1944 storms[22]

Other damages included when administrative daily diaries noted that the "continued use of the mission as a roosting place by bats causes pieces of original plaster to fall from time to time" in 1947,[23] and the presence of lichens within the colored *canales* that were subsequently attempted to be removed with a solution of copper sulfate two years later.[24] In the late 1940s and 1950s, attempts to find a more permanent synthetic preservative did not yield satisfactory results, and Earl Jackson resorted to applying cement-stabilized plaster to exposed adobe areas on the exterior.[25]

Perhaps the most significant study regarding painted decoration at Tumacácori was Rutherford J. Gettens' work in consultation with NPS archaeologist Charlie R. Steen on the interior polychromy in 1949. Gettens was a trained chemist and conservation scientist at the Fogg Museum of Art at Harvard University and is well-known now in the conservation field as one of the foremost pioneers of art conservation, having co-authored one of the pivotal works used in finishes analysis, Painting Materials.[26] Incidentally, he even sent Steen a copy of his book as a gift, remarking on September 20, 1949:

> I am sending you under separate cover a book called "Painting Materials", written several years ago by me and my colleague George Stout. I send this in appreciation of the very wonderful time I had with you in June. You will find this dull reading, but I hope there is a little in it of interest to you in connection with your archaeological work.[27]

His work at Tumacácori came after a two-year search by Earl Jackson for the proper individual to undertake a detailed study of the interior painted plasterwork.[28] He noted in initial observations of finish application that the lime used for plasterwork seemed to have been burned in a large kiln, of which material evidence suggests is the ruins located approximately a hundred yards north of the mission church.[29] Peculiar pigment behavior for several interior colors were notably documented at this time: a hard yellow stain was found in the lower niches, the cinnabar tended to turn into a very dark blue or black in certain design elements, what was likely a deep ochre on the molding had variations of "deep orange-red to a washed-out yellow," and in some areas the decomposed black pigment left the remnants of a negative design.[30]

Samples were taken back to the Fogg Museum for further analysis where X-ray diffraction, optical microscopy by comparison microscope, and microchemical testing were the primary methods of identification.[31] It was determined that the interior plaster is composed of two coats of lime-sand mortar of nearly identical composition, with medium-coarse aggregate of primarily quartz and a variety of other minerals abundant.[32] These findings are consistent with thin-section petrographic analysis described in "Chapter 13: Composition and Identification: Thin-Section Microscopy of Sample TUMA_25" The wall plaster is estimated to contain 20-25% by weight of lime and a thin finish coat of burned gypsum that had reverted back to the dehydrated version of gypsum ($CaSO_42 \cdot H2O$), likely applied as a water-based paint over the entire plaster walls.[33] However in addition to the presence of the more commonly found gypsum dehydrate, Gettens noted that curiously there was a fair amount of fibrious, coarser anhydrite (anhydrous gypsum – $CaSO_4$) as well, not as regularly found within gypsum plaster.[34] This was visible in-situ as small, parallel-laid crystalline bundles and the presence of anhydrite was confirmed with optical microscopy and X-ray diffraction analysis.[35] While Gettens notes that it is possible the anhydrite exists as a natural impurity and may not be of large significance, it may also be possible that the fibrous anhydrite could aid in comparative studies with other nearby missions or in locating the original gypsum source.[36]

Interestingly, the red ochreous hematite floor plasterwork seems to contain comparatively less lime, and the composition of the floor plaster may be more similar to that of the exterior stucco; a more sustained comparative analysis between the floor plaster and that of the façade stucco finishes may prove useful.[37] Gettens did cursory comparison himself between a sample of the red-finished floor plaster and a sample of the red-finished *canales* stucco.[38] Indeed, the bulk samples behaved similarly after treatment with dilute hydrochloric acid, as there was not nearly completed disintegration like with the wall plaster.[39] Instead, there appeared to be undissolved cementitious material present in both the flooring and the exterior *canales* that appeared "crusty and amorphous" with a refractive index between 1.49 and 1.50 which surrounded small particles of quartz, rendering isolated studies difficult; Gettens eventually hypothesized that it could be silica deposited from dissolved silica soil water.[40]

Gettens was unable to conclusively characterize the paint binder nor identify the method of paint application, likely due to the highly fugitive nature of medium vehicles.[41] He posited that some type of aqueous medium was used as a paint medium, as microchemical tests for nitrogen to determine proteinaceous binders proved negative.[42] The only definitive conclusions drawn regarding painting methodology was that the painted decoration at Tumacácori was not painted in a true fresco technique due to the initial gypsum finish coat over the plasterwork.[43]

Initial testing and recommendations for conservation efforts on the interior painted decoration included dry cleaning, the testing of "Tide" and "L-Bo Grease" cleaning products (of which only “L-Bo Grease” provided satisfactory results), and spraying vinyl acetate lacquer to brighten and consolidate pigments.[44] The vinyl acetate lacquer that Gettens specified was adjusted to be 50% xylene to 50% toluene and a purchase order of fifteen gallons of the lacquer and ten gallons of thinner were requested on August 11, 1949.[45]

Contemporaneous to Gettens’ pigment analysis of the interior painted decoration, color-matching recipes for exterior restoration plaster were subject to continued revision through the late 1940s despite the nearly constant battle against disintegration. In a correspondence to the custodian dated June 24, 1947 naturalist Dale S. King advocated for the use of hydrated lime (he wound up using a partially hydrated hot ground lime) as it provided a more efficient alternative to overnight slaking.[46] He recounts the amusing manner in which he obtained his successfully color-matched plaster:

> You remember Mr. Lovelady and I arrived at the unbelievably matching color by somewhat hilarious methods – whenever his back was turned I’d dump burnt umber; when I wasn’t looking, he’d pour in yellow ochre. Consequently, I can’t give a very scientific formula for the color mix. However, take equal parts of burnt umber and yellow ochre, say a pint each, and mix them dry. Add enough water to make a creamy paste. Then add lime putty diluted to creamy consistency and additional water until it is about like white-wash. Match surrounding plaster color by varying the dark umber or the light ochre. (I think the quantity umber was about twice that of the ochre; Lovelady thinks vice versa. You’ll obviously have to experiment.[47]

This was applied in a three-coat manner with a wash of muddy water, similar to the original treatment of exterior plasterwork as specified by Lancaster in 1947.[48] However in the interest of economy and efficiency, there was then a shift towards mixing the pigments into the base or finish plaster instead of applying colorant afterwards as a separate layer.[49] In a correspondence from Superintendent Jackson, he advocated for the use of pigments added directly into the plaster by specifying a mixture of 6 quarts of sand, 1 quart hydrated lime, 1 pint Portland cement, 4 ounces yellow ochre, 2 ounces red cement color (10-LK lithochrome color), and ½ a level teaspoon of burnt umber to be mixed within a bulk plaster matrix of 6 parts screened sand, 1 part hydrated lime, and ½ part Portland cement.[50]

It is incredibly thankful that despite the continued struggles with repairing the exterior plaster that the Mission San José de Tumacácori never suffered the same fate as many other Spanish-Colonial missions with a total replastering or total repainting. Indeed, such an event came quite close to occurring as Regional Archeologist Erik K. Reed contended on May 23, 1950, that "I suggest that serious consideration be given the idea of complete replastering of the exterior of the church, and I recommend specifically that the repeatedly repatched west wall, where comparatively little of the original survives untouched, be given a complete surface of new plaster resembling the older work."[51] Clearly, his suggestion was not carried through to completion although there was a complete replastering of the west wall in 1951.

Intense weathering proved to be a primary issue for exterior plaster, and in March of 1952, the elements disintegrated part of the façade's plaster above the main entrance arch; a year later, rain caused one square foot of red painted plaster, originally from the decorative painted band, to collapse.[52] This drove the research on further synthetic compounds, such as Gordon Vivian's 1954 experimentation with silicone-based water repellants such as Daracone, which he ultimately used on several walls.[53] In 1959 Joel Shiner patched the façade's entrance arch with "Rock Hard putty", patched the baptistery windowsill, cleaned the *canales*, and sprayed silicone onto the mission's west wall again.[54] In addition to Daracone, Daraweld, and a variety of resinous and silicone sealers were all employed between the 1960s and 1970s.[55]

In October 1971 Daniel Evans, a soil physicist from the Hydrology Department at the University of Arizona, drilled test holes in eight locations within the mission to measure moisture content in the adobe walls; the southwest hole corresponds to that of the façade wall.[56] Another documented synthetic treatment was conducted in May 1972 by Sam Henderson, in which the eastern and western exterior walls were painted with a pigmented wash containing a bonding agent, cracks at the joint of the façade's westernmost lower column were grouted, sacristy *canales* were coated with Daraweld and Daracone, and other structural repairs and patches were carried out.[57] It seemed however that the craze for synthetic compounds would finally subsist by 1980s with the last notable specification being in 1974 with instructions to spray F-325 water-repellent on all exterior walls at, "a lower pressure (5 psi maximum) or by flooding the surface with a steady stream of the solution"[58]

Interior work was revisited most notably in 1982, 1992, and 2001 with two series of conservation efforts and a revised analysis of the interior pigments, respectively. In 1982, seven NPS conservators alongside experts from the International Centre for the Study of the Preservation and Restoration of Cultural Property aimed to preserve the interior dome of Tumacácori by cleaning wall surfaces, filling voids, and reattaching loose plaster and paint.[59] A decade later, the nonprofit group Patronato San Xavier worked in collaboration with a team of international conservators to perform analogous work to the dome of San Xavier del Bac, as well as to train four Tohono O'odham community leaders in conservation so as to imbue them with the skills to preserve their heritage.[60] Contact was made to establish the potential for a similar project at Tumacácori and in late February of 1992, three Patronato members visited Tumacácori for general assessment.[61] In consultation with the head of the Patronato, Dr.

Bernard Fontana, members of the Tohono O'odham team agreed to perform conservation work on the interior dome at Tumacácori. Objectives included the repair of delaminated plaster, repair edges, and filling of holes with materials as specified in the 1982 conservation work – the only notable difference was the suggestion of Rhoplex E330 instead of PVA.[62] Treatments to the façade continued through the 1990s as shown below.[63]

Figure 5.2: 1992 treatment to facade

Lastly, in 2000 preservationists Tim Lewis and Matilde Rubio sent 21 samples of the interior painted decoration at Tumacácori to the Center for Studies of Cultural Resources in Madrid for instrumental analysis by specialists André Sánchez Ledesma and Maria Jesús Gómez Garcia.[64] While the Lewis and Rubio report was never fully completed nor ever published, results of the analytical study generally corroborated Gettens' conclusions alongside a few new findings. The results of pigment identification in the 2001 analytical work ordered by Lewis and Rubio are combined with Gettens' 1949 analysis as described below:

Table 5.1: Pigments Found in 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	$FeO(OH)*nH_2O$ (yellow ochre) Fe_2O_3 (red ochre)	R.J. Gettens, 1949
White	Gypsum	$CaSO_4 * 2H_2O$	R.J. Gettens, 1949, Lewis & Rubio
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

5.3 – Current Conditions of Polychromatic Façade Finishes

The most recent assessment of Tumacácori's façade to provide preliminary condition evaluations in preparation for preservation was conducted in October 2013 by Angelyn Bass of the University of New Mexico's Department of Anthropology and Douglas Porter of the University of Vermont's School of Engineering in consultation with former NPS Chief of Resource Management Jeremy Moss.[65] Documentation was provided by NPS staff: Alex Lim mapped the location of historic plaster that was translated to ortho-rectified photographs by Jacob DeGayner and AutoCAD layouts by Keri Stevensen.[66] Approximately 155 square feet of historic plaster was estimated to remain on the exterior, however the difficulty of distinguishing between the historic and repair plasters that may have obscured the original fabric has been noted[67]

Façade conditions observed in 2013 were divided into categories of general, structural, and finish. Generally, where the adobe, brick, and lime mortar displays the greatest weather exposure, surface erosion is greatest. These areas include projecting portions of moldings, horizontal surfaces where water collects, bases of walls, and centers of columns; unsurprisingly, undecorated and decorated historic finishes can be found in protected areas.[68] Structurally, a reevaluation of the subsidence or rotation potential of the south and west walls may need to be reevaluated as failed repairs and broken telltales signify recent movement; cracks were noted in adobe and wooden substrates.[69] Lastly, the repair of the historic finishes has been approached inconsistently and repairs are not well integrated; it is noted that often the repairs (pointing mortar, fills and compensating plaster, edging, and mortar caps) aesthetically overpower the surviving historic fabric and confuse the viewer.[70]

The conditions of greatest concern include the overall detachment, cracking, and delamination of historic plasters and finished surfaces, flaking coatings, and voids behind plasterwork that leave extant surface finishes vulnerable and unsupported.[71] This results in loose fragments and blind voids that render the plaster extremely thin, brittle, and easily disintegrated – traces of plaster can be found along the base of the façade.[72] It is thus bearing in mind the fragile condition of these original polychromatic surface finishes and their relative significance that a technical analysis was requested as the basis of this thesis report.

Notes

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[25] Clemensen, 80.
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Chapter 6 – Practices in Finishes Analysis

6.1 – A Historical View of Finishes Analysis

The analysis and characterization of architectural finishes can help to sequence and understand aesthetic and technological change over time, provide evidence of traditional craft practices, and determine appropriate restoration treatments. While the analysis of historic paints began in the early 20th century with the improvement of cross-sectional techniques by Arthur Pillans Laurie and Rutherford J. Gettens, the restoration project of Colonial Williamsburg heralded the bulk of early paint analysis development through the work of Susan Nash.[1] In October 1929, Nash along with several others began a study of the colonial paint colors of early eastern Virginia and Maryland houses, resulting in one of the first attempts to document and reproduce architectural paint colors in a systematic fashion.[2] By producing a consistent palette of colors that was historically appropriate to either a general shared time period or a given building, Nash's work established paint standards such as the creation of a reference collection of painted sample boards to aid in color matching.[3] Concurrent research on the technical analysis of paints and finishes was done in the field of art conservation, and by 1942 Rutherford J. Gettens and George L. Stout had produced their glossary and bibliography, Painting Materials, that encompassed film substances, paint mediums, adhesives, pigments, solvents, tools and equipment.[4]

After World War II the research at Colonial Williamsburg shifted to further standardization of colors with an increased focus on in-situ testing, however analysis was purely by visual observation.[5] These tests were still somewhat unrefined at the time, and in the case of the Federal Hall National Memorial, National Park Service architects recommended a restoration scheme without having detailed the samples removed or documented condition reports; upon reinvestigation it was later found that the findings were stylistically inappropriate.[6] Indeed, it was not until the early to mid 1950s that samples were sent to external companies for more intensive analysis.[7] The chemical composition of paints was subsequently investigated to provide valuable information, such as the possible date of application based on pigments used, appearance under low magnification, solubilities, and the effects of microchemical testing in texts such as Joyce Plester's 1956 work entitled "Cross-Sections and Chemical Analysis of Paint Samples"[8]

Therefore by the 1960s both art and architectural conservation shared a similar range of utilizing macro to micro-scale analytical methods.[9] Thusly, in the development of a more standardized procedure for the analysis of historic architectural finishes, Penelope Batcheler of the National Parks Service published a methodology in 1968, "Paint Color Research and Restoration".[10] This leaflet detailed procedures for the preservation of paint evidence, exposure of paint layers, determination of finish coats and mediums, dating of finishes, finding evidence of past interventions, color matching, and subsequent paint formulas.[11] A few years later Batcheler's work was further expounded upon by Morgan Phillips, an architectural conservator with the Society for the Preservation of New England Antiquities who published a case study that addressed the issues of color matching and identifying the original surface characteristics of a finish, such as optical character and texture.[12] He and Norman Weiss followed this work in 1975 by outlining a methodology for numbering paint layers, polishing the surface, making a whitewash binder, and producing sanded paints in "Some Notes on Paint

Research and Reproduction."[13] However, the limits of self-taught paint recipes and restorations were also recognized as Frank Welsh concurrently published an article, "Paint and Color Restoration" in Old House Journal, a text geared toward the layman that discussed the methodology of paint research, common painting materials used in 18th and 19th century houses, proper sampling technique, and more importantly, the limits of repainting and do-it-yourself analysis.[14]

Thus paint analysis has developed into a more systematic methodology in that the attempt to reproduce historic paints and finishes has resulted in the analysis of the constituent components themselves.[15] Ultimately conservators, architects, and their clients acknowledged the necessity of creating systemic standards in the analysis of architectural finishes.[16] Indeed, in the case of Colonial Williamsburg it was not until the 1980s with the appointment of Frank Welsh that a more consistent analytical study, including microanalysis and modern color matching, of Williamsburg's early paints was completed.[17] Matthew Mosca's work at Mount Vernon in the 1980s also significantly added to the field of finishes analyses as he took into account the effects of aging, consequently disproving the previously established paint palette. [18]Susan Buck's work incorporating photomicrographs and the tagging of binding medium characteristics with fluorescence stains followed in the 1990s, ultimately creating new precedents for the microanalysis of architectural finishes.[19]

Ultimately, the current state of research within architectural finishes has evolved over the last quarter of a century to encompass analyses of both greater technical complexity and higher proficiency on the part of the analysts.[20] Several key developments have contributed to the improvement of professional practice in the field of architectural finishes, including the impact of increased access to training, expanded client expectations, and the development of the field across diverse disciplines.[21] Indeed, beyond historic paints the field has now grown to the analysis of modern paints and a greater sophistication of instrumental analyses.

Generally, a full stratigraphic analysis proceeds from the macro to micro scale and ideally includes both field investigation as well as cross-sectional analysis. Investigation will begin by establishing objectives for the paint analysis and reviewing the appropriate historical resources.[22] In doing so, the analysis can provide assessments as to a building's relative construction chronology and guide future restoration initiatives by helping to formulate a suitably compatible restoration or cleaning campaign.[23]

Following the determination of the project objectives and necessary historical research, in-situ investigation is employed to first situate an exposed paint scrape or crater in its appropriate context and then to determine which areas would be best suited for more in-depth analysis. Mechanical exposure is one of the earliest methods of in-situ investigation, in which finish layers are mechanically removed by utilizing scalpels and solvents.[24] However this more traditional procedure has been found to be both inaccurate and slow in certain situations, gradually leading to the rise of "cratering" as a more effective means of in-situ investigation.[25] In the process of cratering, a small knife is used to cut a hollow into the substrate; the edges are then alternatively sanded and treated with mineral oil in order to expose the stratigraphy on a graded slope.[26] The sequence of layers, including dirt, can be then documented in chronological fashion by visual observation.[27] Finally after scraping or cratering, complete paint areas of interest can then be extracted, ideally with substrate attached, to be further analyzed in the laboratory.[28] Ultimately, each method has its merits in certain situations and a conservator should consider carefully which would be ideal in each case – scraping enables a conservator to observe surface texture of finish layers, cratering can provide quick assessment of relative dating and diagnose areas for further analysis, and extraction can augment a database for further investigation.[29]

In selecting a sample location, the sample should be taken from areas that are difficult to access or have been built up with layers over time to avoid sampling areas that may have been previously stripped of finishes or heavily weathered.[30] Furthermore, samples intended for analysis should be ideally selected for their comparative relative value by correlating the chemical and physical qualities of the sample such as fracture locations, thickness of layers, dirt layers, colors, and finish types so as to provide guidance as to appropriate restoration data.[31] Indeed, the differences in chromochronology and number of layers can provide a myriad of information such as surface deterioration, different finishes' sensitivities to light and environment, weathering, paint application, frequency of space use, characteristic color and finish schemes, and alterations over time.[32] However, in terms of absolute versus relative dating of a paint layer, absolute often requires concrete documentation such as historic inventories, verified paint supply receipts, or photographs or known pigment introduction dates and analysis; relative dating on the other hand is often more practical for analytical fieldwork, as dates are determined through relative datable locations by utilizing knowledge of technology, stylistic trends, and dated alterations.[33]

Once a sample is removed from its original location, it can be embedded in a resinous mounting medium for cross-sectional analysis that provides more detailed investigation of constituent finish layers.[34] Data regarding the colorant's particle size and color, paint-film thickness, translucency, and opacity can then be determined in order to provide parameters for accurate color matching.[35]

Indeed one of the only definitive ways in which to determine whether a finish layer contained a pigment or binder that has changed appearance over time is by identifying the constituent components through microscopic analysis.[36] Some pigments are known to change appearance over time, therefore in order match to an appropriate analogous modern paint, it is imperative to match paints to standardized color systems.[37] Exposed layers are first visually compared to the Munsell color system and commercial paint palettes; these findings can then corroborated by a spectrophotometer or colorimeter to the CIE L*a*b* color system.[38] While color matching is a challenging endeavor due to varying degrees of degradation of the paint or subjectivity of analysis, generally a quantitative difference of 1.0 or less as measured by the delta E value between the spectrophotometer-determined CIE L*a*b* value and closest commercial match can be considered as virtually the same to the naked eye.[39]

Lastly, analytical instrumentation and microchemical tests can be employed for final phases of more targeted investigation. Microchemical tests can help to determine both solubility and reactivity of certain layers or certain pigments. Additionally, various types of microscopic and spectroscopic analyses can be utilized, such as polarized light microscopy to observe and compare particles to known references under plane and cross-polarized light, fluorescence microscopy by targeting particular layers' autofluorescent characteristics, scanning electron microscopy with energy-dispersive spectroscopy to analyze elemental composition, Fourier transform infrared spectroscopy and gas chromatography mass spectrometry.

6.2 – Relevant Research for Painted Surface Finishes on Earthen Architecture

While finishes analysis has grown considerably as a fully realized method of inquiry, the sector of exterior surface finishes for earthen architecture – and particularly for Spanish-Colonial mission architecture – has yielded comparatively less published research. Perhaps owing to the preponderance of missions with original polychromy schemes that had been whitewashed, as well as the extreme friability of the few surviving examples such as Mission San José de Tumacácori, research on painted limewashes or mission polychromy have fallen somewhere in between the categories of the immense literature published on true painted frescoes and prehistoric earthen finishes of archaeological sites.

Recognizing the paucity of scholarship done on this arena, the Getty Conservation Institute collaborated with the National Park Service to hold an international colloquium entitled "The Conservation of Decorated Surfaces on Earthen Architecture" at Mesa Verde National Park, Colorado from September 22-25, 2004. Publication editors Leslie Rainer, Senior Project Specialist in the Field Projects division of the Getty, and Angelyn Bass Rivera, conservator based in Santa Fe, New Mexico, have both written extensively about the subject of earthen architectural finishes in addition to having acted as consultants for Tumacácori.

However while the colloquium proceedings provided several rich case studies and possessed a purposefully internationally minded scope, the only representations of architecture from the United States were of archaeological sites such as Mesa Verde, Awatovi, and Kawaika-a. Thus, further sustained research into the exterior finishes of mission architecture remains a sector with an imperative need for future development and scholarship so as to insure the longevity and preservation of those few sites, like Tumacácori, that possess remnants of original painted exterior decoration.

Notes

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Chapter 7 – Overview of Analytical Methodology

7.1 – General Methodology

Methodologies for the materials analysis portion of this investigation were initially proposed during archival and contextual research, yet prior to on site field investigations. While knowing that specific analytical approaches would likely shift after in-situ observations, a general investigative and testing scheme was laid out in a roughly macro to microscopic progression with an emphasis on finish composition.

In order to distill the scope of this project to allow for completion in the preexisting schedule, the original surface finishes were deemed the chief focus of examination. Cursory investigations of the stucco substrate by bulk visual observation and thin-section petrographic analysis were also performed. Thus while samples of repair campaigns were taken, they were not included in primary analyses; a materials analysis of their composition and subsequent associated properties could be a topic for future research. Furthermore, while the second set of surface finishes taken from a collection of fallen fragments were included in general analyses, they were deprioritized due to the inability to know their exact provenance.

7.2 – Field Investigations

In January of 2015, the author was part of a team from the Penn Architectural Conservation Laboratory that visited the site in order to conduct preliminary investigations to aid in subsequent analyses and assessment. During this trip, high-resolution photographs of the façade were taken to create an ortho-rectified photomontage as a base image for future inspections. This was done by using a DSLR camera on a scissor lift to photograph portions of the façade's surface, then digitally stitching the images in Adobe Photoshop to fit previous photogrammetric measurements as recorded during the Historic American Buildings Survey conducted in 1975 by Perry, Myra, and Christina Borchers at Ohio State University.

Figure 7.1: Creating an ortho-rectified image January 2015

Figure 7.2: Taking samples of a repair campaign January 2015

While on site, NPS Exhibition Specialist Alex Lim noted that the current NPS mason tends to prefer coarse coats of plaster for repairs visible on faces and that storms tend to travel east to west on site. Following preliminary documentation, original surface finishes and subsequent repair campaigns were examined in-situ and small samples from protected areas were taken for further laboratory analysis.

Annotated sample location documents can be found in "Appendix B: Sample Location Map Set (January 2015)" A series of historic images ("Appendix A: Historic Photograph Set of Mission San José de Tumacácori's Façade") were brought to site to inform sampling strategy, and all sample locations were carefully photographed and notated upon a large printed elevation of the 1970s HABS façade drawing. Unfortunately, the blue surface finish as documented in the *nicho* was both not readily apparent while on site but also difficult to access, so samples were not taken from those areas. Samples of finish coatings were also taken from previously fallen fragments that had been collected by NPS staff.

The overarching observation from this field visit was that there is a surprising amount of original painted plaster still remaining in protected locations. For all of the stabilization and restoration efforts imposed upon the structure, it is truly remarkable that so much original painted fabric still survives, albeit in extremely fragile, friable condition. Much of the stucco is quite unstable and the merest amount of applied force tends to cause delamination from the surface, powdering easily.

7.3 – Hypotheses for Subsequent Analyses

These initial field investigations and preliminary documentation informed the finalization and adjustment of which methods of materials analysis would be most prudent to perform in the case of the Mission San José de Tumacácori. The decisions regarding materials investigation were taken bearing in mind the following guiding questions:

- *What is the original composition of these painted finishes*
- *What was the original manner of application?*
- *Are there distinct differences within and between color groups and their subsequent application?*
- *What are the most appropriate methods of materials analysis to perform?*
- *How can these findings help to appropriately plan for future conservation and subsequent interpretation?*

Upon return to the Penn Architectural Conservation Laboratory, it was noted that a few samples did not fare well in transit between Arizona and Pennsylvania. However from the cohort of samples taken from the field, a group of twenty was gathered as the intact, representative candidates for finishes analysis. Investigation into the inorganic components – the pigment, plaster paste, and aggregate – was given precedence. Indeed, analysis of binders and additives on exterior surface finishes is notoriously difficult, and not only requires a great deal more sample but also extended consultation and the skilled expertise of those trained in instrumental chemical analysis.

A final flowchart depicting the methodological approaches and subsequent analytical schemes is presented as follows:

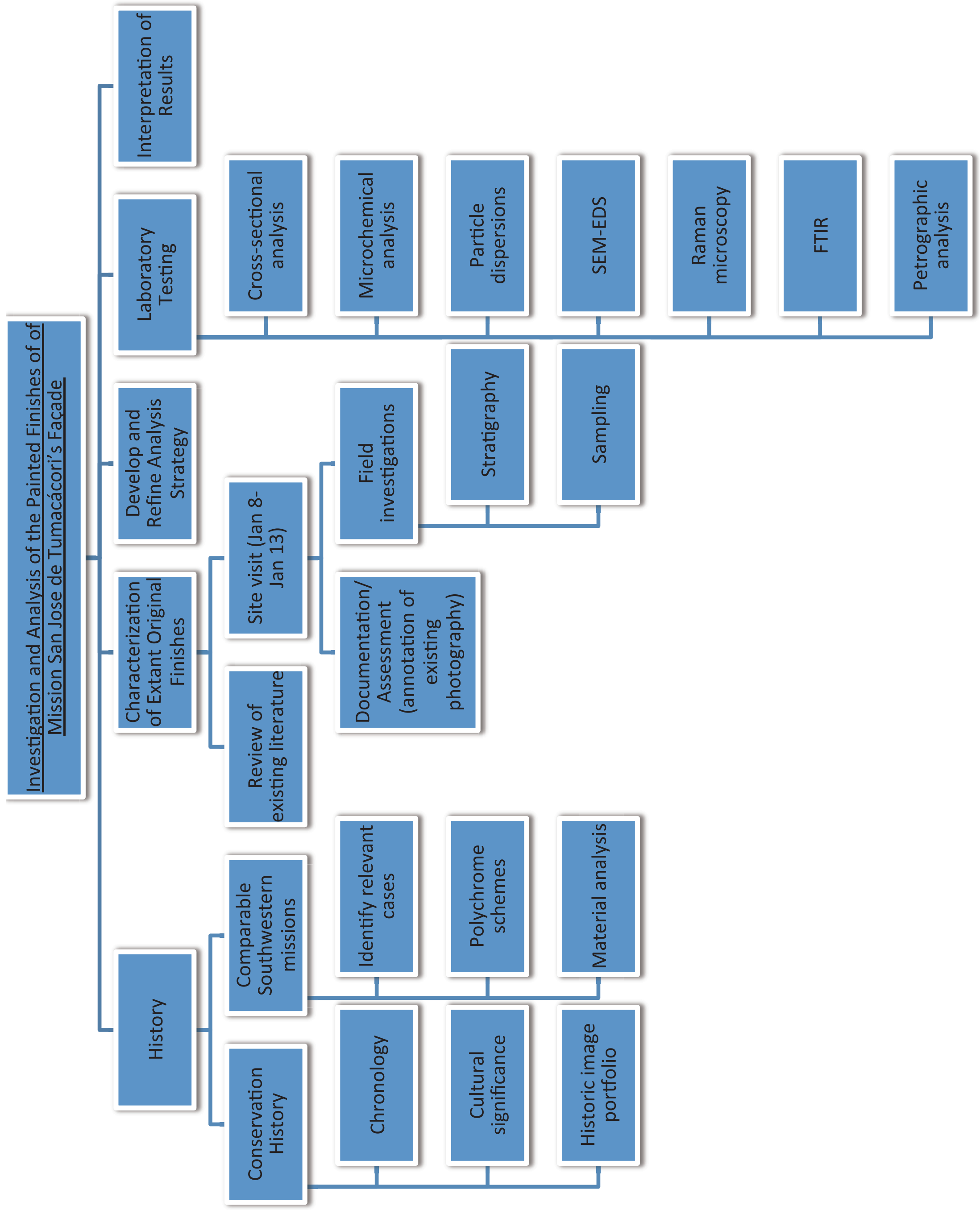


Figure 7.3: Methodological flowchart

Chapter 8 – Bulk Stratigraphy: Cross-Sectional Analysis by Optical Microscopy

8.1 – Analytical and Methodological Principles

Cross-sectional analysis by optical microscopy is one of the primary starting points of finishes analysis as it allows for an examination of the finish interface. By embedding the samples in a polyester acrylic resin, taking a representative slice from the sample, and creating highly polished cross-sections, bulk stratigraphy can be characterized.

The embedding medium Bioplast, a polyester monomer casting resin, has been heavily utilized and documented for its use in biological industries.[1] Unlike many epoxies and acrylic-based resins, it has exhibited relatively stable behavior and lack of major long-term degradation over time.[2] Furthermore, its behavior after the addition of the catalyst holds several benefits for the embedding of cultural heritage materials as it retains quality edges, has a lower hardness compared to epoxies, overall low viscosity, exhibits less stress when subjected to a vacuumed environment, and has a relatively slower cure time[3] All activity involving Bioplast was performed within a laboratory fume hood due to the liberation of hazardous fumes upon addition of the catalyst that begins the polymerization process, indicated by a color change from light blue to light green.

Once cross-sections are made, reflected optical microscopy is employed in order to make characterizations about the finish's bulk stratigraphy. The observations and conclusions gleaned from initial visual characterization were later used to subsequently adjust for the addition and refinement of future sample sets.

8.2 – Sample Preparation Methodology

Samples were first examined under a Leica stereomicroscope using reflected light microscopy in order to determine overall texture and bulk stratigraphy. These unmounted samples were photographed using Nikon Digital Elements BR software. When possible, fragments of bulk samples were saved in case they proved helpful for any future analysis.

To prepare the samples for embedding, Buehler mold release agent was applied to small cube trays and an initial layer of Bioplast mixed with the appropriate catalyst was poured. Once cured, small sample labels were printed using 4-point font while a fresh stock of Bioplast was prepared in order to fully embed the samples. However after placing the samples and their corresponding labels into the cube trays and beginning to pour the Bioplast resin, copious amounts of air bubbles were noted owing to the extremely porous nature of the substrate. Therefore, the amount of catalyst used and time elapsed between pours were subsequently adjusted to allow for time in which to manually disperse and minimize the bubbles as they appeared.

The sample tray was then wrapped with paper towel to prevent dust particulates and other potential contaminants from being caught within the resin as it cured. The samples were placed to cure underneath a 100-watt incandescent light bulb in order to gently accelerate the curing process by exposure to light and heat. After approximately a week of cure time, the samples were removed from their embedding trays and examined again under a Leica MZ16a stereomicroscope to observe general embedding characteristics and overall stratigraphy. These observations were used in order to strategically determine approximate location from which to cut the cross-section slice from.

The samples were cut using a Buehler IsoMet low-speed saw with polycrystalline diamond blade. Cut cross-sections were then polished by using sandpapers and polishing pads of successively finer grit; Stoddard solvent was the only type of lubricant used in the polishing process as Micropolish would interfere with intended scanning electron microscopy and elemental analysis. Due to this planned future analysis, samples were subsequently left unmounted and kept in separate coin envelopes for the duration of the investigative process. This allowed for more efficient transfer between various types of instrumental analysis such as SEM-EDS and Raman microscopy. These cross sections may be kept unmounted or Cargille Meltmount can be used to adhere the cross-sections to a microscope slide for more permanent, secure storage purposes.

Photomicrographs were taken at various stages of the process and magnifications in order to compile comprehensive stratigraphic data sets. The first is comprised of photomicrographs of the overall bulk samples prior to embedding. Once the embedded and polished cross-sections were produced, a set of photomicrographs depicting the full lengths of each cross-section were taken. These first two sets of photomicrographs were taken on the aforementioned Leica MZ16a stereomicoscope and utilized reflected light with the aid of fiber optics for additional lighting. However for all subsequent photomicrographs a retrofitted Nikon Alphaphot-2 was utilized that allowed for observations under both visible and ultraviolet light. This provided increased clarity when analyzing cross-sections and final sets of photomicrographs depicting each sample in plain visible light, a mixture of ultraviolet and visible light, and plain ultraviolet light were taken at two different magnfications.

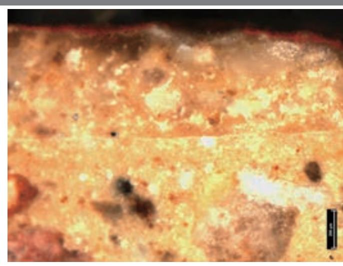
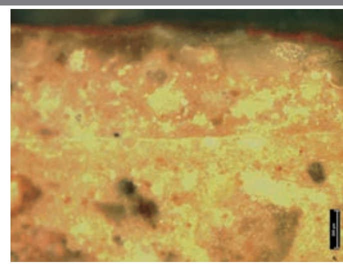
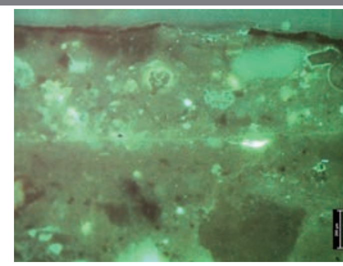
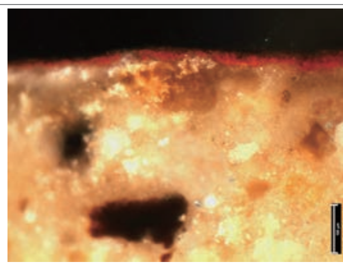
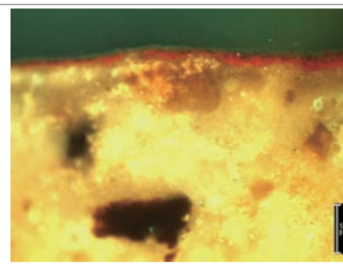
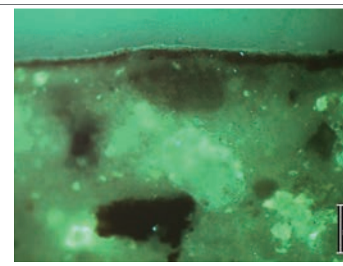
8.3 – Observations and Analysis

It should be noted that in taking photomicrographs across various instruments, an inconsistency in fields of view and magnifications was noted. While the microscopes were calibrated against a standard micrometer to ensure that the scale bars were correct, the issues of field of view are still not currently resolved. Thus while inserted ruler bars show correct scale and photomicrographs themselves are taken correctly, the unresolved question of the microscopes' field of view complicates comparison across photomicrograph sets slightly.

The full data sets compiled for each surface finish sample can be found in "Appendix C: Cross-Section Stratigraphy Data Sets" alongside their corresponding sample locations. A summary of the colors found amongst the twenty samples taken from the January 2015 site visit follows below, as well as sample stratigraphy sheets depicting the two final photomicrograph sets taken from five particularly noteworthy samples. These samples include a red finish sample (TUMA_12), two yellow finish samples (TUMA_06 and TUMA_11), a white finish sample (TUMA_03), and the orange finish sample (TUMA_14).

Table 8.1: Summary of Tumacácori Surface Finish Cross-Section Observations			
Color	Samples	Location	Notes
Red	TUMA_01	Upper left broken cornice	Thicker white preparatory with thin red finish
	TUMA_12	Lower left face above nicho	Red on white preparatory, can see lime border lines visible in UV
	TUMA_27	Lower right column? A. Lim	Traces of orange-red pigment on white preparatory layer, lime border line visible in UV
	TUMA_28	Lower right column? A. Lim	Traces of red over thick white preparatory layer, lime border lines visible in UV
Yellow	TUMA_06	Upper face above nicho	Very thick yellow layer – pigment appears dispersed and not on a preparatory layer?
	TUMA_07	Upper left face	Yellow thick layer
	TUMA_09	Upper column shaft	Paste of substrate, white, yellow – discrete layers
	TUMA_11	Lower left cornice	Very clear, pigmented with red and yellow on white preparatory layer. White layer appears to be on a very weathered white substrate, black appears to be biological microflora
	TUMA_13B	Extradose molding	Yellow layer with mixed red pigments, thin preparatory layer
	TUMA_19	Lower left return of inner edge (outer surround)	Pigment appears dispersed in preparatory layer?
	TUMA_26	Lower right column? A. Lim	Discrete layers with yellow-cream finish, lime border lines visible in UV
	TUMA_29	Lower right column? A. Lim	Remnant of yellow on white preparatory layer
White	TUMA_02	Upper left frieze	White even preparatory layer, yellowish cream intermittent?
	TUMA_03	West side leftmost capital	Thick white preparatory layer, white finish layer
	TUMA_04	Upper left frieze	Missing a lot of surface
	TUMA_08	Column shaft to right of nicho	Appears there was a white finish, gone
	TUMA_13A	Scored joint of the extradose above voussoirs	Vey thin white layer on top of yellow layer
	TUMA_25	Lower right column? A. Lim	Thick cream layer with some pigment, not discrete layer
	TUMA_30	Lower right column? A. Lim	Cream layer – possibly preparatory layer?
Orange	TUMA_14	Intradose voussoir	Yellow stained upper zone, not a discrete layer sitting on surface

Stratigraphic Analysis of TUMA_12 (Red)

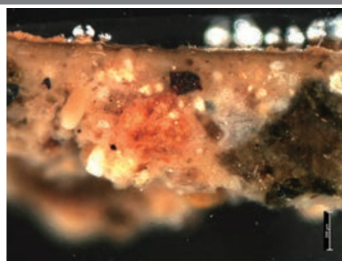
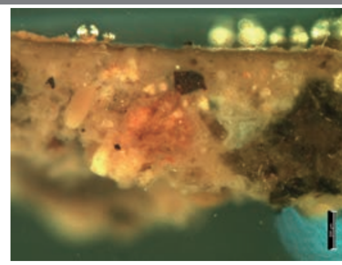
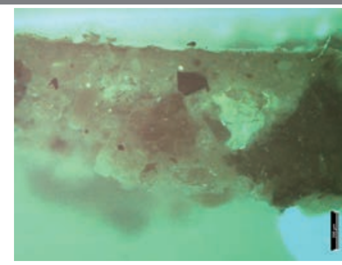
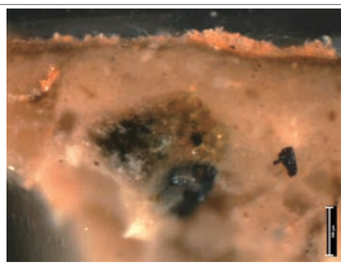
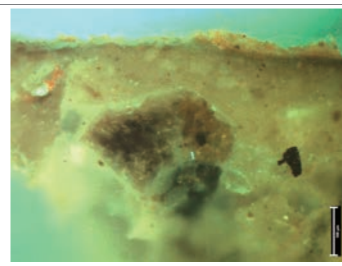
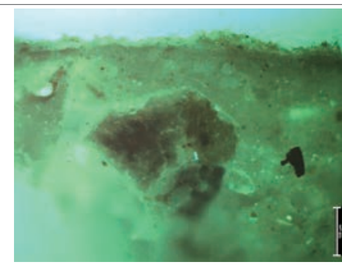
Table 8.2: Stratigraphic Analysis of TUMA_12 (Red)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Lower left face above nicho	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thin preparatory white finish layer
- Layer 2: bright red pigmented finish, discrete particles visible suggesting inorganic pigment
- Very clear, discrete layers
- Can see what may potentially be indication of lime laitance (more visible in ultraviolet light)
- Will be used for subsequent analyses as representative red pigment sample

Stratigraphic Analysis of TUMA_06 (Yellow)

Table 8.3: Stratigraphic Analysis of TUMA_06 (Yellow)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

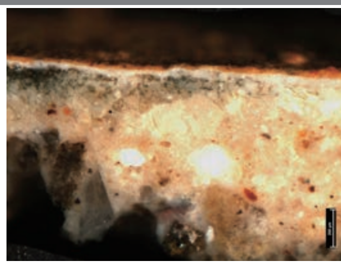
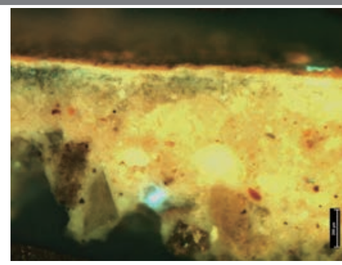
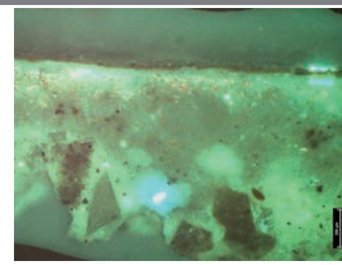
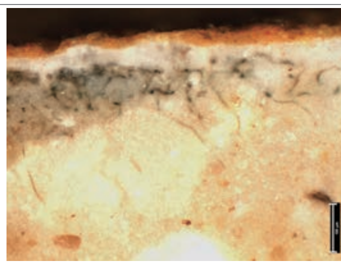
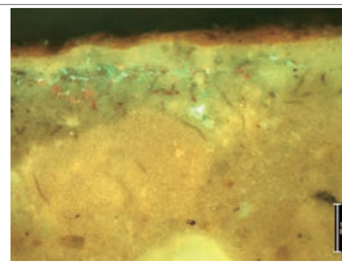
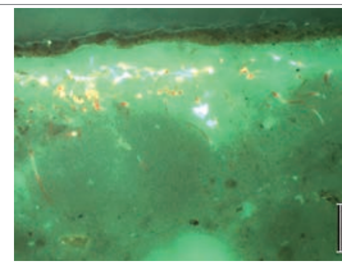
Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Upper fact (left) above nicho	F. Matero, J. Chan	1/9/15	J. Chan
Microscope	Light Source	Filters	Camera
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular mag	Trinocular mag	Objective mag	Zoom
10.0x	1.0x	4.0x, 10.0x.	-

NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: brownish-yellow layer across entirety of sample that does not appear to be applied on preparatory layer or as a discrete surface (particles seem integral to plaster substrate)
- Layer 2: some bright yellow pigment left on surface that appears more consistent with other applied pigment particles suggesting inorganic nature

- Brownish-yellow layer appears more organic
- To be used for subsequent analyses as sample of potential limewash staining (e.g. to test for application of ferrous sulfate) or application of organic layer

Stratigraphic Analysis of TUMA_11 (Yellow)

TABLE 8.4 STRATIGRAPHIC ANALYSIS OF TUMA_11 (YELLOW)			
	VISIBLE	ULTRAVIOLET/VISIBLE	ULTRAVIOLET
40X			
100X			

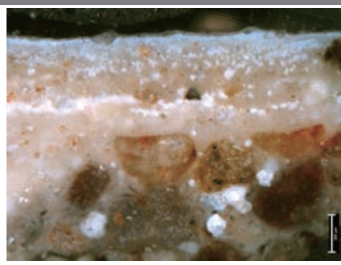
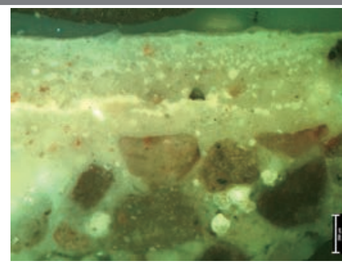
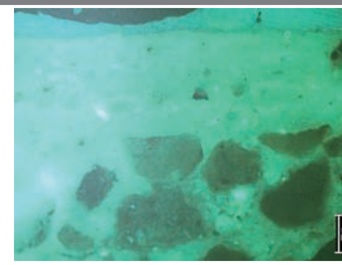
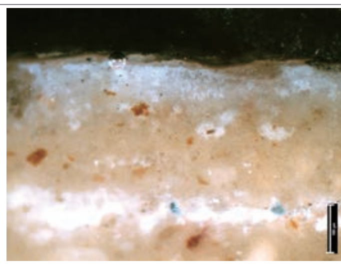
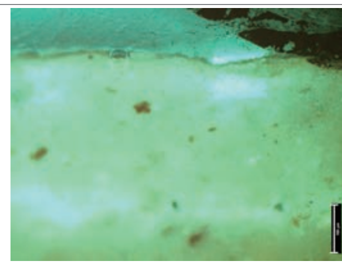
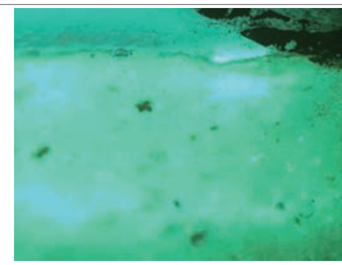
MICROSCOPY METADATA			
LOCATION	SAMPLED BY	SAMPLED ON	ANALYZED BY
Lower left cornice	F. Matero, J. Chan	1/9/15	J. Chan
MICROSCOPE	LIGHT SOURCE	FILTERS	CAMERA
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
OCULAR MAG	TRINOCULAR MAG	OBJECTIVE MAG	ZOOM
10.0X	1.0X	4.0X, 10.0X.	-

NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thick preparatory white finish layer
- Layer 2: orange-yellow pigmented finish, discrete particles visible suggesting inorganic pigment; some red pigment particles visible in upper finish layer

- Very clear, discrete layering
- White preparatory finish layer appears to be on very weathered white substrate, suggested that it was applied atop an already dried surface
- Black tendrils appear to be some type of biological microflora

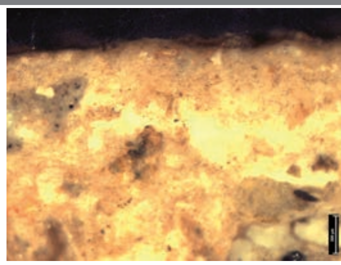
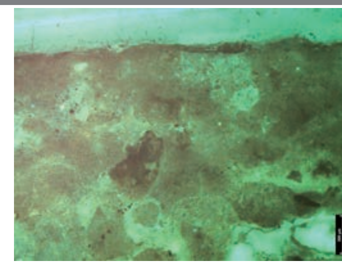
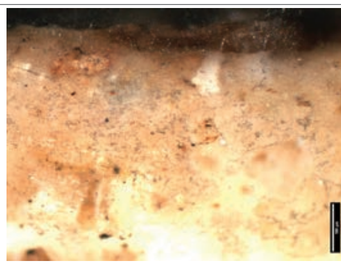
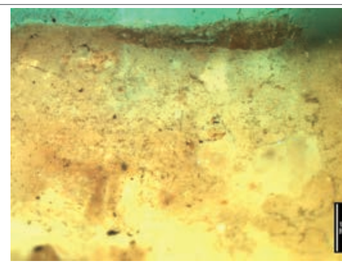
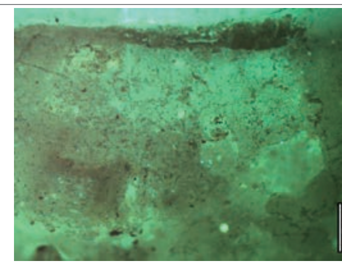
Stratigraphic Analysis of TUMA_03 (White)

Table 8.5 Stratigraphic Analysis of TUMA_03 (White)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			
Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Upper, outer left capital (west side)	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-
NOTES			

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thick preparatory white finish layer
- Layer 2: orange-yellow pigmented finish, discrete particles visible suggesting inorganic pigment; some red pigment particles visible in upper finish layer

- Very clear, discrete layering

Stratigraphic Analysis of TUMA_14 (Orange)

Table 8.6 Stratigraphic Analysis of TUMA_14 (Orange)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			
Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Intradose voussoir	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-
NOTES			

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: brownish-yellow layer across entirety of sample that does not appear to be applied on preparatory layer or as a discrete surface – potentially similar to TUMA_06
- Colored layer appears distressed
- Black particles are likely residue from carbon paint applied during SEM-EDS, may be instructive to retake photographs with new cross-section off billet

While cross-sectional analysis successfully provided a manner in which to form initial observations and characterizations, in the future it may be prudent to consider a different methodological approach when dealing with emedding extremely porous samples for cross-sectional analysis. Indeed, an alternative methodology for the cross-sectional analysis of porous materials has been previously developed, which posited that soaking the samples in uncatalyzed Bioplast then utilizing a vacuum chamber to minimize the entrapment of air bubbles would yield improved results.[4] Following the emedding of samples in Bioplast, it was noted that several air bubbles remained on the surface as well as within the overall resinous matrix. For some samples, upon the addition of Stoddard solvent it was apparent that there were several areas where the resin did not fully absorb.

Cross-sectional analysis was markedly improved by the use of fluorescence microscopy at varying intensities of ultraviolet light. While autofluorescent properties can be exaggerated by the application of various stains, typically used to help determine binding medium, these samples were purposely left unstained since these coatings tend to not be as efficacious when the sample itself is quite porous. In certain samples, photomicrograph sets were retaken after SEM-EDS analysis, however particles of carbon paint used during SEM-EDS may have flaked when Stoddard solvent was used in examination. Thus when viewing these carbon-paint coated cross-sections under the microscope in the future, distilled water instead of Stoddard solvent is recommended.

Perhaps the most curious observations and conclusions gleaned from cross-sectional analysis was the marked differences between samples with discrete, layered stratigraphies versus those samples with stratigraphies where it appeared the colorant was not as a discrete layer but rather an integral part of the substrate. This prompted further research into the use of various compounds for historic limewash staining and informed subsequent analytical work.

Notes

[1] Victoria Pingarron Alvarez, "ACL Cross Section Preparation" for *HSPV 555-01: Introduction to Conservation Science* (University of Pennsylvania: Philadelphia 2014, Print)
[2] Ibid.
[3] Ibid.
[4] Dan Stuart Castele, *Unveiling Ancestral Iconography: An Analysis of 13th C. AD Earthen Finishes Through Infrared Thermography at Fire Temple, Mesa Verde National Park*. Thesis, (University of Pennsylvania, 2013. *ScholarlyCommons - Penn Libraries University of Pennsylvania*) Web.

Chapter 9 – Pigment Identification: Microchemical Analysis

9.1 – Analytical and Methodological Principles

Microchemical testing is a simple, inexpensive, and expedient method in which to identify pigments or components of historic finishes. Requiring only basic reagents commonly found in most typical laboratory setups, microchemical analysis can be easily performed without the use of highly specialized knowledge or sophisticated equipment. Furthermore, only a very small amount of sample is needed for testing, as these chemical tests are both specific and fairly sensitive in testing for commonly occurring ions that react in characteristic manners to certain reagents due to solubility or decomposition rules. Generally, the pigment sample is first decomposed then a particular reagent is added in order to induce a reaction that can be visually detected.

When aqueous solutions of ionic compounds are mixed, certain ionic species will form solid precipitates as governed by the solubilities of the reagents. Microchemical testing of common cations and anions found in architectural materials often take advantage of these solubility rules in order to yield confirmatory tests by the formation of insoluble precipitates. Generally, salts containing Group I elements, the ammonium ion, and the nitrate ion are soluble with a few exceptions.[1] Halide containing salts are also mostly soluble, while important exceptions to this solubility rule include the halide salts of silver, lead, and mercury.[2] Indeed, most silver salts are generally insoluble.[3] Most sulfate salts are soluble, however important exceptions include calcium, barium, lead, silver, and strontium sulfates.[4] Hydroxide salts are only slightly soluble, with Group I hydroxide salts being soluble and Group II hydroxide salts being slightly soluble – however hydroxide salts of transition metals and Al^{3+} are insoluble.[5] Finally, other generally insoluble compounds include sulfides of transition metals, carbonates, chromates, phosphates, and fluorides.[6]

For the purposes of analyzing the historic Tumacácori finishes, three tests were performed with specific hypotheses in mind and the aim that these results could corroborate and guide the other analytical work to be performed, such as SEM-EDS. As microchemical testing was performed between sessions of SEM-EDS, subsequent hypotheses were formulated in tandem with the previously gathered instrumental data.

One of the primary considerations before performing SEM-EDS was to determine whether the preparatory layers were lime based as opposed to gypsum based. Knowing that sulfur is an elemental component of gypsum, if the preparatory layers were found to contain sulfur through microchemical testing it would have implications on differentiating the pigment layers from the preparatory layers during SEM-EDS since other potential colored pigments, such as vermillion, also contain sulfur. While microchemical testing regarding the cream preparatory layers was performed in advance of performing any initial sessions of SEM-EDS, subsequent chemical analyses that followed SEM-EDS centered upon identifying the composition of the red pigment layer. Thus, microchemical analysis was used as a confirmatory method to support or disprove the data acquired through instrumental means. Specific compounds targeted included iron, due to the curious absence of iron in the elemental mapping, and lead, whose spectra is known to overlap with that of sulfur and molybdenum.

Overall, the four tests that were performed are outlined as shown below with their corresponding objectives:

TABLE 9.1: METHODOLOGICAL APPROACH FOR SELECTED MICROCHEMICAL ANALYSIS				
HYPOTHESIS	PIGMENT	FORMULA	COLOR	EXPECTED REACTIONS
Prior to SEM-EDS, are the preparatory layers that have been noted in several samples lime or gypsum based?	Chalk	$CaCO_3$	White	Gas evolution upon the addition of nitric acid
	Gypsum	$CaSO_4 \cdot 2H_2O$	White	Formation of needle-like calcium sulfate crystals upon addition of nitric acid and heat
After the first set of SEM-EDS, is the red pigment that appears as a discrete bright red layer iron based, lead based, or sulfur containing?	Red Ochre (Hematite)	Fe_2O_3	Red	Formation of blue color after addition of potassium ferrocyanide to treated sample
	Red Lead	Pb_3O_4	Red	Formation of yellow color after addition of potassium iodide to treated sample

9.2 – Sample Preparation Methodology

Experimental procedure was developed in accordance to Nancy Odegaard, Scott Carroll, and Werner S. Zimmt's *Material Characterization Tests for Objects of Art* as well as the laboratory handout, "Qualitative Analysis of Pigments: Microchemical Identification of Pigments" from the Advanced Conservation Science course at the University of Pennsylvania.[7] Using a series of initial and confirmatory tests, TUMA_25 and TUMA_12 were tested as representative samples of white bulk preparatory and red finish layer respectively alongside standard known pigments.

For the microchemical testing of selected white pigments to differentiate between lime and gypsum, all samples were first treated with dilute nitric acid to observe the presence or absence of gas evolution. Upon gentle heating, the gypsum sample will form characteristic needle-like calcium sulfate crystals when viewed under the stereomicroscope, while chalk will require the addition of dilute sulfuric acid to the acid treated sample to induce the information of these crystals.

Preliminary treatment for the microchemical testing of iron and lead ions in red pigments proceeded by treating all samples with dilute hydrochloric acid, heating to evaporation, then allowing to cool. To test for iron, one drop of potassium ferrocyanide is added to produce the formation of a slight blue color. To indicate the presence of lead, the acid-treated sample is redissolved in distilled water and a crystal of potassium iodide is added to observe the formation of a bright yellow precipitate.

9.3 – Observations and Analysis

As microchemical testing is generally a qualitative method of analysis, each sample was run alongside corresponding standards of known pigments as follows.

Identification of White Preparatory Pigments:

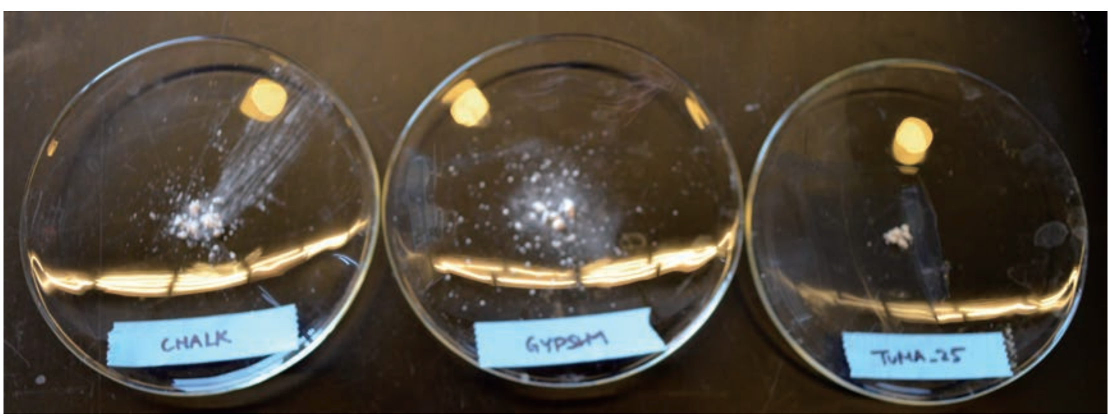


Figure 9.1: Standard samples of chalk and gypsum tested alongside sample scraped from TUMA_25

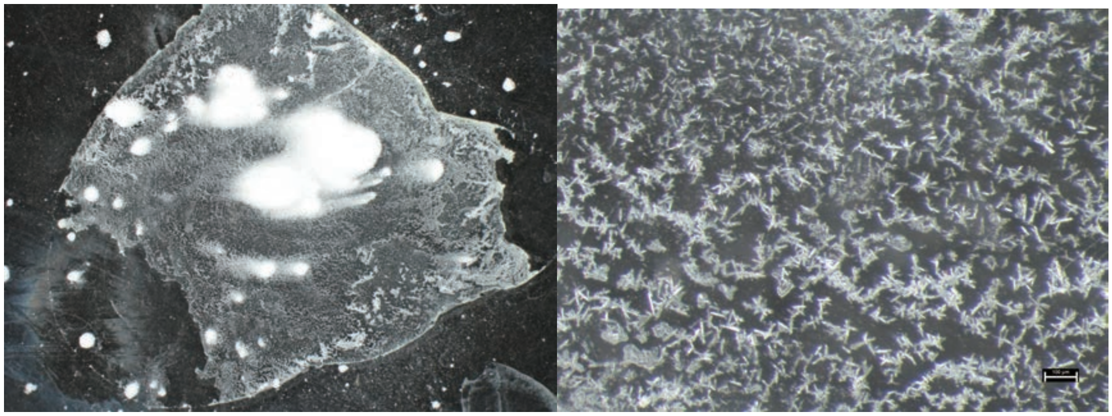


Figure 9.2: Standard sample of gypsum after nitric acid treatment and heat. Left shows sample under reflected light stereomicroscope at 0.5x magnification and right shows sample at 5x magnification. Note the formation of characteristic needle-like calcium sulfate crystals.

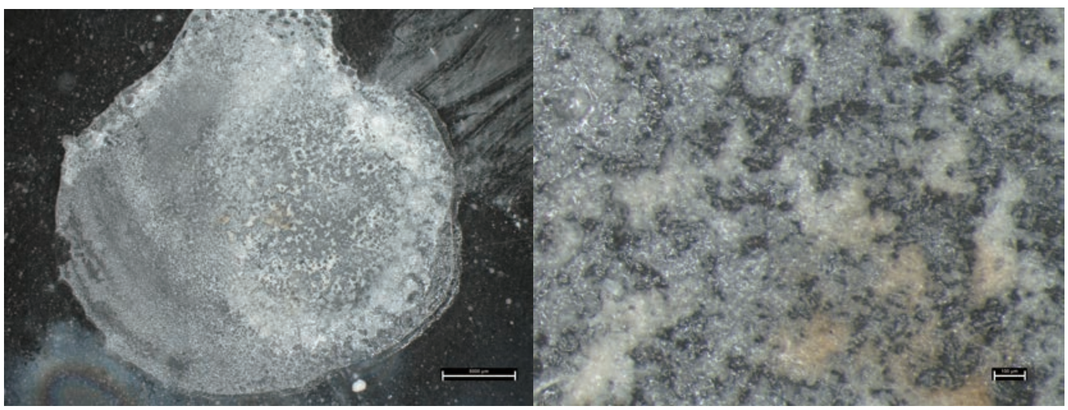


Figure 9.3: Standard sample of chalk after nitric acid treatment and heat. Left shows sample under at 0.5x magnification and right shows sample at 5x magnification.

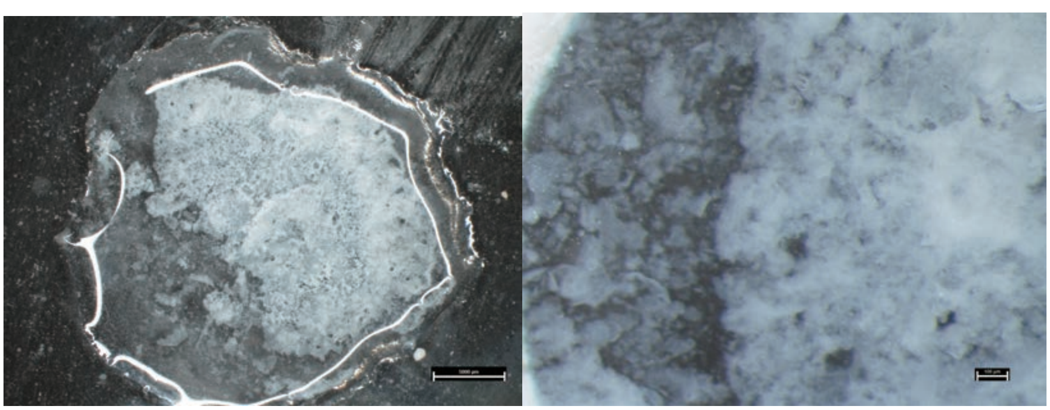


Figure 9.4: Standard sample of chalk after addition of sulfuric acid. Left shows sample under reflected light stereomicroscope at 0.5x magnification and right shows sample at 5x magnification. Crystals seem to be a conglomerated mass.

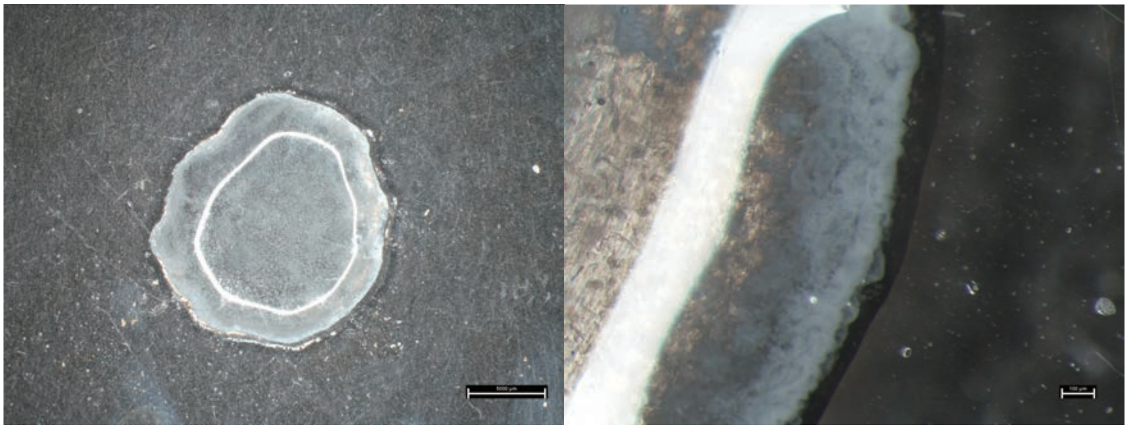


Figure 9.5: Sample of TUMA_25 preparatory layer after preliminary nitric acid treatment, heat, and addition of sulfuric acid. Left shows sample under reflected light stereomicroscope at 0.5x magnification and right shows sample at 5x magnification. Sample behavior appears more close to that of the chalk standard sample, with conglomerated crystals and the formation of some thin-needle like crystals in solution.

TABLE 9.2: IDENTIFICATION OF WHITE PREPARATORY PIGMENTS				
REAGENTS USED	ION	CHALK	GYPSUM	TUMA_25
NITRIC ACID (HNO3)	CO_3^{2-}	Gas evolution	No gas evolution	Gas evolution, less violent than sample of pure chalk
HEAT	SO_4^{2+}	No discernable change other than evaporation	Formation of needle-like crystals when viewed under stereomicroscope	No discernable change other than evaporation
SULFURIC ACID (H_2SO_4)	SO_4^{2+}	Slight reaction upon addition of sulfuric acid, conglomeration of crystals	NA	Appears more similar to chalk standard, conglomeration of crystals on edge, appears some thin needle-like crystals in solution

Identification of Iron in Red Preparatory Layer:

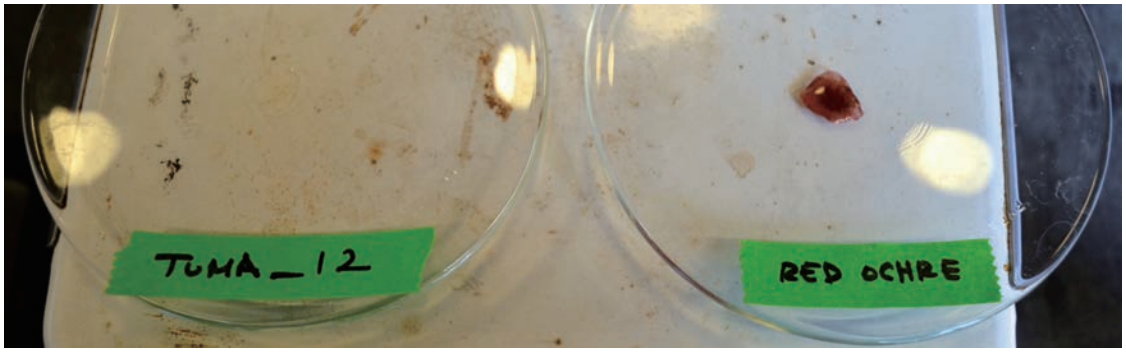


Figure 9.6: Standard samples of red ochre tested alongside sample from TUMA_12

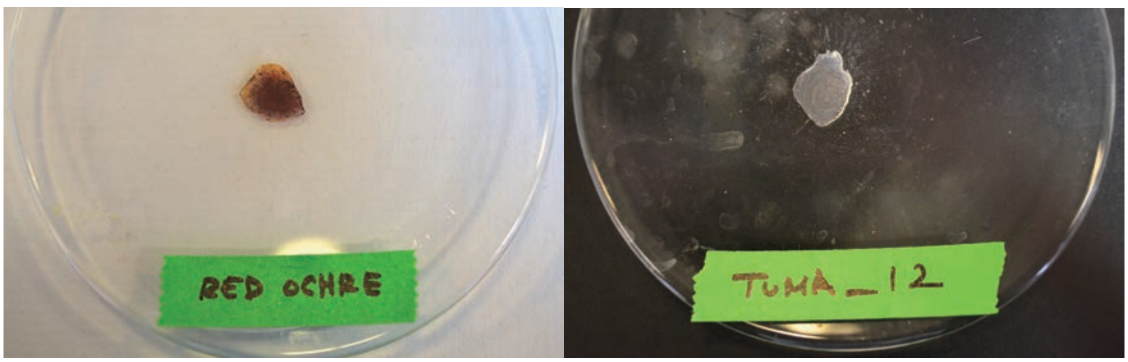


Figure 9.7: Standard samples of red ochre and sample from TUMA_12 after treatment of hydrochloric acid and heat.

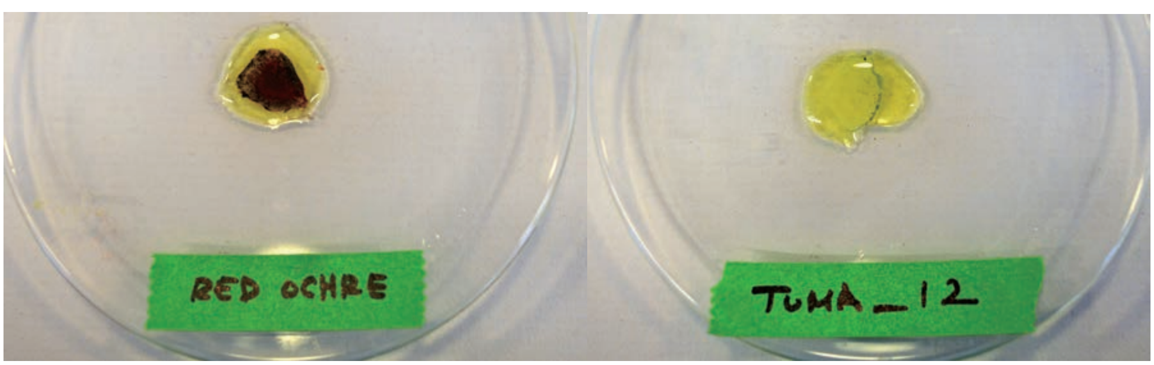


Figure 9.8: Standard sample of red ochre and TUMA_12 sample after HCl-treated sample was redissolved in distilled water and addition of a drop of potassium ferrocyanide. Note formation of thin blue ring around the sample area in TUMA_12.

Table 9.3: Identification of Iron in Red Pigment layer			
Reagents used	Ion	Red Ochre (Hematite)	TUMA_12
Hydrochloric Acid (HCl) + H_2O	Cl^-	Reaction upon addition of HCl	Slight reaction upon addition of HCl
HCl + H_2O + Potassium ferrocyanide	Fe^{3+}	Darkened maroon reaction with dark purple-blue ring around edge of sample	Formation of thin dark blue ring around edge of sample

Identification of Lead in Red Preparatory Layer:

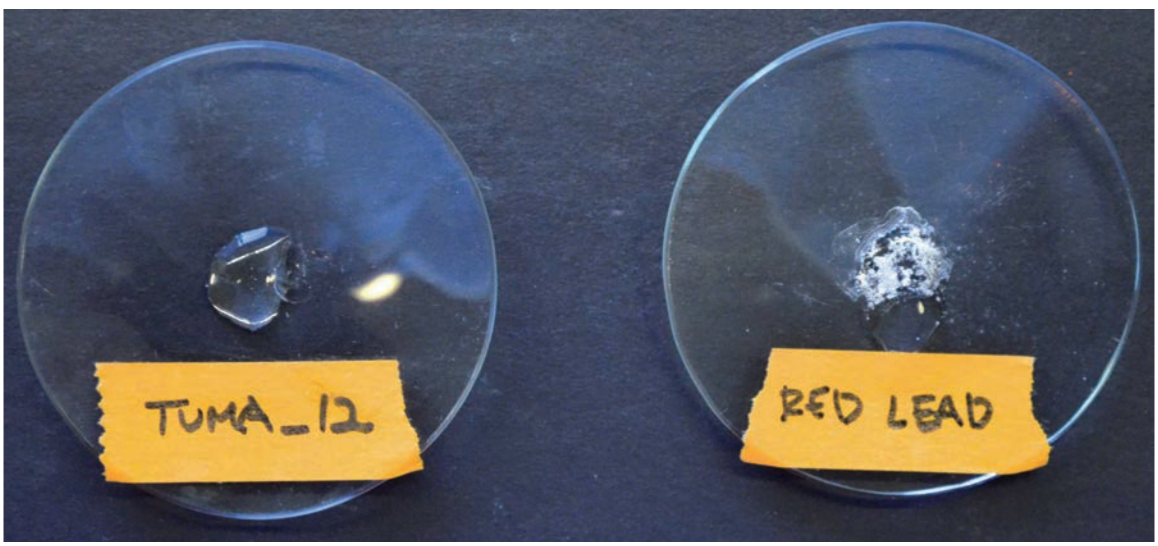


Figure 9.9: Standard samples of red lead tested alongside sample from TUMA_12 after treatment with hydrochloric acid.

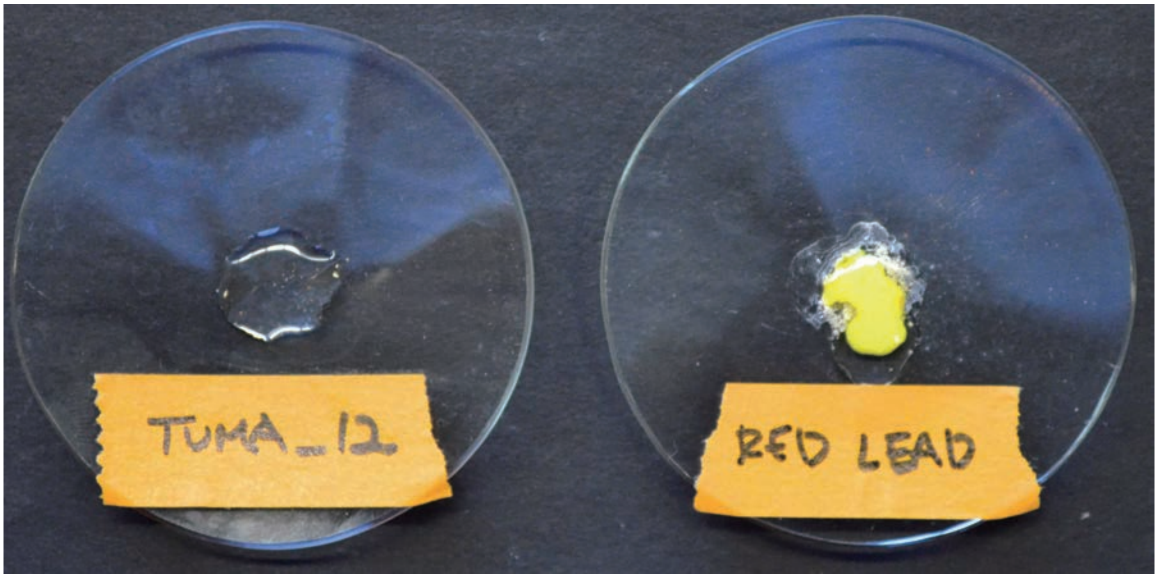


Figure 9.10: Standard samples of red lead tested alongside sample scraped from TUMA_12 after acid-treated sample was heated, crystals redissolved with distilled water, and one crystal of potassium iodide was added. Note the formation of a characteristic bright yellow precipitate indicating presence of lead in red lead standard.

TABLE 9.4: IDENTIFICATION OF LEAD IN RED PIGMENT LAYER			
REAGENTS USED	ION	RED LEAD	TUMA_12
HYDROCHLORIC ACID (HCL)	Cl^-	Reaction upon addition of HCl and heat	No reaction upon addition of HCl and heat
POTASSIUM IODIDE (KI)	Pb^{2+}	Formation of bright yellow precipitate	No reaction

Overall, microchemical testing suggests that the bulk preparatory layers are primarily composed of lime and the red pigments contain iron. Moreover, owing to initial SEM-EDS analysis indicating a spectrum that typically overlaps with lead and sulfur, it can be hypothesized that since lead was not detected through microchemical testing that there is a contributing component of sulfur. While the advantages of microchemical testing have been previously detailed, analyses must be carefully controlled in order to minimize contamination. It should also be noted that because it is a qualitative method there will be a degree of variability across various operators and situations. Additionally, while the simultaneous testing of standards provide a degree of quality control, mixtures of different components may sometimes give the results of other conflicting components. However despite these considerations, the conclusions drawn from microchemical analysis still stand as an inexpensive and chemically sensitive manner in which to guide and support the observations drawn from other types of analytical methods utilized in the identification of the Tumacácori finish layers.

Notes

[1] Stephen L. Morgan, "Solubility Rules" *Solubility Rules. Guidelines for Chemical Compound Solubility* (Analytical Chemistry, University of South Carolina, 2012).
[2] Ibid
[3] Ibid.
[4] Ibid.
[5] Ibid.
[6] Ibid.
[7] Alberto de Tagle, "Lecture Notes: Qualitative Analysis of Pigments" for *HSPV 656-01: Advanced Conservation Science*. (University of Pennsylvania: Philadelphia, 2014, Print)

Chapter 10 – Pigment Identification: Particle Dispersions

10.1 – Analytical and Methodological Principles

Pigments can be isolated and dispersed within a resinous medium in order to examine their mineralogical optical properties and aid in identification. Polarized transmitted light microscopy in both plane and cross-polarized light reveal characteristics such as color, grain shape, crystal habit, birefringence, and refractive index that can all provide characterization information not attainable through instrumental means.[1] Indeed, optical microscopy in many ways can be one of the preferred methods of initial analysis as it is requires much less instrumentation, equipment, and specialized knowledge in comparison to chemical instrumentation such as SEM-EDS, Raman, or FTIR. Furthermore, it is one of the few ways in which to observe an isolated pigment particle for identification purposes.

Painting Materials, the very same text that Rutherford J. Gettens sent to Charlie Steen in 1949 is still one of the foremost and extensive resources concerning painting materials and their technical qualities. In addition to Gettens' work, particle dispersions were compared to images of standard pigments in Nicholas Eastaugh, Valentine Walsh, Tracey Chaplin, and Ruth Siddall's Particle Compendium: A Dictionary and Optical Microscopy of Historical Pigments.

10.2 – Sample Preparation Methodology

Cargille Meltmount, a replacement for the previously preferred medium of Acrolor, is a thermoplastic resin that can be reheated and replasticized.[2] Free of polychlorinated biphenyl (PCB), a hazardous organic compound present in Acrolor, Meltmount possesses a refractive index of $n_D = 1.662$.

In order to prepare a particle dispersion, pigment particles were first carefully scraped from unembedded Tumacácori samples. Due to the fact that these samples are extremely small and friable – more often than not the majority of each sample had been reserved for cross-sectional embedding – particles had to be scraped carefully by using tweezers and a micro-scalpel under the Leica MZ16 stereomicroscope. In preparation for sample placement, small circles were drawn onto the middles of microscope slides to mark the target area for particle dispersion. Scraped pigment particles were then placed within the target circle, another microscope slide was overlaid, and pressure was applied in order to firmly crush and spread pigments within the target circle.

Concurrently, the Meltmount was heated gently with a hot plate until the resin was hot enough to flow easily. A round cover slip was placed upon the target circle containing the ground, scraped pigment and the entire assemblage was placed on the hot plate to provide gentle warming. Using a thin glass seeker with pointed end, a small droplet of Meltmount was dripped onto a corner edge of the round glass cover slip. By capillary action, the Meltmount spreads from one side of the cover slip to the other, thus dispersing the pigment particles within the Meltmount resin underneath the cover slip. After the Meltmount spread through the entire cover slip circular area, the microscope slide was removed from the hot plate and allowed to cool.

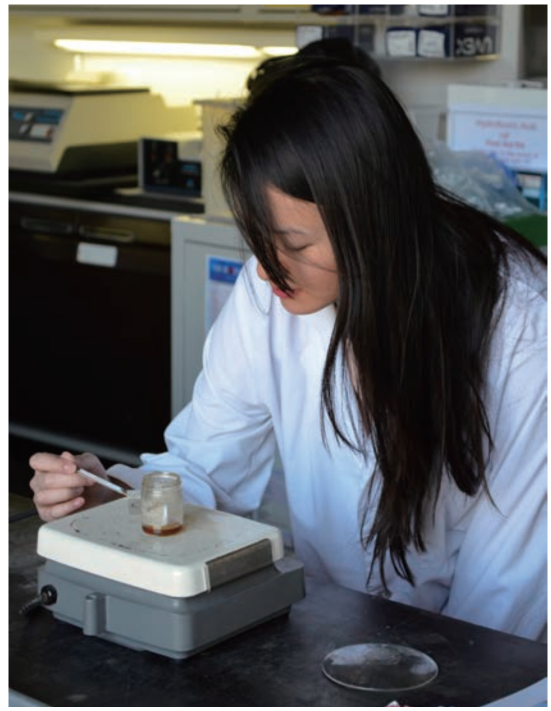


Figure 10.1: Scraping pigment particles under stereomicroscope
Figure 10.2: Preparing particle dispersion using Cargille Meltmount

Representative pigment samples that contained enough bulk finish pigment were selected from the same set of samples considered for SEM-EDS and other methods of analysis. Seven pigment samples were deemed as satisfactory enough to use as source material for particle dispersions. Prepared particle dispersions were then examined under transmitted light microscopy in both plane and cross-polarized light by using Nikon Optiphot-2Pol and Olympus CX31 microscopes. Catherine Myers, lecturer on surface finishes within the Historic Preservation program and conservator in private practice, provided preliminary analytical guidance.

10.3 – Observations and Analysis

Selected particle dispersions and observations are presented below; comprehensive data sets for each prepared sample can be found in "Appendix D: Particle Dispersion Data Sheets."

Table 10.1: Samples Isolated for Particle Dispersions		
Color	Samples	Notes
Red	TUMA_01	Thinner sample than TUMA_12
	TUMA_12	Thicker sample, clearer layers with fluorescence of lime line under UV
Yellow	TUMA_06	To test for possible application of ferrous sulfate
	TUMA_09	Discrete layering of yellow finish and white preparatory layer
	TUMA_11	Very clear layering, biological microflora?
White	TUMA_03	Thick white preparatory layer, white finish layer
	TUMA_25	Thick cream layer with some pigment, sample sent for thin section

TABLE 10.2: PARTICLE DISPERSION OF TUMA_12 (RED) IN PPL AND XPL

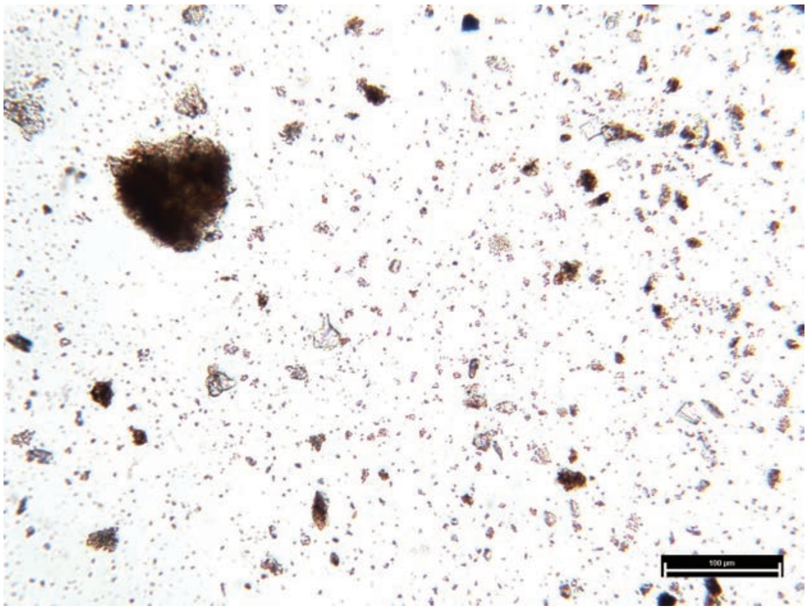
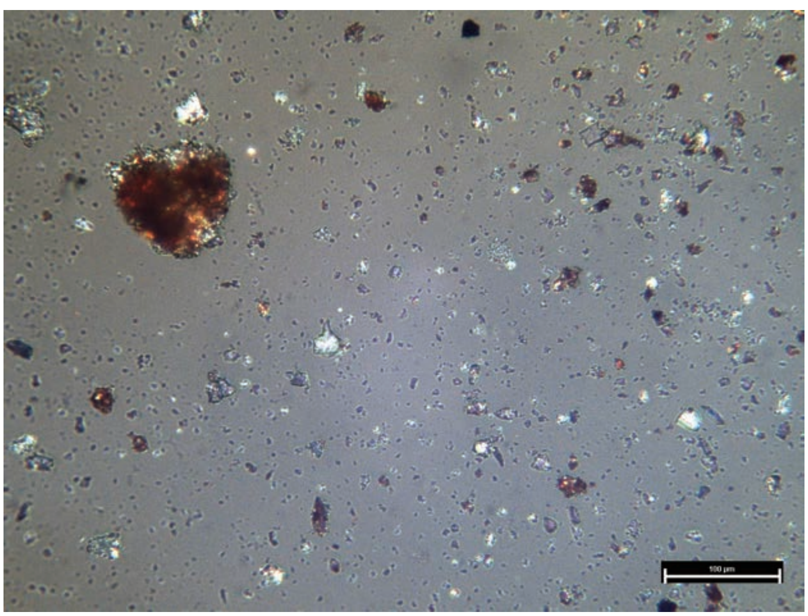
	SAMPLE TUMA_12 PARTICLE DISPERSION – PPL
	ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) SAMPLED: 1/9/15
	IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software
	MICROSCOPE: Olympus CX31 OCULAR MAG: 10 x
	OBJECTIVE: 20x ZOOM: n/a
	TRINOCULAR MAG: 0.6x LIGHT SOURCE: halogen
	FILTERS: daylight COLOR TEMP: n / a
	SAMPLE TUMA_25 PARTICLE DISPERSION – XPL
	ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) SAMPLED: 1/9/15
	IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software
	MICROSCOPE: Olympus CX31 OCULAR MAG: 10 x
	OBJECTIVE: 20x ZOOM: n/a
	TRINOCULAR MAG: 0.6x LIGHT SOURCE: halogen
	FILTERS: daylight COLOR TEMP: n / a
-Dull red coarse grain particles -High birefringence -Mixture of grain sizes, some more opaque red -Several clear particles that appear to be quartz coated in red pigment, similar to hematite standard in Pigment Compendium	

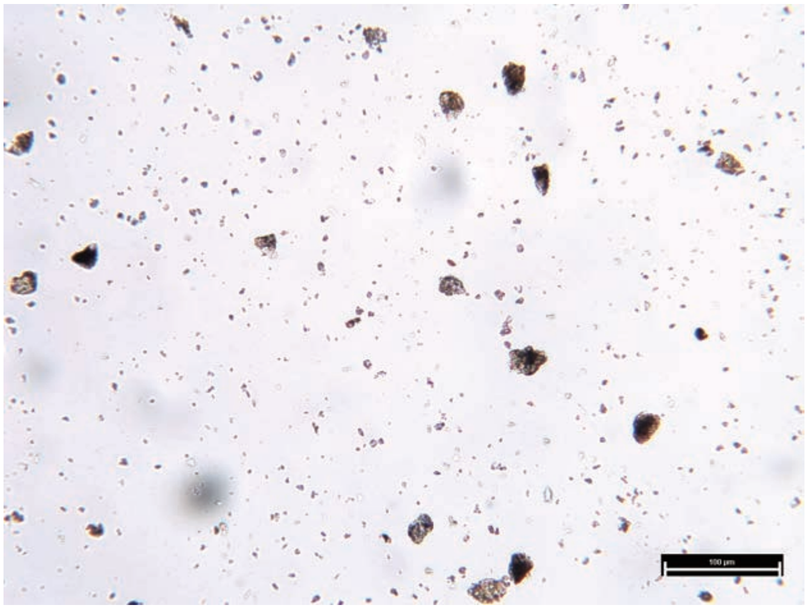
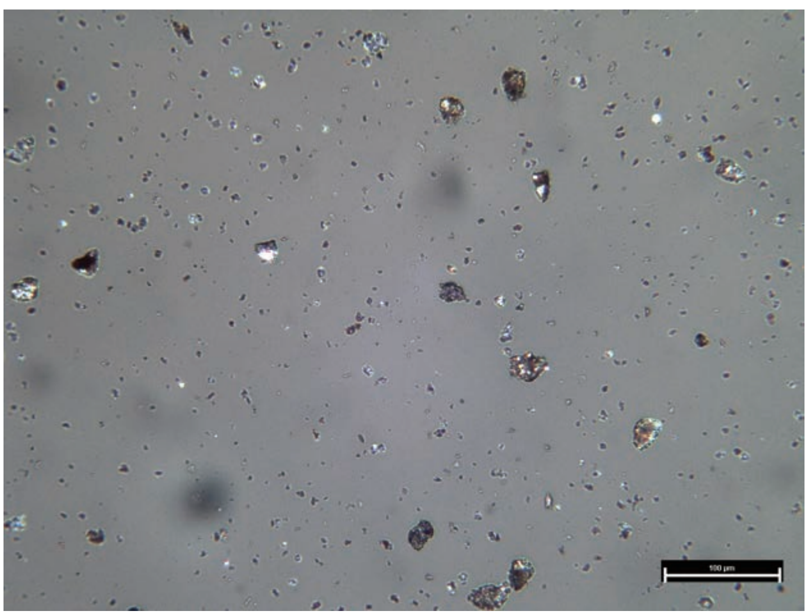
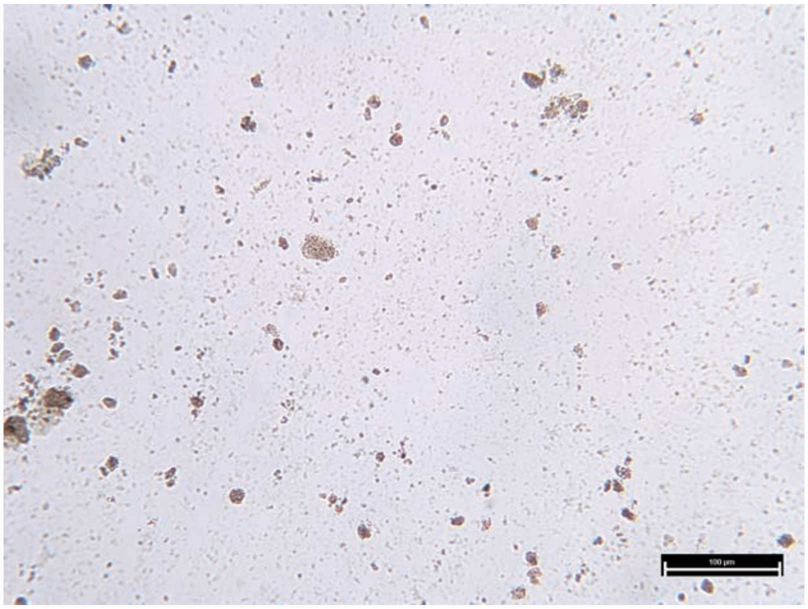
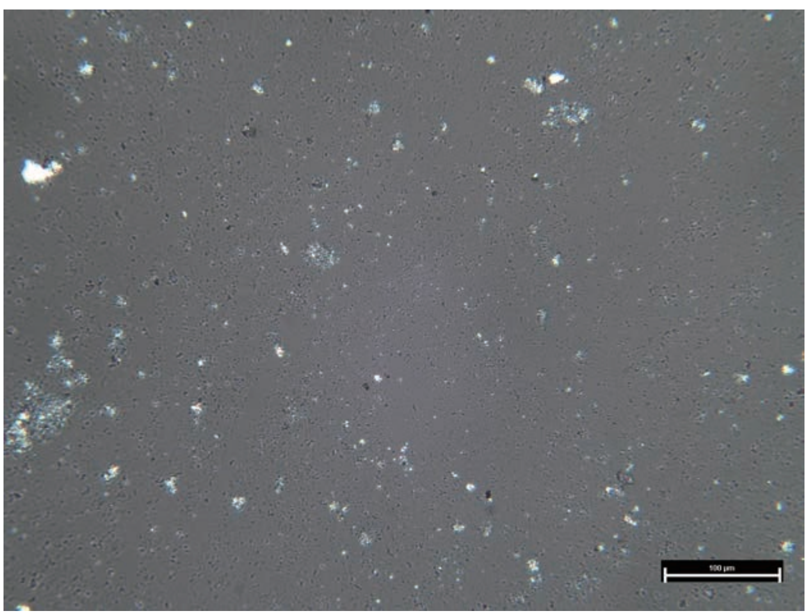
Table 10.3: Particle Dispersion of TUMA_11 (Yellow) in PPL and XPL	
	SAMPLE TUMA_11 PARTICLE DISPERSION – PPL ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) RECEIVED: 4/6/15 IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x OBJECTIVE: 20x ZOOM: n/a TRINOCULAR MAG: 0.6x LIGHT SOURCE: halogen FILTERS: daylight COLOR TEMP: n / a
	SAMPLE TUMA_25 PARTICLE DISPERSION – XPL ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) RECEIVED: 4/6/15 IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x OBJECTIVE: 20x ZOOM: n/a TRINOCULAR MAG: 0.6x LIGHT SOURCE: halogen FILTERS: daylight COLOR TEMP: n / a
-Dull yellow-brown coarse grain particles -High birefringence -Mixture of grain sizes, some more opaque -Presence of some red particles within the dispersion -Appear similar to goethite standard in Pigment Compendium	

Table 10.4: Particle Dispersion of TUMA_25 (White) in PPL and XPL	
	<u>SAMPLE TUMA_25</u> <u>PARTICLE DISPERSION – PPL</u>
	ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) RECEIVED: 4/6/15
	IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software
	MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x
	OBJECTIVE: 4x ZOOM: n/a
	TRINOCULAR MAG: 1.0x LIGHT SOURCE: halogen
	FILTERS: daylight COLOR TEMP: n / a
	<u>SAMPLE TUMA_25</u> <u>PARTICLE DISPERSION – XPL</u>
	ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) RECEIVED: 4/6/15
	IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software
	MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x
	OBJECTIVE: 4x ZOOM: n/a
	TRINOCULAR MAG: 1.0x LIGHT SOURCE: halogen
	FILTERS: daylight COLOR TEMP: n / a
-Irregularly shaped white/clear crystals -High birefringence -Mixture of grain sizes -Similar to chalk standard in <u>Pigment Compendium,</u> potential presence of microfossils?	

Overall, pigments were difficult to isolate due to the small amount of viable sample material. For successful sets, particle sizes exhibited a fairly large range in each cohort. Some pigment particles were not fully dispersed and resulted in clumps of pigment, while in some samples particulates of other material, likely quartz, were notably coated in colored pigment particles. While the Pigment Compendium provided an invaluable resource, it would perhaps be instructive to examine these samples further with finishes analysts who specialize in optical microscopy.

Notes

[1] Victoria Pingarron Alvarez, "ACL Cross Section Preparation" for *HSPV 555-01: Introduction to Conservation Science* (University of Pennsylvania: Philadelphia 2014, Print)
[2] Ibid.

Chapter 11 – Composition and Identification: Scanning Electron Microscopy with Energy Dispersive X-Ray Spectroscopy (SEM-EDS)

11.1 – Analytical and Methodological Principles

Scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS) proved to be one of the primary methods of investigation in which to analyze the Tumacácori finish samples. SEM is a powerful imaging technique that uses electron beams instead of light to produce much greater resolving power than a light microscope. SEM can give information of a material's topography (texture/surface of a sample), morphology (size, shape, order of particles), composition (EDS provides elemental composition), and crystalline structure (arrangement within a sample).

In SEM, a beam of electrons is scanned across the sample and the interactions between the electron beam and sample allows for the detection of electrons by scattering or ejection.[1] The scanning coil moves the beam across the sample in a raster scan pattern, line-by-line, in order to create a greyscale image in which each "pixel" is the result of an electron beam hitting the sample to produce a certain number of electrons.[2] Indeed, when an electron beam strikes a sample material, both electrons and photons are emitted and the following information phenomena can give different types of information about a material:

- X-rays – through thickness, composition information (can also yield elemental information)
- Auger electrons – surface sensitive, composition information
- Primary backscattered electrons – atomic number and topographical information

- Catholuminescence – electrical information
- Secondary electrons – topographical information
- Specimen current – electrical information

When an electron beam hits a sample, the incident beam will be scattered both elastically and inelastically. This will produce various signals in which the interaction volume will increase with increasing acceleration voltage and decrease with increasing atomic number.[3] Generally, there are many more secondary electrons that will be transmitted as compared to number of backscattered electrons. Secondary electrons (SE) are affected by the beam energy, beam current, atomic number, work function of a surface, and the local curvature of a surface.[4] These are low energy electrons and generated from the collision between loosely bonded outer electrons and incoming electrons. SE will give topographic information since only SE generated close to the surface will escape and can be divided into two categories: SE1 and SE2.[5]

Overall, SEM-EDS is a powerful tool that can give a variety of chemical and physical information. Its depth of focus is typically orders of magnitude better than an optical microscope, and thus SEM is good for studying rougher sample surfaces. Advances in modern technology have allowed for certain obstacles in SEM-EDS to be overcome – for example, conservation often deals with challenging samples that sometimes prove difficult for traditional SEM-EDS. However, the advent of Environmental SEM (ESEM) allows for a higher pressure to be used with various gases and can subsequently resolve challenging samples such as those that are irradiation-sensitive (thin organic films), vacuum-sensitive samples (biological samples), insulating samples, or “wet” samples.[6]

11.2 – Sample Preparation Methodology

Three sessions of SEM-EDS were conducted during April 2015. The first session was performed on April 14, 2015 at the University of Pennsylvania's Singh Center for Nanotechnology and was operated by Dr. Reza Vantankhah utilizing a FEI Quanta 600 FEG Mark II Environmental Scanning Electron Microscope and analyzed with XT Microscope Control software. While four samples (TUMA_03, TUMA_11, TUMA_12, and TUMA_14) were initially loaded into the chamber, three were ultimately analyzed due to time constraints (TUMA_03, TUMA_11, TUMA_12) These samples were selected as representative examples of the main constituent colors found on the Tumacácori façade – while all contained a thicker preparatory layer above a sandy substrate, TUMA_03 contains a thin white finish, TUMA_11 has a yellow finish atop an additional thin white preparatory layer, TUMA_12 possesses a thin red pigmented layer over the thin white preparatory layer, and TUMA_14 is an orange sample that exhibited less clearly defined, discrete layering as noted in other samples.

Table 11.1: Cohort of Samples Suitable for SEM-EDS

Color	Samples	Notes
Red	TUMA_01	Thinner sample than TUMA_12
	TUMA_12	Thicker sample, clearer layers with fluorescence of lime line under UV
Yellow	TUMA_06	To test for possible application of ferrous sulfate
	TUMA_09	Discrete layering of yellow finish and white preparatory layer
	TUMA_11	Very clear layering, biological microflora?
	TUMA_13B	Yellow layer with mixed red pigments, thin preparatory layer
White	TUMA_03	Thick white preparatory layer, white finish layer
	TUMA_13A	Very thin white layer on top of yellow layer
	TUMA_25	Thick cream layer with some pigment, sample sent for thin section
Orange	TUMA_14	Yellow stained upper zone, pigment appears darker than other examples

Table 11.2: Pigments Identified in Tumacácori Interior Decorations			
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	$FeO(OH)*nH_2O$ (yellow ochre) Fe_2O_3 (red ochre)	R.J. Gettens, 1949
White	Gypsum	$CaSO_4 * 2H_2O$	R.J. Gettens, 1949, Lewis & Rubio
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

Elements to Map with SEM-EDS:

- Hg (confirmation of cinnabar)
- S (confirmation of cinnabar, differentiation between lime and gypsum, indication of use of ferrous sulfate as staining)
- Ca (differentiation of discrete zones of lime)
- Mg (confirmation of type of lime utilized)
- Fe (identification of reddish-based pigments as iron oxides)

The samples were left uncoated and were mounted to aluminum stubs using double-sided tape. Due to the nonconductive nature of the samples, a low vacuum environment was chosen with a Large Field Detector (LFD). This detector is often an ideal standard choice when used for general imaging in a low vacuum environment due to an increased amount of BSE information that can be obtained[7] The SEM was then run at a chamber pressure of 1.00 torr with a spot size of 3.0 nm, voltage of 15.00 kV, and emission current of 150 μA.

Subsequent sessions of SEM-EDS were performed at the Scientific Research and Analysis Laboratory (SRAL) at Winterthur Museum and were operated by associate scientist Catherine Matsen. While a secondary analytical session at Winterthur was already scheduled prior to initial SEM-EDS, cursory interpretation of the Penn data set indicated several inconclusive or uncertain results that shifted the investigative scope of the Winterthur sessions to focus upon corroborating the first data set's results. These specific observations of the first SEM-EDS set that led to the rationalization of how to approach the following sessions of SEM-EDS are further expounded upon in "10.3 – Observations and Analysis."

Thus during the second SEM-EDS session the original cohort of samples (TUMA_03, TUMA_11, TUMA_12, and TUMA_14) were analyzed for consistency and confirmatory purposes; in the final following session, TUMA_06 and TUMA_07 were also analyzed. Using a 12mm diameter SPI Supplies double-side carbon tab, cross sections were mounted to a 12.7x3.1mm SPI Supplies Zeiss aluminum slot head stub. The polyester resin bulk of each sample was then coated with SPI Supplies conductive carbon paint composed of colloidal graphite suspended in isopropanol and the actual sample cross section was left uncoated. This coating was applied to both the top and side surfaces of the casting medium in order to prevent charging when analysis was being conducted.

Once the samples were loaded into the SEM chamber, a copper grid with gold flecks was initially used as a reference point for focusing and orientation. A Zeiss EVO MA15 scanning electron microscope was utilized with a lanthanum hexaboride cathode source at an accelerating voltage of 20kV, working distance of approximately 10mm, and sample tilt of 0°. EDS data was subsequently acquired with a Bruker Nano XFlash® 6|30 and processed using Quantax 200/Espirt 1.9 software.

11.3 – Observations and Analysis

Selected salient observations drawn from the SEM-EDS performed at the Scientific Research and Analysis Laboratory (SRAL) at Winterthur Museum are presented below, while the comprehensive data sets for each sample run can be found in "Appendix E: SEM-EDS Data Sheets."

SEM Data for TUMA_12 (Red)

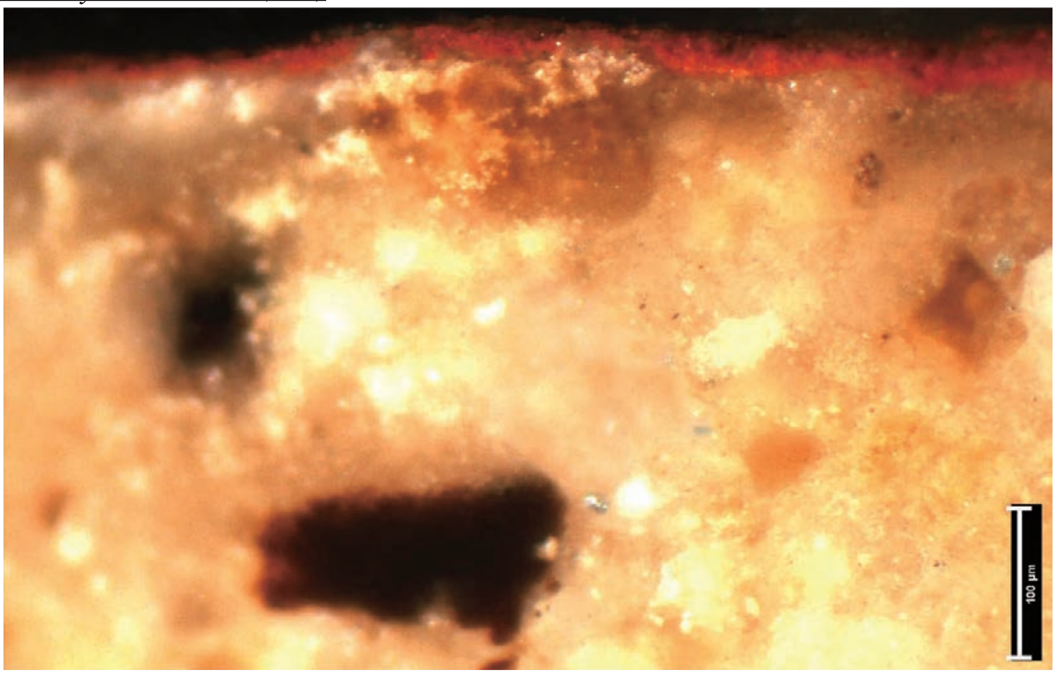


Figure 11.1: TUMA_12 cross section under visible light

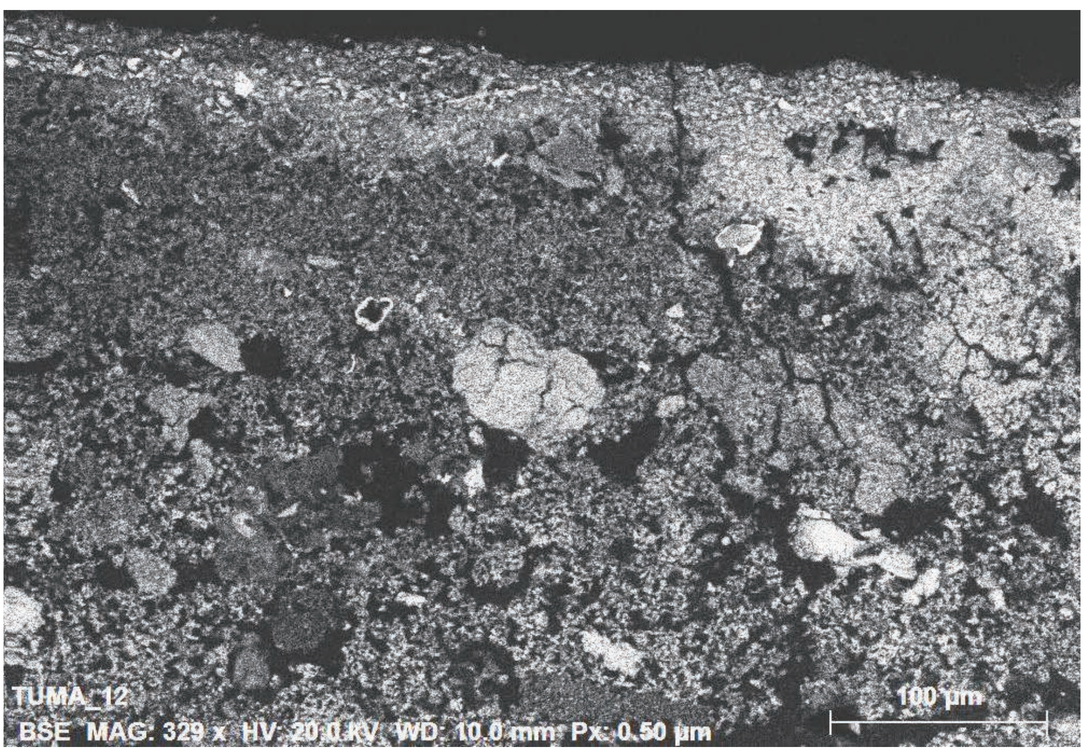


Figure 11.2: TUMA_12 SEM-EDS backscattered electron image

Elemental Mapping Data for TUMA_12 (Red)

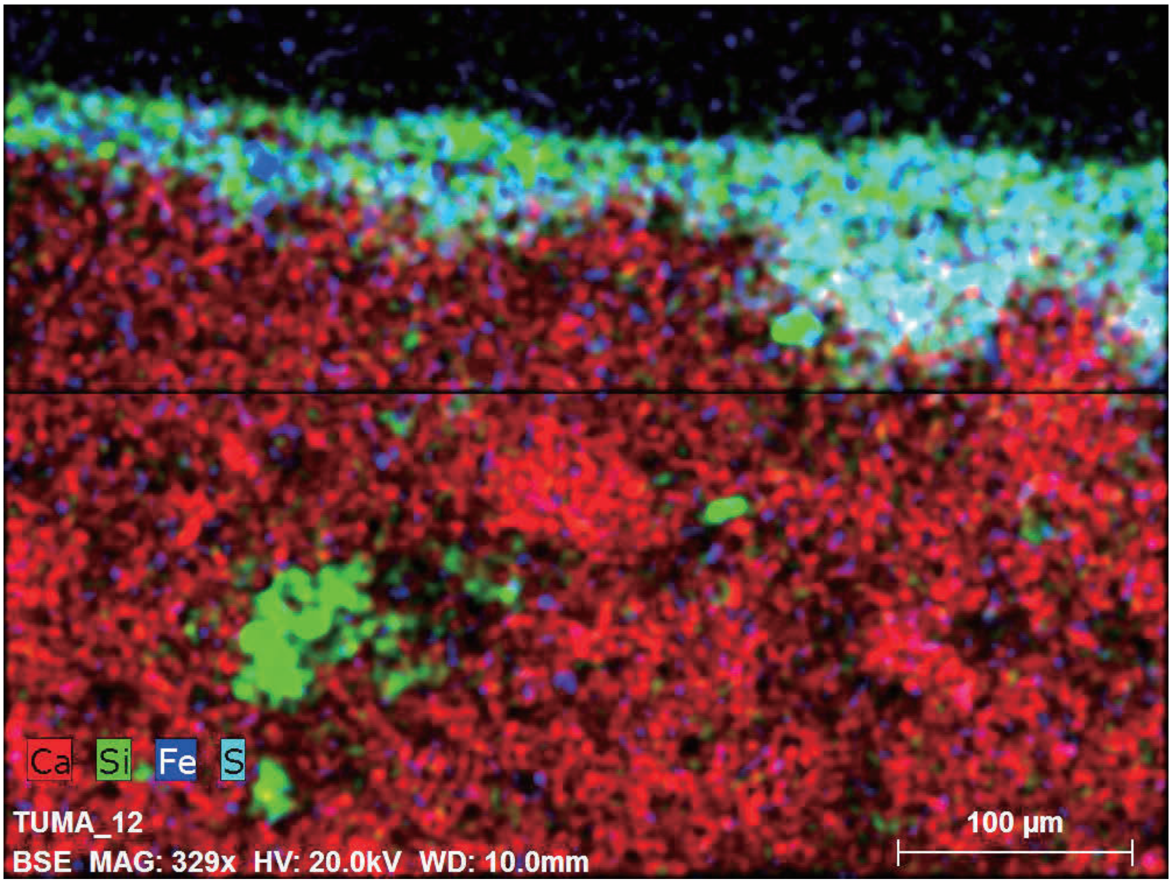


Figure 11.3: TUMA_12 SEM-EDS elemental map

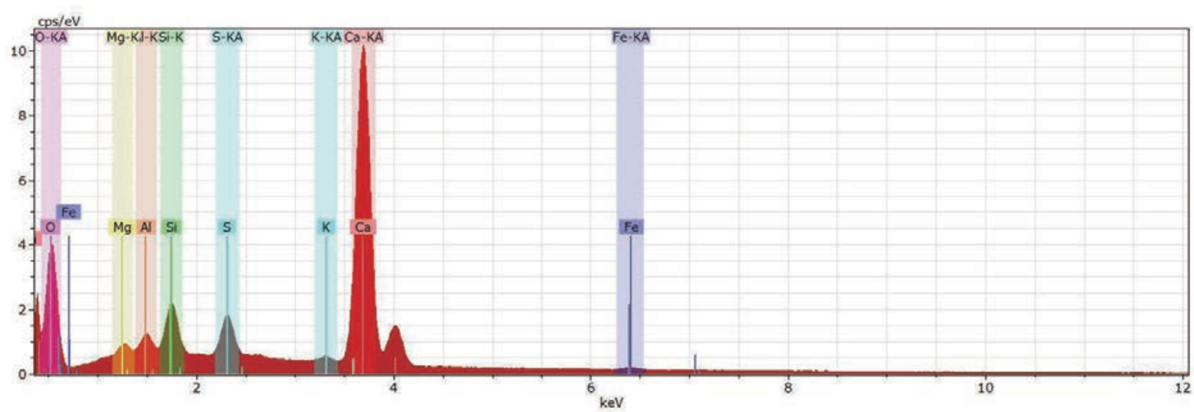


Figure 11.4: TUMA_12 SEM-EDS elemental graph

SEM Data for TUMA_11 (Yellow)

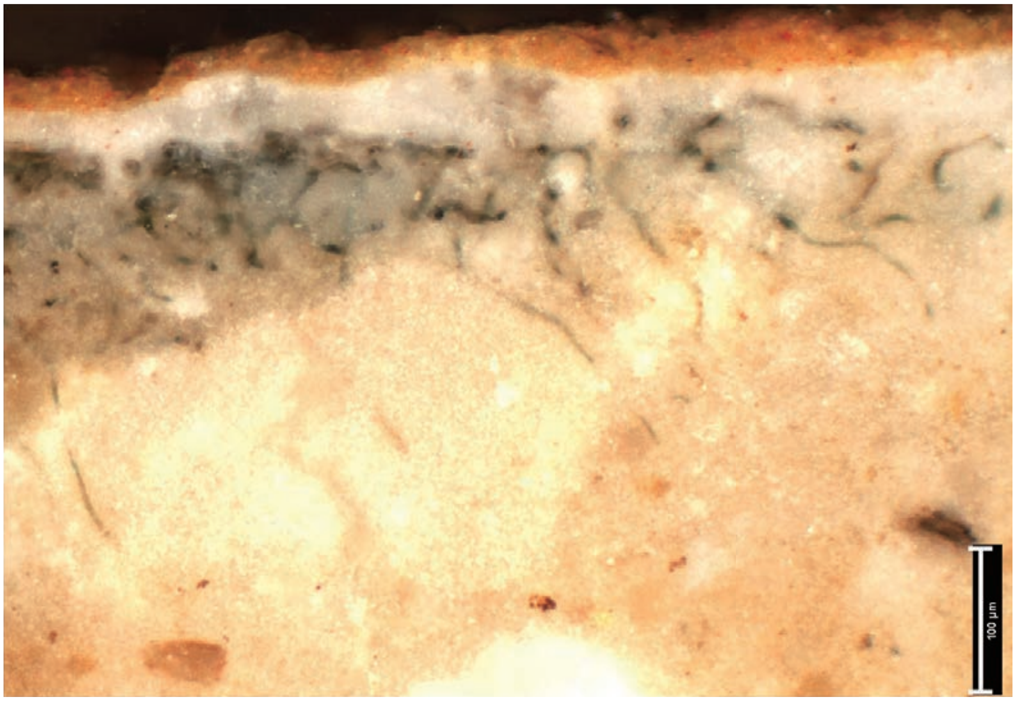


Figure 11.5: TUMA_11 cross section under visible light

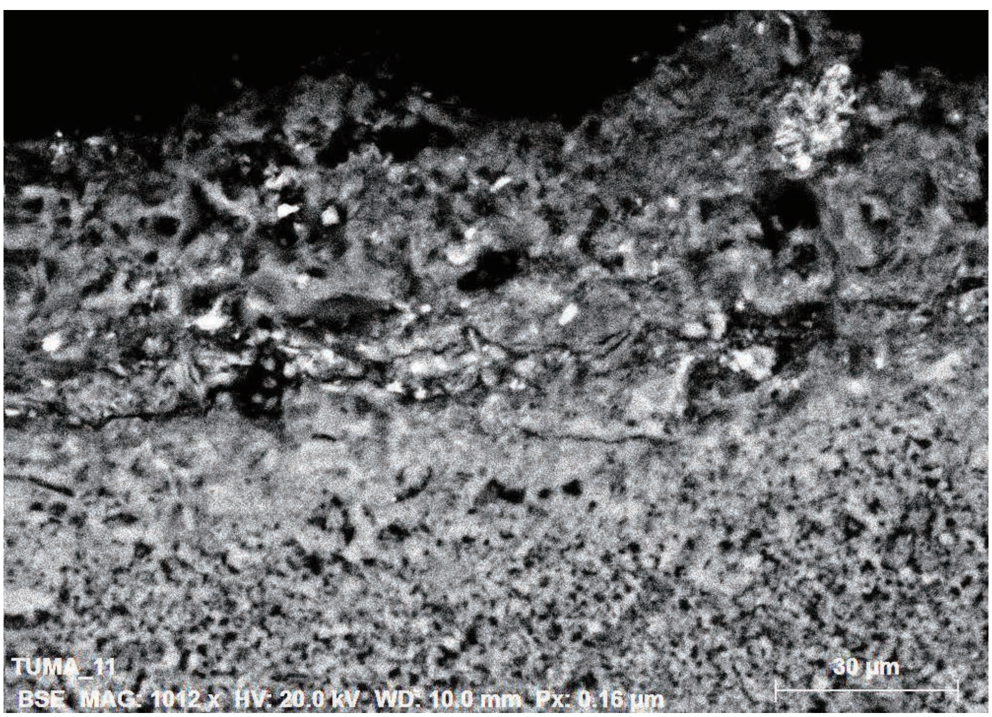


Figure 11.6: TUMA_11 SEM-EDS backscattered electron image

Elemental Mapping Data for TUMA_11 (Yellow)

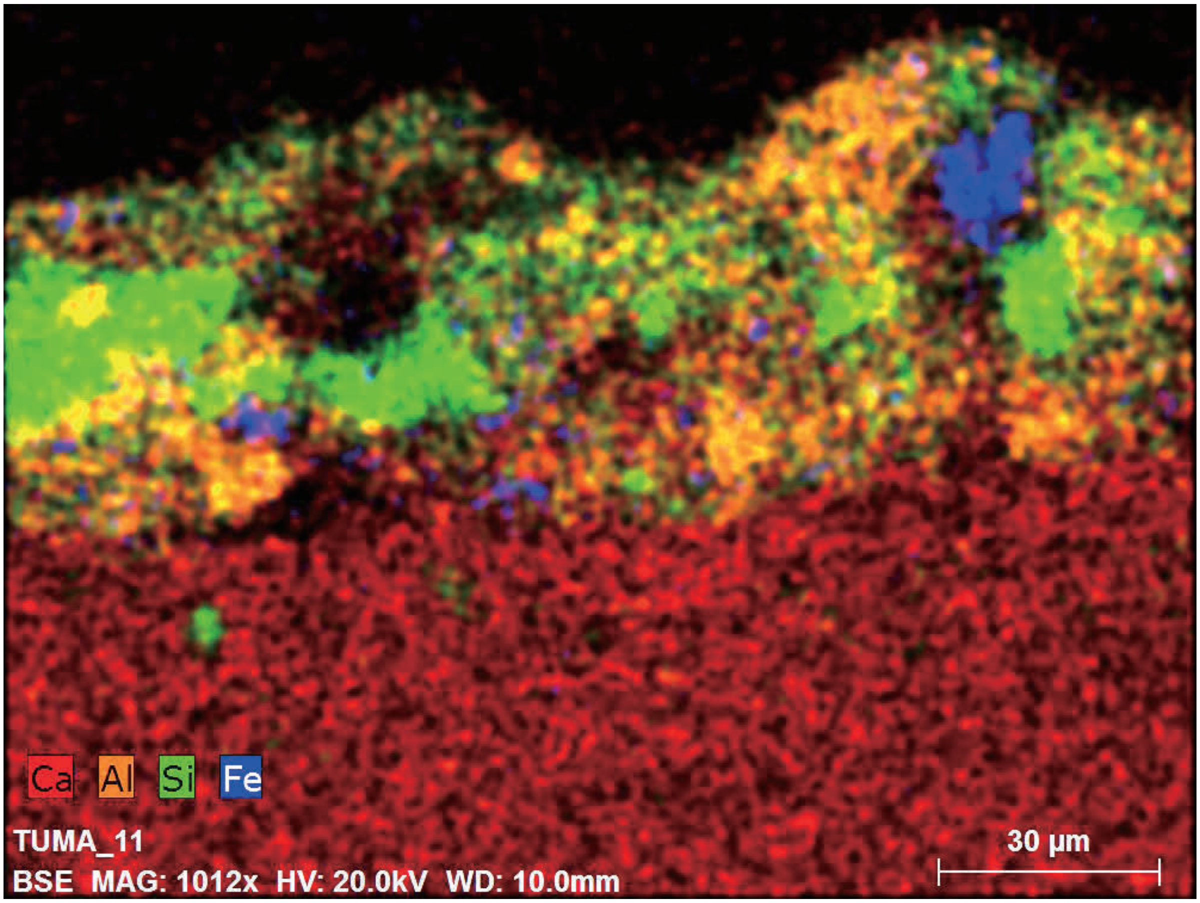


Figure 11.7: TUMA_11 SEM-EDS elemental map

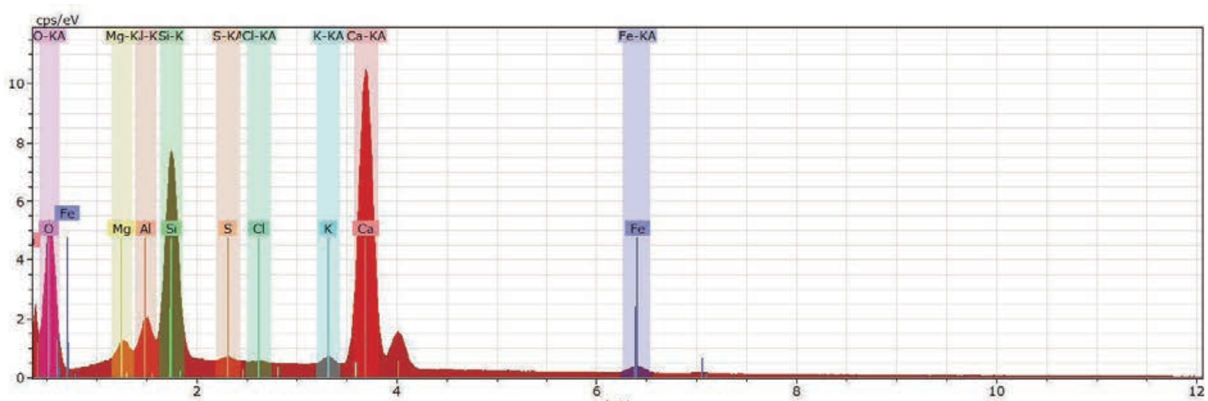


Figure 11.8: TUMA_11 SEM-EDS elemental graph

<u>*SEM Data for TUMA_06 (Yellow)*</u>

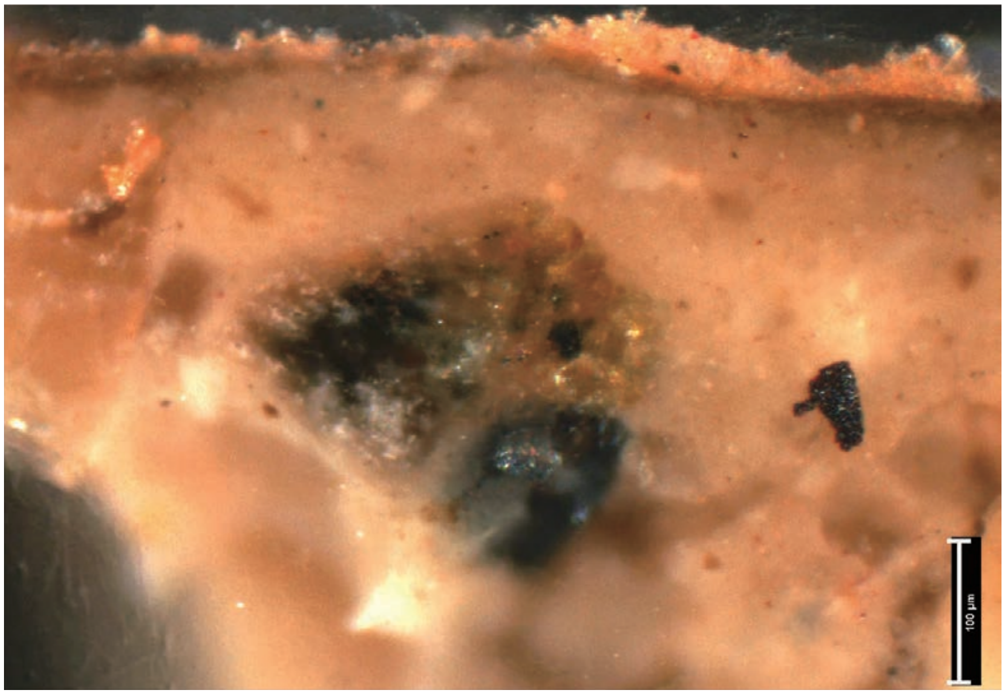


Figure 11.9: TUMA_06 cross section under visible light

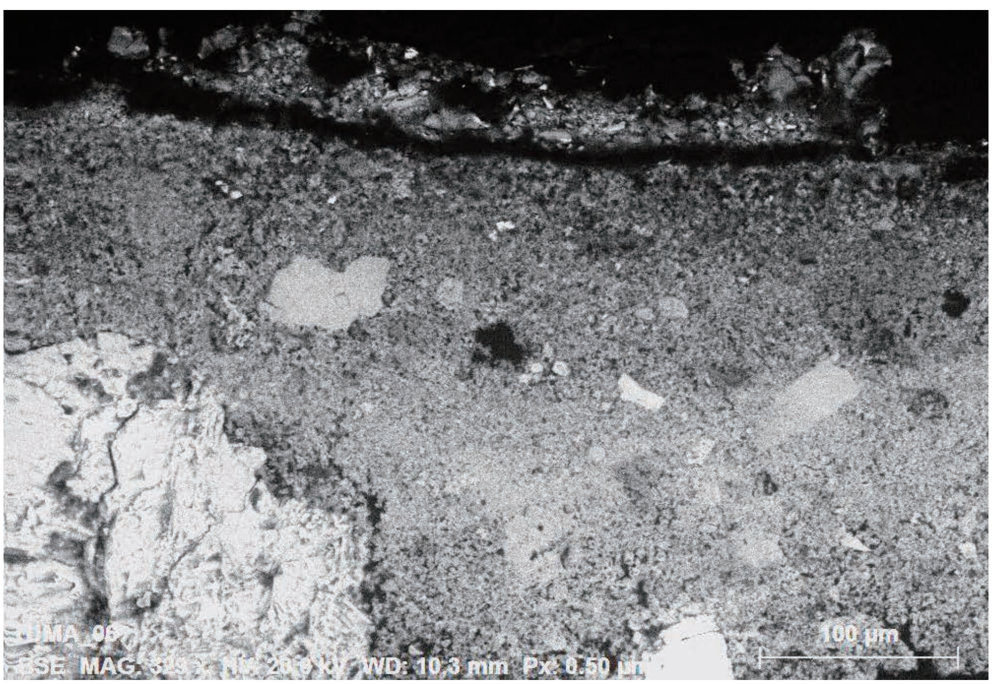


Figure 11.10: TUMA_06 SEM-EDS backscattered electron image

Elemental Mapping Data for TUMA_06 (Red)

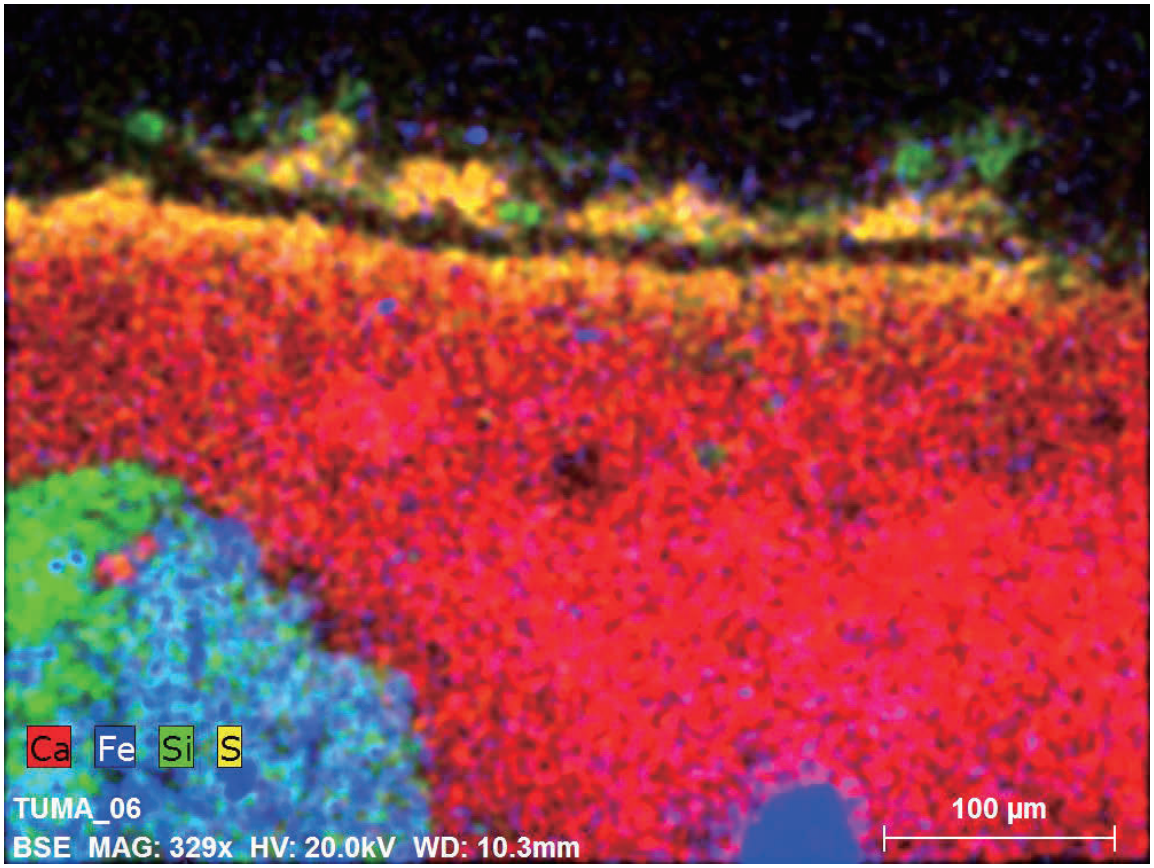


Figure 11.11: TUMA_06 SEM-EDS elemental map

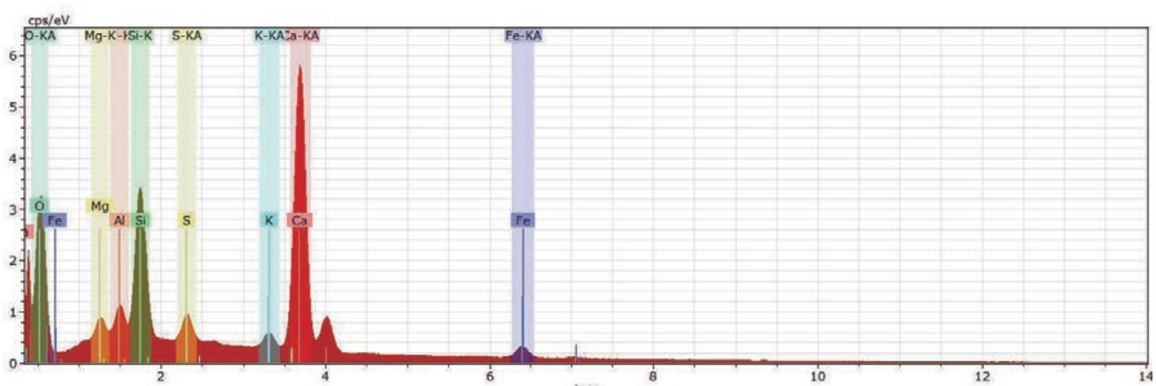


Figure 11.12: TUMA_06 SEM-EDS elemental graph

Table 11.3: Overall Elements Detected through SEM-EDS Analysis (Winterthur)				
Sample	Color	Objective	Elements Detected	Notes
TUMA_12	Red	To determine elemental constituents of discrete red finish layer	-Calcium -Sulfur -Silicon -Oxygen -Iron -Magnesium -Potassium -Aluminum	Iron less concentrated at the surface than expected
TUMA_06	Yellow	To test for possible application of a limewash stain	-Calcium -Silicon -Sulfur -Oxygen -Aluminum -Magnesium -Potassium -Iron	Brownish-yellow layer did not appear on elemental map suggesting it is of organic nature prompting attempt to isolate for FTIR
TUMA_07	Yellow	To compare to TUMA_06 as these two samples are the only one from the façade's overall face	-Calcium -Silicon -Oxygen -Aluminum -Magnesium -Potassium -Iron	No sulfur detected in elemental map
TUMA_11	Yellow	To determine elemental constituents of discrete yellow finish layer	-Calcium -Silicon -Oxygen -Iron -Magnesium -Potassium -Aluminum	No sulfur detected in elemental map
TUMA_03	White	To determine elemental constituents of discrete white finish layer and differentiate the substrate paste from applied white finish layer	-Calcium -Oxygen -Silicon -Sulfur -Iron -Magnesium -Potassium -Aluminum	Substantiates the hypothesis that a thin white finish layer of gypsum was applied to lime-based substrate
TUMA_14	Orange	To determine elemental constituents of orange intradose voussoir sample, the only orange sample procured	-Calcium -Oxygen -Silicon -Sulfur -Iron -Aluminum -Magnesium -Potassium	Expected difficulty in isolating a finish layer, sulfur elemental map shows strongly, only other element to show quite strongly and discrete for finish layer is aluminum

Though the SEM images obtained from the Penn LRSM data set are clearer than that of the images obtained at Winterthur's SRAL, several curious inconsistencies with the Penn elemental data set prompted confirmatory analysis at Winterthur. Firstly, the EDS spectra in the Penn LRSM spectra only run up to approximately 7.5 keV. Typically when EDS is run, and particularly for the analysis of surface finishes, spectral data is collected from approximately 1-15 keV.[8] Thus certain elements, such as lead that has a characteristic L line around 12 keV could not be confirmed through the Penn LRSM data set alone due to the absence of data from 7.5 keV onwards.[9] Furthermore, in the Penn data set, a spectral peak for molybdenum, a transition metal element, consistently occurred, while both iron and sulfur peaks did not appear as labeled in elemental mapping sets. The unexpected presence of molybdenum prompted further research and it was later found that there exists a notorious overlap between the spectral peaks of molybendum, sulfur, and lead.[10] Lastly, while iron was not shown as labeled in the elemental mapping set, the peak present at 6.4 keV is certainly an iron peak that was simply left unlabeled by the software.

Bearing these results in mind, the following data sets acquired at Winterthur's SRAL clarified and also provided further points for research. The preparatory plaster layers for all samples appear to be lime-based with aggregate indicating elements consistent with that of the felsic minerals and aluminosilicate clay groups. In the red sample analyzed (TUMA_12), lead was not present and thus the pigment was hypothesized to be iron-based, despite how in all layers iron did not appear in concentrated finish layers but somewhat diffuse – this prompted confirmation by Raman microscopy. This red layer was seen to be on top of a white preparatory layer that indicated a strong presence of sulfur, likely gypsum. This was corroborated by the analysis of the white pigment (TUMA_03) that indicated a clear distinction between the calcium-rich paste and sulfur-rich applied finish layer.

However the yellow and orange pigments provide curious findings that could benefit from additional research and sampling. In the yellow samples, the colored finish layer of TUMA_06 – the sample that did not appear as discrete layers suspected to be a limewash stain – appeared to be of an organic nature, or certainly different than the other samples when viewed both under optical microscopy and SEM-EDS. TUMA_07, chosen for the fact that it was the only other sample taken from the background of the façade and also suspected to not be a discrete colored layer, was subsequently run as a comparison. This sample indicated a greater concentration of iron at the region of colorant. In TUMA_11, the yellow sample that possessed highly discrete finish layers, sulfur was oddly not detected however there appeared to be a discernible mix of yellow and red pigments mixed for the finish layer. Having completed analysis by SEM-EDS, Raman microscopy and FTIR were subsequently utilized in order to shed further light upon some of the lingering questions regarding the surface finish components.

Notes

[1] Reza Vatankhah, "Lecture Notes: Scanning Electron Microscopy" for *HSPV 656-01: Advanced Conservation Science*. (University of Pennsylvania: Philadelphia 2014, Print)
[2] Ibid.
[3] Ibid.
[4] Ibid.
[5] Ibid.
[6] Ibid.
[7] Pamela B. Vandiver, James Druzik, and George S. Wheeler, "Applications of Environmental Scanning Electron Microscopy in Art Conservation and Archaeology." *Materials Issues in Art and Archaeology II:*

Symposium Held April 17-21, 1990, San Francisco, California, USA 185 (Pittsburgh: Materials Research Society, 1991) 23-30.

[8] Matsen

[9] Matsen.

[10] Douglas Vaughan, *Energy-dispersive X-ray Microanalysis: An Introduction*, (San Carlos, CA: Kevex Instruments, 1989) Print.

Chapter 12 – Molecular Composition: Raman Microscopy and Fourier Transform Infrared Spectroscopy

12.1 – Analytical and Methodological Principles

Raman spectroscopy and Fourier Transform Infrared Spectroscopy (FTIR) are complementary methods of spectroscopic analysis that identify constituent materials on a molecular rather than elemental level (such as the data acquired through SEM-EDS). When approaching the investigation of the samples from the Mission San José de Tumacácori, Raman spectroscopy was utilized due to its high level of sensitivity when studying inorganic molecules and the availability of a Raman microscope that allowed for analysis of the preexisting embedded cross-section without additional sample preparation. The use of FTIR was restricted to one sample, TUMA_06, after SEM-EDS analysis suggested the presence of an organic layer. While FTIR is touted for being particularly appropriate for the identification of organic compounds, this method requires a small amount of additional sample preparation.

Spectroscopic analysis is based upon the interaction between matter and radiated energy.[1] All molecules will exhibit a type of vibrational spectrum with frequencies unique to bond types and atoms found within the molecule. The resultant spectrum created from an applied excitation frequency will identify molecular constituents and their corresponding bonding patterns, producing a characteristic arrangement akin to a molecular fingerprint. However although infrared and Raman spectroscopy yield similar types of spectral and molecular information, they are the products of two different types of physical phenomena and also originate from different spectroscopic spaces within the electromagnetic spectrum.[2]

Infrared spectroscopy operates upon the principle that if a sample is exposed to radiation of a resonant frequency then the vibration will increase dramatically in amplitude, creating characteristic peaks that mirror functional groups.[3] As there are differing types of molecular modes of motion such as symmetric, asymmetric, in-plane scissoring, in-plane rocking, and out-of-plane wagging, the spectrum will identify bonding.[4] Infrared spectroscopy is particularly useful for the broad identification and characterization of natural organic materials such as waxes, proteins, oils, polysaccharides, and resins, as well as certain synthetic resins, inorganic pigments, and natural minerals.

Raman spectroscopy is a result of the inelastic scattering that occurs when photons interact with molecules.[5] Using a monochromatic source to generate a spectrum, Raman spectroscopy indirectly probes the same vibrational levels that infrared spectroscopy directly interacts with.[6] Due to this technique that relies upon scattering emission levels, Raman provides a high degree of spatial resolution and can be used to distinguish between phases.[7] One distinct benefit of the analysis performed on the Tumacácori samples was the availability of a Raman microscope, an optical microscope that possesses a laser light source coupled to a spectrometer that allows for in-situ analysis of samples that can be fit under a typical microscope stage.[8]

The resultant spectra obtained from spectroscopic analysis is based upon Beer's Law and is either reported as transmittance or absorbance. Spectra are read from left to right, and functional groups can be assigned to bands using reference tables and flow charts in conjunction with observing band position versus intensities or heights and shapes. Overall, spectroscopic analysis presents many advantages as it is a technique in which sample preparation is relatively simple, data can be acquired quite quickly, and "by class" characterization is often more helpful than elemental data.[9] However, accurate and legible data acquisition must be performed by a knowledgeable operator, and often historic samples will result in complex spectral data that is quite difficult to interpret due to the complexity and high degree of degradation inherently present in samples of cultural heritage. Thus as with any type of instrumental analysis, these methods should be used in conjunction with a variety of supporting analytical approaches. Summaries of the two highlighted spectroscopic methods and their corresponding features, benefits, and disadvantages are presented as follows:

TABLE 12.1: COMPARISON CHART OF METHODS OF SPECTROSCOPIC ANALYSIS [10]

	RAMAN SPECTROSCOPY	INFRARED SPECTROSCOPY
1	A result of the inelastic scattering due to the interaction of photons and molecules	A result of light absorption due to molecular vibrations
2	Raman vibration due to a change in polarizability	Infrared vibration due to a change in dipole moment
3	Molecule to be analyzed does not need to have a permanent dipole moment	Vibration to be analyzed should have a change in dipole moment at that given vibration
4	Water can be used as a solvent	Sample preparation more complex
5	Less rigorous standards for sample preparation	More involved sample preparation
6	Provides indication of covalent nature in molecule	Provides indication of ionic nature in molecule
7	Generally instrumental cost is quite high	Comparatively more common and less expensive

Table 12.2: Comparison Chart of Spectroscopic Analytical Features [11]		
Feature	Raman Spectroscopy	Infrared Spectroscopy
Range/cm^{-1}	10-400	650-4000
Signal Source	Change in polarizability	Change in dipole moment
Strength	Weak	Strong
Material	Inorganic	Organic
Organic Groups	C-C, O-O- aromatics	CO, NH, OH
Bands	Sharp, discreet	More involved sample preparation
Non-Invasive	Yes	Provides indication of ionic nature in molecule
Interference	Fluorescence, Rayleigh scattering, absorption	Comparatively more common and less expensive
Spatial Resolution	<2 μm	20 μm
Sample Preparation	Can be wet	Must be dry

12.2 – Sample Preparation Methodology

For consistency, samples for analysis were generally selected from the corresponding sample set that had been analyzed via SEM-EDS. Instrumental operation was conducted by Catherine Matsen, associate scientist at the Winterthur Museum's Scientific Research and Analysis Laboratory (SRAL) Because samples were studied following SEM-EDS analysis, they were subsequently left mounted to their aluminum metal stubs for ease of handling. The samples were analyzed with a Renishaw Invia Raman spectrometer equipped with a 785nm diode laser in conjunction with WiRE 3.4 software with extended scan from 200-2200cm^{-1}, and 50X objective lens with an exposure time of generally 10 seconds per scan for 1 accumulations, and 5% laser power.

One particular sample, TUMA_06, exhibited characteristics under both SEM-EDS as well as Raman microscopy that suggested that an observed polychromatic layer was composed of organic material. It was then decided to extract a small portion of the yellow-brown layer from the embedded cross section for analysis by FTIR. Under a stereomicroscope, the layer of interest was carefully acquired using a stainless steel scalpel and directly placed upon a diamond cell. The extracted portion was then rolled flat on the diamond cell to decrease thickness and increase transparency by utilizing a steel micro-roller. Using a Thermo Scientific Nicolet 6700 FT-IR with Nicolet Continuμm FTIR microscope in transmission mode, data was acquired for 128 scans from 4000 to 650cm^{-1} at a spectral resolution of 4cm^{-1}. Collected spectral data was processed by Omnic 8.0 software and compared against published reference libraries such as that of the Infrared & Raman Users Group (IRUG).

12.3 – Observations and Analysis

For the following discussion purposes, stacked, singular spectral data is generally shown below, however the full spectral results including overlaid spectra can be found in "Appendix F: Raman Microscopy and FTIR Data Sets."

Raman Analysis of TUMA_03 White Finish Layer

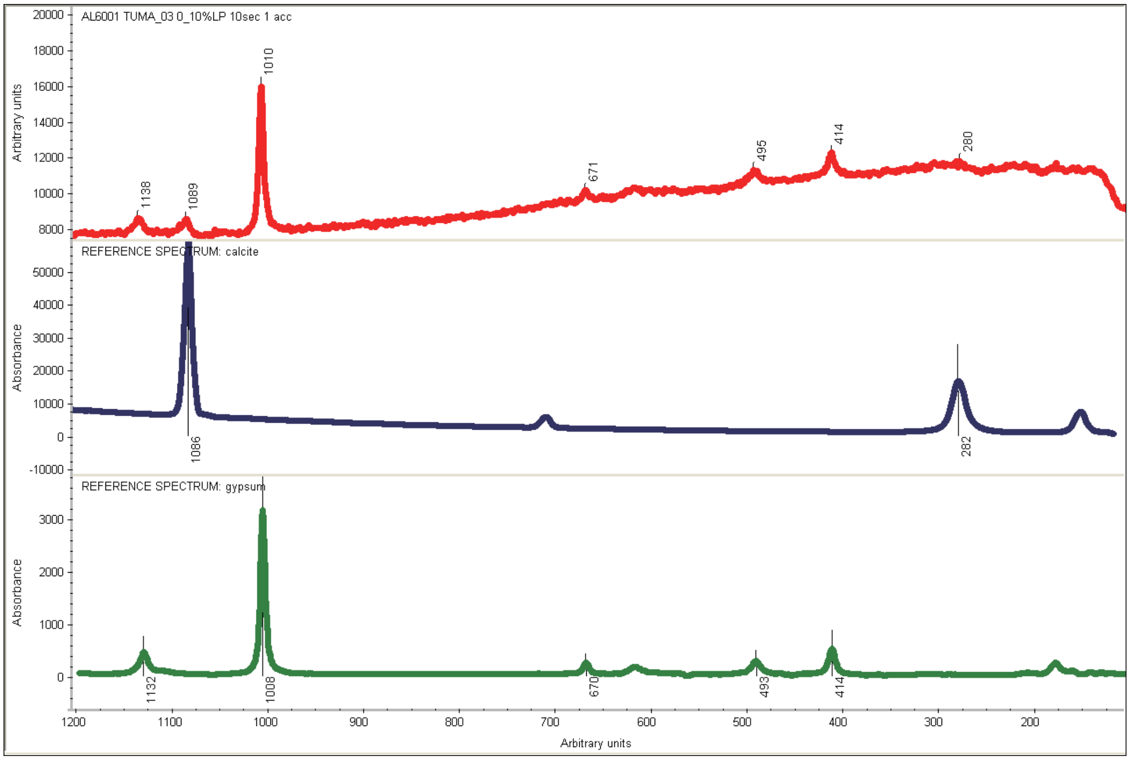


Figure 12.1: Raman spectral data showing presence of both calcite and gypsum within the white finish layer of TUMA_03

Raman Analysis of TUMA_06 Yellow-Brown Finish Layer

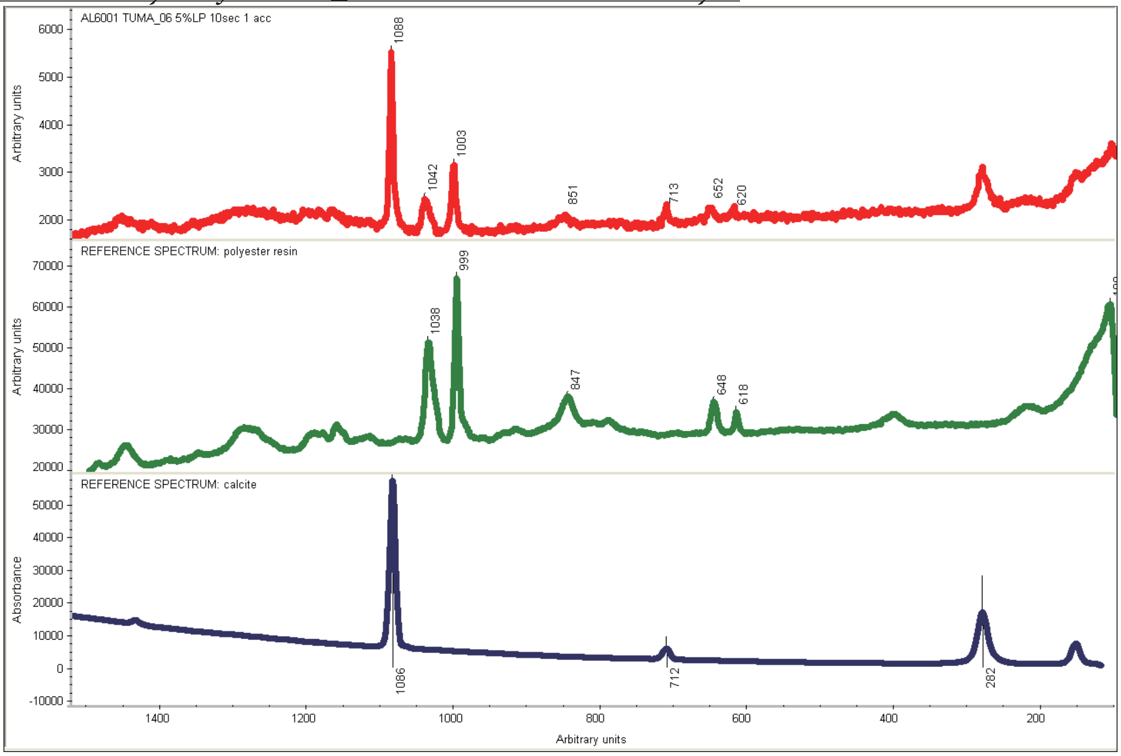


Figure 12.2: Raman spectral data showing presence of calcite and polyester resin, likely the embedding medium, within the yellow-brown finish layer of TUMA_06 (suspected organic)

FTIR Analysis of TUMA_06 Yellow-Brown Finish Layer

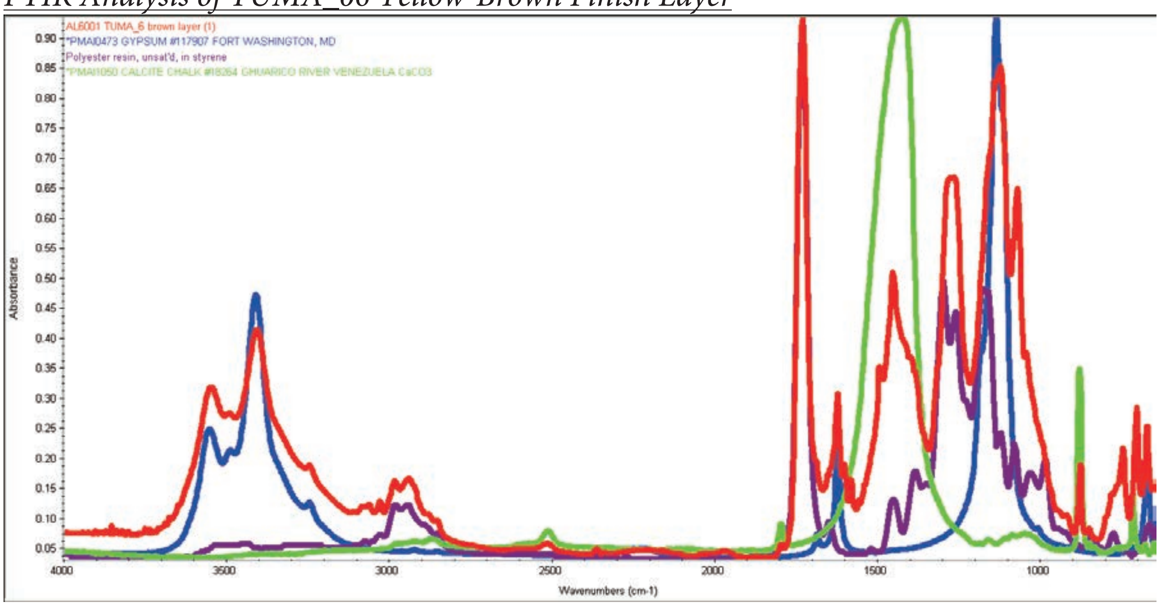


Figure 12.3: FTIR spectral data showing presence of calcite, gypsum, and polyester resin, likely the embedding medium, within the yellow-brown finish layer of TUMA_06 (suspected organic)

Raman Analysis of TUMA_11 Yellow Finish Layer

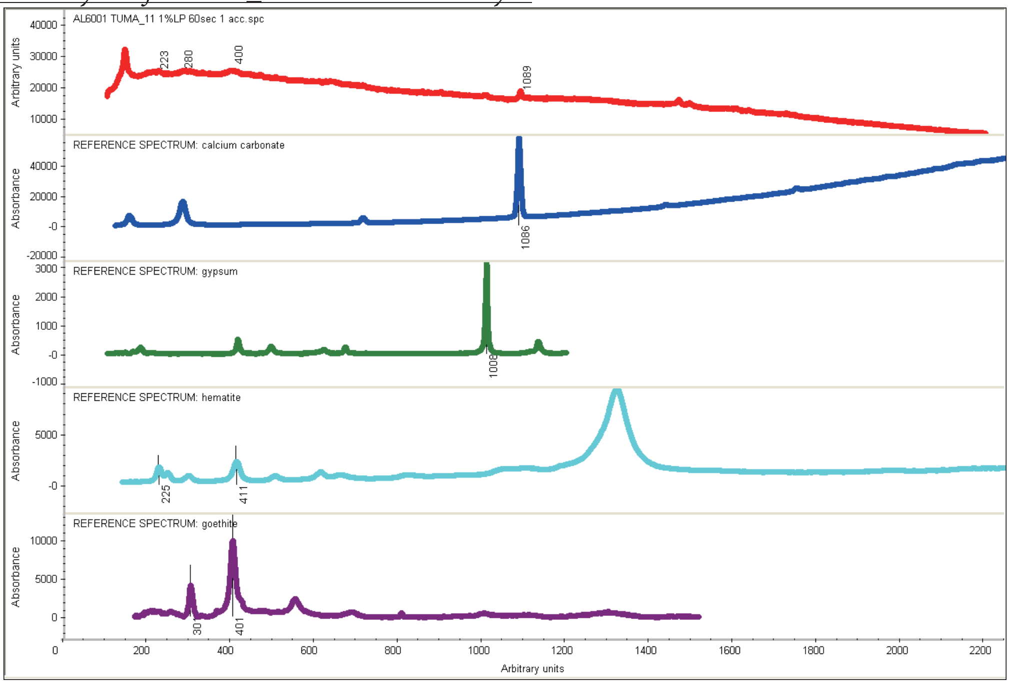


Figure 12.4: Raman spectral data showing presence of goethite, hematite, calcium carbonate, and gypsum within the bright yellow finish layer of TUMA_11

Raman Analysis of TUMA_11 Thin White Preparatory Finish Layer

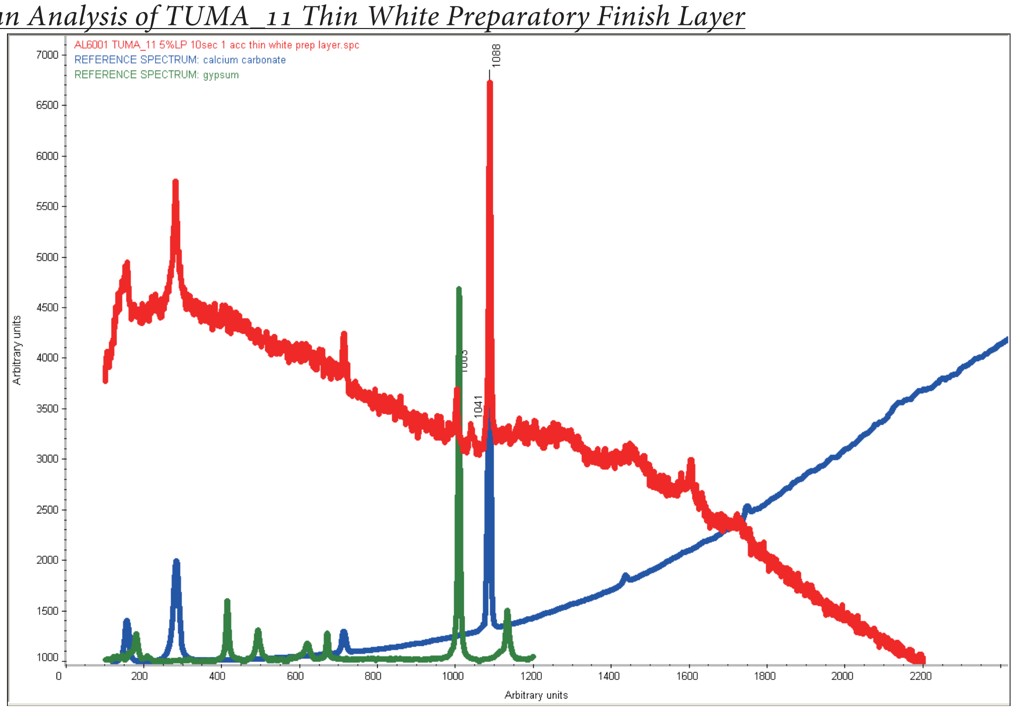


Figure 12.5: Raman spectral data showing presence of both calcium carbonate and gypsum within the thin white preparatory finish layer of TUMA_11

Raman Analysis of TUMA_12 Red Finish Layer

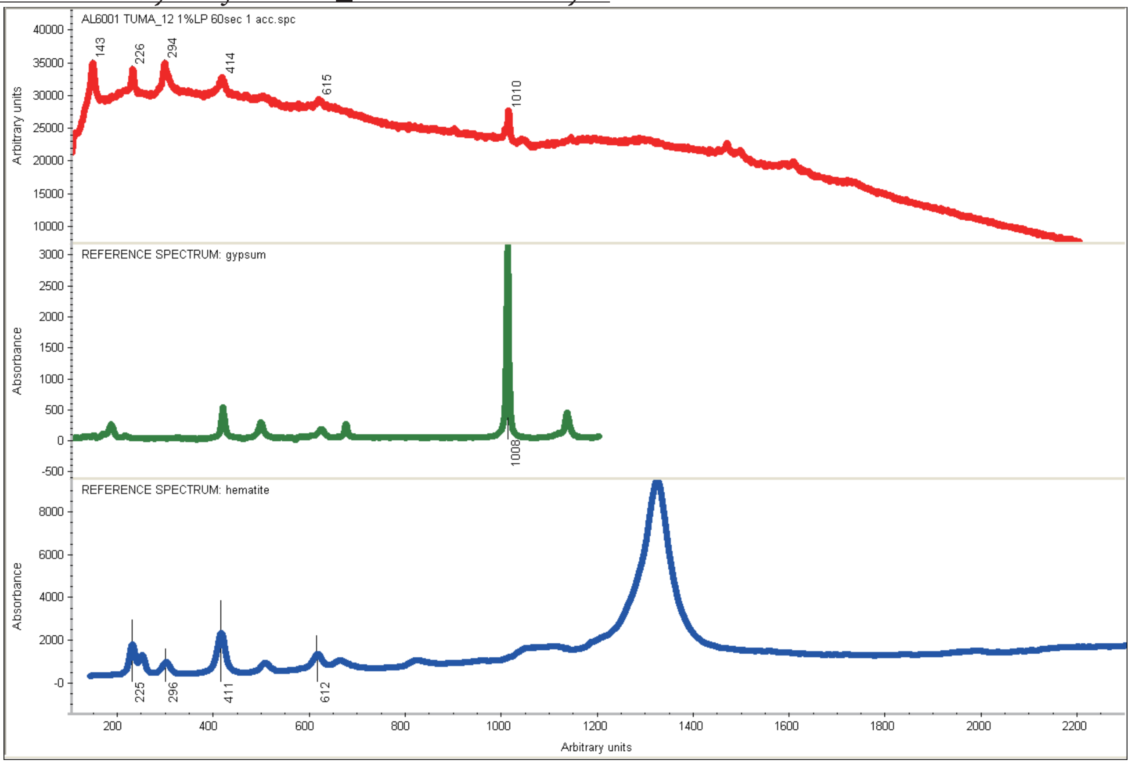


Figure 12.6: Raman spectral data showing presence of hematite and gypsum within the bright red finish layer of TUMA_12

Summary of Raman Microscopy and Fourier Transform Infrared Spectroscopy Analysis

Table 12.3: Summary of Conclusions Acquired Through Raman and FTIR Spectroscopy				
Sample	Color	Layer Type	Method	Results & Notes
TUMA_03	White	Finish	Raman	Calcite Gypsum
TUMA_06	Yellow-brown	Organic finish?	Raman	Calcite Polyester resin
TUMA_06	Yellow-brown	Organic finish?	FTIR	Calcite Polyester resin Gypsum
TUMA_11	Yellow	Finish	Raman	Goethite Hematite Calcium carbonate Gypsum
TUMA_11	White	Preparatory	Raman	Calcium carbonate Gypsum
TUMA_12	Red	Finish	Raman	Hematite Gypsum

Notes

[1] Sylvia-Monique Thomas, "Infrared and Raman Spectroscopy," *On the Cutting Edge: Strong Geoscience Undergraduate Training* (National Association of Geoscience Teachers, 19 June 2014. Web)
[2] Reza Vatankhah, "Lecture Notes: Vibrational Spectroscopy in Heritage Conservation" for *HSPV 656-01: Advanced Conservation Science*. (University of Pennsylvania: Philadelphia, 2014, Print)
[3] Beth Price, "Lecture Notes: FTIR" for *HSPV 656-01: Advanced Conservation Science*. (Philadelphia Museum of Art: Philadelphia, 2014, Print)
[4] Ibid.
[5] Vatankhah.
[6] Ibid.
[7] Ibid.
[8] Ibid.
[9] Ibid.
[10] Mehboob Peeran, and K.G. Srinivasamurthy, "Comparison of Raman and IR Spectroscopy," *Comparison of Raman and IR Spectroscopy*, (ChemVista, 2005, Web)
[11] Vatankhah.

Chapter 13 – Substrate Composition: Thin-Section Petrographic Analysis of Sample TUMA_25

13.1 – Analytical and Methodological Principles

While the primary focus of this investigative study was the finishes of the Mission San José de Tumacácori, examining the underlying stucco substrate is also of great importance for general characterization. Cursory analysis of the stucco substrate was conducted by using sample TUMA_25 as a representative case study, as it is composed of a comparatively large bulk sample containing an uninterrupted preparatory finish layer. This sample was sourced from the collection of fallen fragments that was in possession of Alex Lim, NPS Exhibit Specialist for Tumacácori National Historical Park.

Although initial observations proceeded by a general characterization of the overall bulk sample, the primary method of analysis employed was in the creation and examination of a thin-section sample of TUMA_25 through the use of transmitted light microscopy in both plane and cross polarized light. Due to the characteristic orientation and structure of a crystalline material, refraction and inference phenomena will be induced as light is transmitted through the mineralogical components of a given sample. Thus a material's microstructure, or its composition of crystalline and amorphous constituents, pores, and boundaries, can be described through its optical properties, complexity, variety, order, and shape.[1] Typically, a sample will be an amalgam of several mineralogical compounds that results in several phases of various particles.

Compound microscopes like those utilized in petrographic analysis contain a 360°

rotating stage, a polarizer above and below the stage, an analyzer, and a Bertrand lens in order to accurately observe types of optical phenomena.[2] Plane polarized light is light that has been filtered to possess a vibration direction that lies within a single plane, while cross polarized light occurs when the analyzer is inserted.[3] Types of optical properties that are particularly beneficial to the identification and characterization of mineralogical compounds include birefringence, extinction, isotropic and anisotropy, pleochroism, relief, and refractive index – often determined by use of the Becke Line test.

13.2 – Sample Preparation Methodology

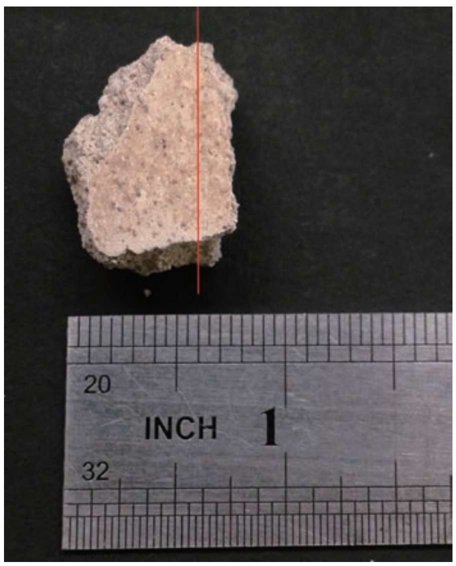
A smaller sample of TUMA_25 measuring approximately 1" long by 7/8" wide was extracted from the bulk to create a thin-section. Subsequent thin-section preparation was carried out by consulting geologic laboratory National Petrographic Service, Inc., based in Houston, Texas. Generally upon receipt of the bulk sample, the consulting laboratory will trim the sample down if necessary then vacuum-impregnate with an epoxy resin possessing a refractive index of approximately nD=1.54.[4] Like in cross-section preparation, a diamond saw is utilized to take a sectioned slice off of the embedded sample billet. Once this section slice is obtained, it is mounted onto a microscope slide and ground to a thickness that will allow for transmitted light to pass through. Certain types of stains, such as alizarin red for calcite, can be applied in order to clarify specific mineralogical features.[5] For the TUMA_25 thin section, the sectioned slice was taken at the indicated axis shown in Table 13.1 below. It was ground to approximately 28-30 μm in thickness in oil and cover slipped. No staining or microprobe polishing was requested, and the epoxy utilized was of a clear impregnation.

When the sample arrived back at the University of Pennsylvania, preliminary visual analysis was conducted by Jocelyn Chan and Frank Matero in the Penn Architectural Conservation Laboratory on both a Nikon Optiphot 2-Pol compound microscope and Nikon Alphaphot-2 microscope that is retrofitted to generate a pseudo-dark field that allows for a thin-section to be viewed as if it was in reflected light. Further investigation was conducted by ceramic petrologist Dr. Marie-Claude Boileau of the Penn Museum's Center for the Analysis of Archaeological Material by use of a compound transmitted Zeiss AX10 microscope.

13.3 – Observations and Analysis

Observations and data regarding substrate characterization is presented as follows:

Characterization of TUMA_25 Bulk Sample Sent for Thin-Section



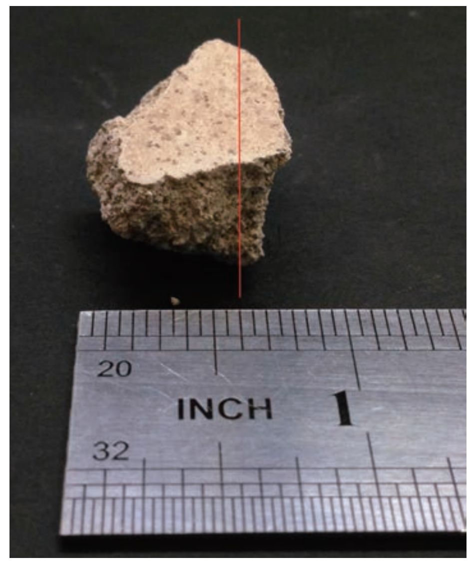
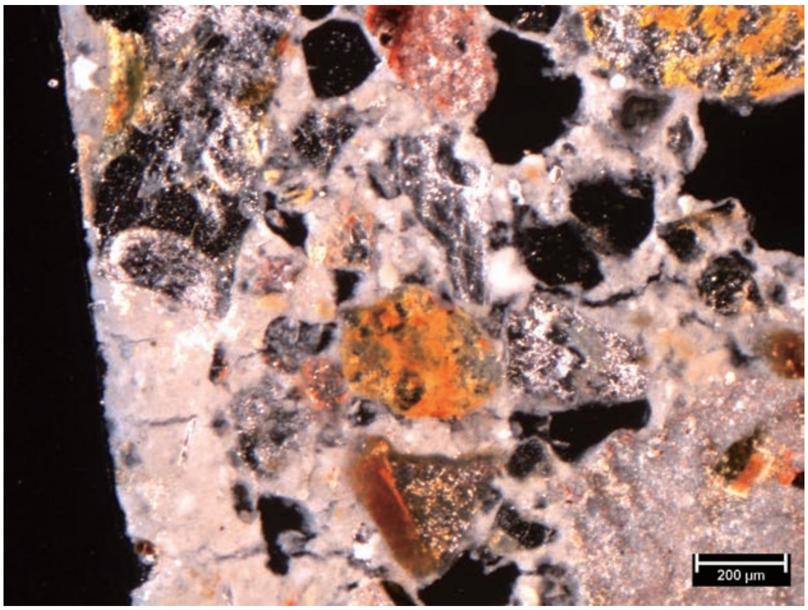


Table 13.1: Characterization of TUMA_25 Bulk Sample Sent for Thin-Section	
Site / Sample ID	Tumacácori, AZ/TUMA_25
Sampled by	Alex Lim
Sampled on	Unknown
Analyzed by	Jocelyn Chan
Analyzed on	13 April 2015
Description	Sample of substrate with uninterrupted cream preparatory finish layer
Appearance	Moderately coarse aggregate with noticeable large blebs throughout bulk. Some large reddish streaks, likely from brick
Snap Strength	Very low
Layering	Substrate and finish layer
Bulk Color (Munsell)	2.5 Y 8/1 (White)
Hardness (Mohs)	<2
Texture (Matero)	80-120 grit

Characterization of TUMA_25 Thin-Section Under Pseudo Dark-Field

TABLE 13.2: CHARACTERIZATION OF TUMA_25 THIN SECTION UNDER IMITATED DARK FIELD



SAMPLE TUMA_25
THIN SECTION – DARK FIELD

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

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

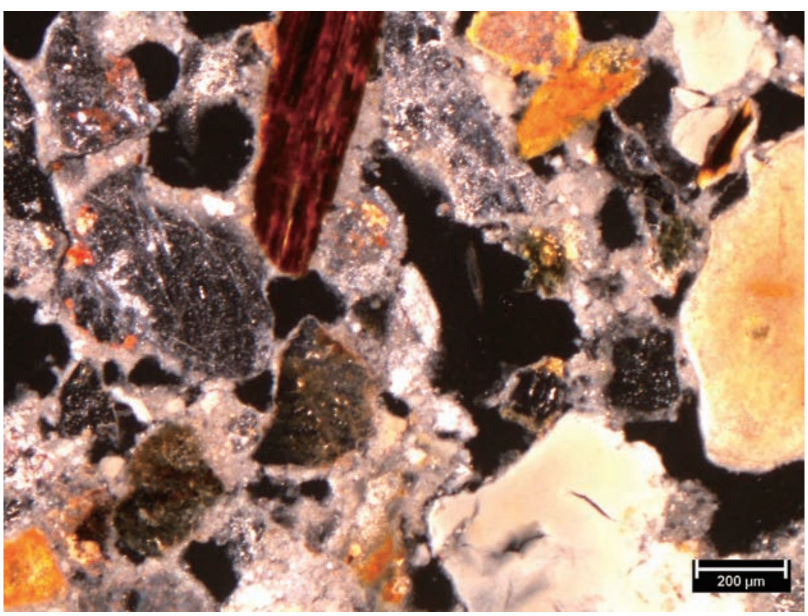
MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

OBJECTIVE: 4x
ZOOM: n/a

TRINOCULAR MAG: 1.0x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

Figure: Thin-section of TUMA_25 viewed under pseudo dark field, note white preparatory paste to the left of the sample image



SAMPLE TUMA_25
THIN SECTION – DARK FIELD

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

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

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

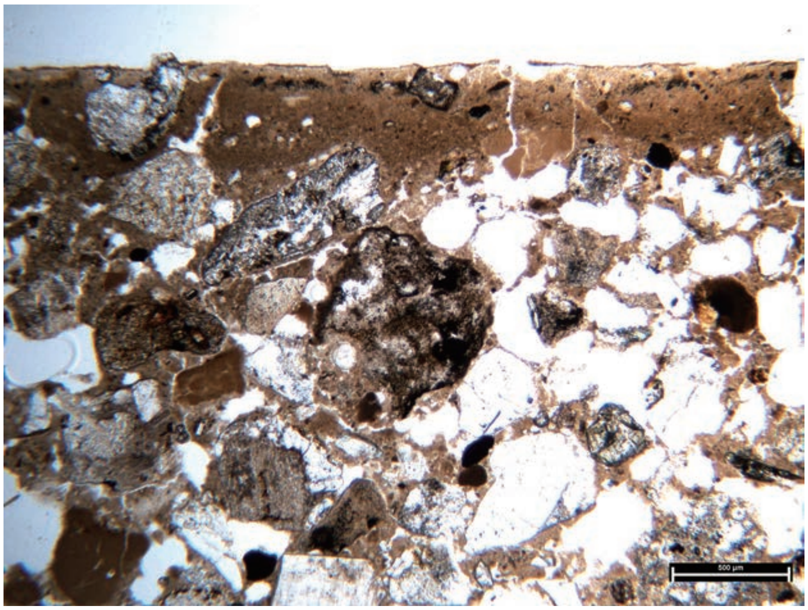
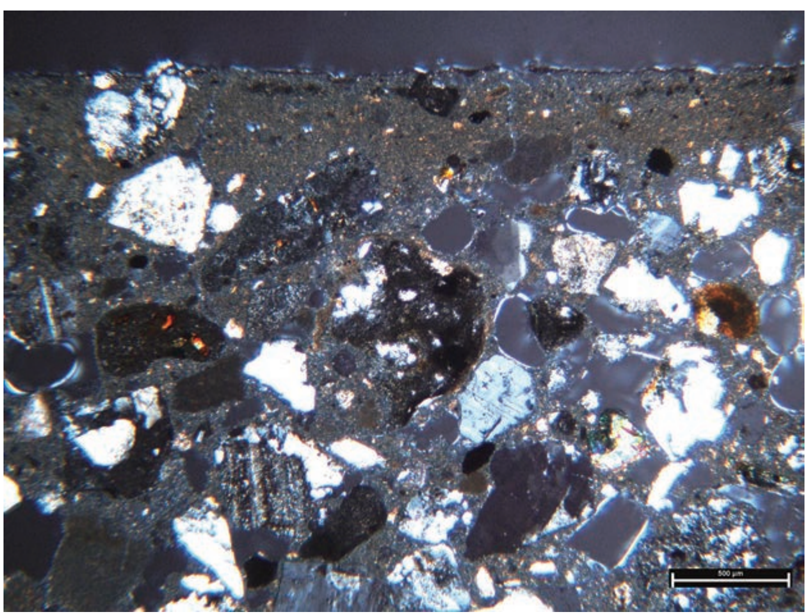
OBJECTIVE: 4x
ZOOM: n/a

TRINOCULAR MAG: 1.0x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

Figure: Thin-section of TUMA_25 viewed under pseudo dark field, view of stucco substrate bulk

Characterization of TUMA_25 Thin-Section Using Polarized Light Microscopy

Table 13.3: Characterization of TUMA_25 Thin Section Using Polarized Light Microscopy	
	SAMPLE TUMA_25 THIN SECTION – DARK FIELD
	ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) **RECEIVED: 4/6/15**
	IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software
	MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x
	OBJECTIVE: 4x ZOOM: n/a
	TRINOCULAR MAG: 1.0x LIGHT SOURCE: halogen
	FILTERS: daylight COLOR TEMP: n / a
Figure: Thin-section of TUMA_25 viewed under plane-polarized light, sample oriented with the preparatory paste on top and substrate on bottom	
	SAMPLE TUMA_25 THIN SECTION – DARK FIELD
	ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) **RECEIVED: 4/6/15**
	IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software
	MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x
	OBJECTIVE: 4x ZOOM: n/a
	TRINOCULAR MAG: 1.0x LIGHT SOURCE: halogen
	FILTERS: daylight COLOR TEMP: n / a
Figure: Thin-section of TUMA_25 viewed under cross-polarized light, sample oriented with the preparatory paste on top and substrate on bottom	

Geologic Map of Arizona and Site of Tumacácori National Historical Park

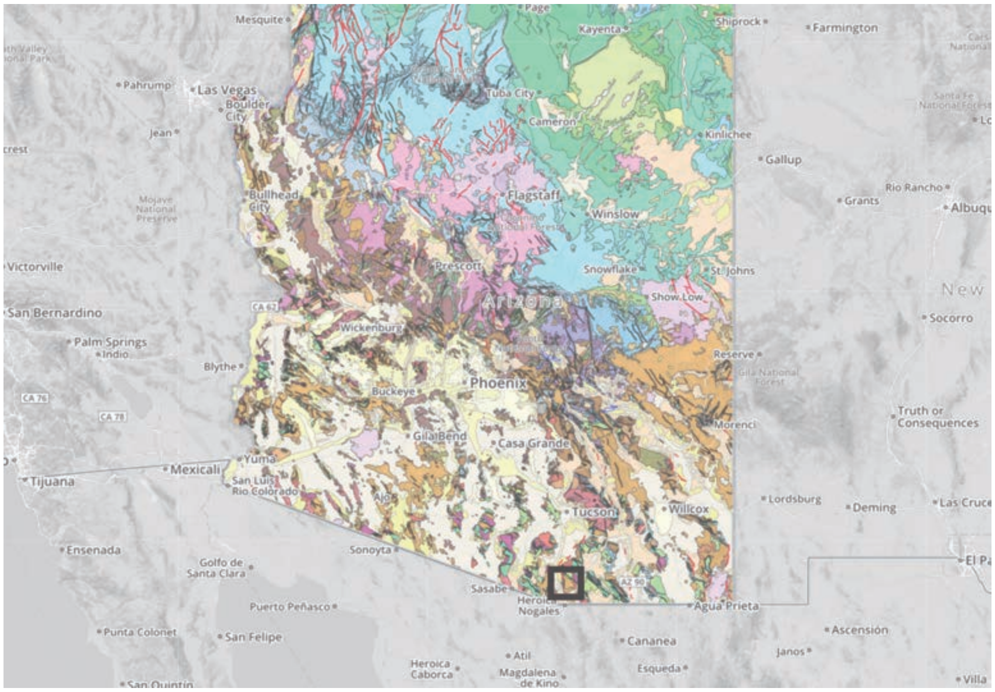


Figure 12.1: Geologic map of Arizona demonstrating the diversity of geological deposits, black bounding box is area containing Tumacácori National Historical Park

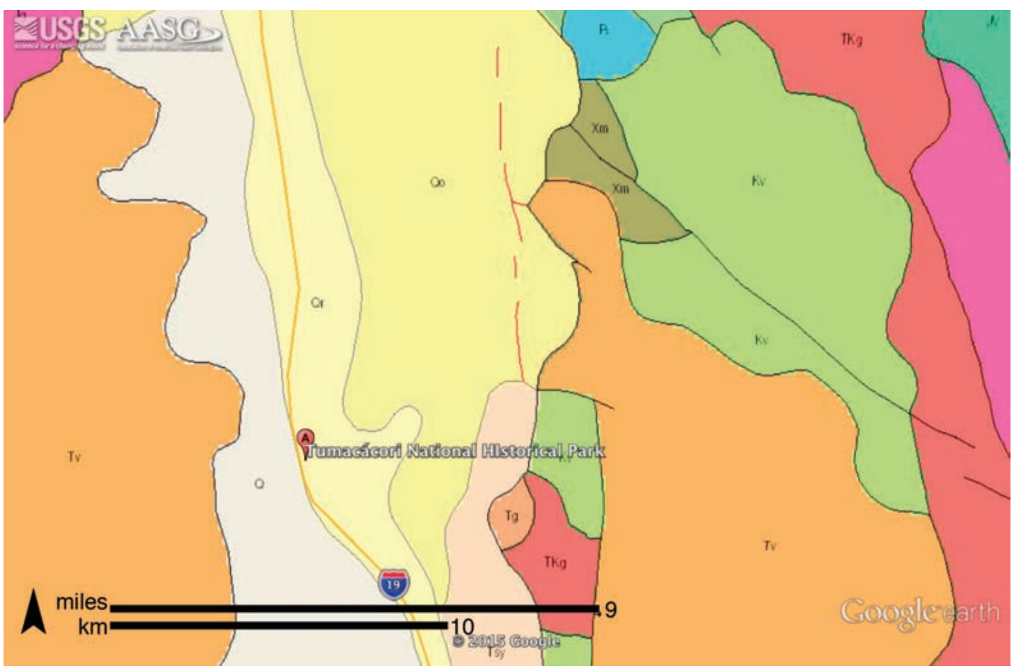


Figure 12.2: Geologic map of Arizona indicating that the Qr designation is the primary geological formation in which Tumacácori National Historical Park is located in

While the bulk sample seemed fairly homogenous and exhibited extremely low snap strength, thin-section microscopy indicated that the mineral constituents of the stucco used on the façade of the Mission San José de Tumacácori are much more varied than originally anticipated. Overall, the sample appears quite coarse grained and porphyritic, with several rock fragments that appear to be of igneous nature. Mineralogically, there is a high degree of alteration and a large range of mineral types and rock fragments. However the minerals present within the TUMA_25 sample appear very felsic with not very many mafic components present. Indeed, this would corroborate SEM-EDS findings that indicated a general scattered presence of elements such as potassium, aluminum, silica, oxygen, calcium – elements that are all primary constituent of feldspars. Dr. Boileau confirmed the presence of quartz and feldspar, of varying degrees of clarity and alteration. Other specific minerals identified include zoned plagioclase, oxidized and elongated biotite mica, and calcite grains that were noted for their high twinning and relief. Many rock fragments of both fine and coarse-grained nature were also noted, including what appeared to be andesite due to its fine-grained rock matrix with some inclusions, and chert. However the chert appeared to be seen with epidote, an occurrence that is rarely seen together.

This session with Dr. Boileau was intended to identify the most prominently featured mineral and rock features within the sample. Upon consulting The Arizona Geological Survey's online geologic map of Arizona in both their open source online viewer as well as in Google Earth, Arizona's geologic formations are highly varied. However the primary formation in which the Tumacácori National Historical Park is located is classified as "Qr."[6] This deposit corresponds to the designation of Holocene River Alluvium (0-10 ka), that possesses "unconsolidated to weakly consolidated sand and gravel in river channels and sand, silt, and clay on floodplains…includes young terrace deposits fringing floodplains"[7] Indeed, after more deeply examining the indicated geologic designations and surrounding deposits, more work could be done to further identify and confirm several minerals that were not as readily identifiable through a second session with Dr. Boileau.

Notes

[1] Victoria Pingarron Alvarez, "Experiment 04: Introduction to Mineralogy" for *HSPV 555-01: Introduction to Architectural Conservation*. (University of Pennsylvania: Philadelphia, 2014, Print)
[2] Ibid.
[3] Ibid.
[4] Ibid.
[5] Ibid.
[6] "The Arizona Geological Survey | Map Services | Geological Map of AZ," *The Arizona Geological Survey | Map Services | Geological Map of AZ*, (The Arizona Geological Survey, 2011. Web)
[7] Ibid.

Chapter 14 – Recommendations and Conclusions

14.1 – Recommendations for Future Research

The completed analytical investigations into the sampled polychromatic surface finishes of the Mission San José de Tumacácori are presented as follows:

Table 14.1 – Summary of Completed Analyses on Tumacácori Surface Finish Samples

Color	Sample	Location	Stratigraphy	Microchemical	Dispersion	SEM-EDS	Raman	FTIR
Red	TUMA_01	Upper left broken cornice	X		X			
	TUMA_12	Lower left face above nicho	X	X	X	X	X	
	TUMA_27	Lower right column? A. Lim	X					
	TUMA_28	Lower right column? A. Lim	X				X	
Yellow	TUMA_06	Upper face above nicho	X		X	X	X	X
	TUMA_07	Upper left face	X				X	
	TUMA_09	Upper column shaft	X		X			
	TUMA_11	Lower left cornice	X		X		X	
	TUMA_13 B	Extradose molding	X					
	TUMA_19	Lower left return of inner edge (outer surround)	X					
	TUMA_26	Lower right column? A. Lim	X					
	TUMA_29	Lower right column? A. Lim	X					
White	TUMA_02	Upper left frieze	X					
	TUMA_03	West side leftmost capital	X		X	X	X	
	TUMA_04	Upper left frieze	X					
	TUMA_08	Column shaft to right of nicho	X					
	TUMA_13 A	Scored joint of the extradose above voussoirs	X					
	TUMA_25	Lower right column? A. Lim	X	X	X			
	TUMA_30	Lower right column? A. Lim	X					
Orange	TUMA_14	Intradose voussoir	X				X	

This investigation of the original polychromatic painted surface finishes of Tumacácori's façade consisted of archival research, historic contextualization, comparative studies, in-situ investigation, and laboratory analysis – encompassing optical microscopy of the surface finish cross-sections and dispersed pigment layer particles, scanning electron microscopy with energy-dispersive X-ray spectroscopy, Raman microscopy, Fourier Transform Infrared Spectroscopy, microchemical testing, and petrographic analysis of the stucco substrate. While every effort was taken to ensure a holistic approach to this analysis, as with any type of materials investigation there remain questions that had arisen through the investigative duration that provide ample opportunity for future research.

Indeed, this research was intended from its conception to provide the foundation for future pilot conservation work. Thus successive areas of research that could be undertaken are outlined as follows:

- ***Limewash Staining***: due to the nature of certain brownish-yellow samples found on the façade's background face, hypotheses about whether this overall yellow wash was applied as a stain linger. More research into methods of limewash staining is recommended and mockups of limewash stains to create cross-sections from and observe under optical microscopy for comparison may be prudent. Even if the original finish at Tumacácori is confirmed to not be a stain, this research could be useful as a historically sensitive method of restoration and future maintenance.
- ***Further Instrumental Analysis***: several samples proved more difficult to obtain definitive confirmatory results. Two methods of instrumental analysis, X-ray diffraction (XRD) for inorganic, crystalline compounds and attenuated total reflectance Fourier Transform

Infrared Spectroscopy (ATR-FTIR) for organic compounds could be utilized upon existing samples with minimal additional preparation. XRD provides molecular characterization for crystalline substances, while ATR-FTIR improves FTIR signal and can be sensitive enough to be performed upon a layer of a cross section in-situ without further extraction. For the suspected organic layers noted, a more precise method of instrumental analysis, such as gas chromatography mass-spectroscopy (GC-MS) or high-pressure liquid chromatography (HPLC) could be utilized, although it would result in the destruction of the extracted sample. Lastly, cutting-edge laser technology for in-situ analysis and controlled cleaning of painted surfaces currently exists, most notably in Greece where the Acropolis Restoration Service in conjunction with the Foundation for Research and Technology has been pioneering this technology. All instrumental analyses should be completed in consultation with a trained conservation scientist who is highly experienced in the operation of the aforementioned instruments.

- ***Further Sampling***: in order to provide additional instrumental analysis and targeted comparisons, further sampling in order to appropriately plan for the immediate stabilization of these friable extant surface finishes as well as long-term preservation would be beneficial. Suggested sample areas include the façade *nichos*, façade background, as well as samples from the interior floor plaster that Gettens suggested was more similar to exterior plasterwork
- ***Methods of Documentation***: additional approaches of digital documentation drawn from other fields could be instructive. Methods of digital analysis utilized in the conservation of rock art merits additional research, particularly in the use of DStretch, an open-source

plugin to the program ImageJ written by Jon Harman for "the digital enhancement of pictographs." Should this program be deemed appropriate, it could help reveal further pigment characteristics on the façade.[1]

- ***Repair Campaigns***: samples of repair campaigns were taken in January 2015, however priority was given to the original historic finishes for the scope of this investigative analysis. Consequently, all studies regarding past interventions was limited to archival research. Analysis of repair samples is recommended, particularly if the presence of any type of synthetic coatings can be detected.
- ***Stucco Characterization***: further characterization of the highly varied stucco in preparation for conservation efforts is recommended. This includes a gravimetric analysis by mortar digestion in order to determine an appropriate sand mix for restoration purposes, as well as greater research into the local geological deposits near the site itself. Extended petrographic analysis could also prove instructive.

14.2 – Recommendations for Pilot Conservation

As the history of conservation efforts undertaken at the Mission San José de Tumacácori as well as current conservation philosophy dictates, pilot conservation efforts should strive for the most materially appropriate treatments. This would likely result in the application of historically-based, yet carefully modified treatments.

Angelyn Bass and Douglas Porter's 2013 "Preliminary Condition Assessment of the Architectural Finishes, South Façade" outlined their identified prioritized actions. Structural stability of walls and wooden elements – particularly in consideration of Tumacácori's location within a seismic zone – were highlighted, as the south wall of the façade was deemed "essentially detached from east and west wall nave walls."[2] Areas of unsheltered adobe were also elevated to a high priority due to erosion and all sacrificial plaster caps were considered past their service life, potentially inducing more damage to the plaster below.[3] Many areas of detached plaster are unsupported atop blind voids, thus necessitating injection grouting for stabilization. Furthermore, the removal of patchy cementitious and rough-cast parging for replacement with a more compatible repair should be considered, as it is not only likely deleterious to the soft, original plaster but also visually distracting and incohesive.[4] Due to the diversity of materials applied to the façade over time, material compatibility and subsequent properties such as porosity, permeability, water absorption, and water vapor transmission, are all correspondingly varied.

The pilot conservation treatment for the original polychromatic surface finishes to be tested on a small area of the façade will likely encompass the development of a methodology for further materials testing, the removal of parging, emergency stabilization for unsupported plasterwork, additional documentation, matching of conservation materials, and the reattachment of flaking historic finishes. Materials analysis following the pilot conservation treatment will also be likely in order to evaluate treatments; for example, the penetrative properties of any applied consolidants can be analyzed through thin-section petrographic analysis.[5] Interpretive content should also be included when pilot treatment is occurring in-situ, so as to provide for the dissemination of preservation education to the visiting public.

There has been a great deal of published research into modified, yet historically compatible repairs. Through reviewing current literature, documents of particularly valuable potential use include "Preservation Brief 22 – The Preservation and Repair of Historic Stucco" by Anne E. Grimmer, "Durability of Traditional and Modified Limewashes" by Sarah Marie Jackson, Tye Botting, and Mary Striegel, "High Calcium Lime Mortar: Effects of Traditional Preparation and Curing" by Dagmar Michoinová and Pavla Rovnaníková, "Limewater Absorption and Calcite Crystal Formation on a Limewater-Impregnated Secco Wall Painting" by Isabelle Brajer and Nicoline Kalsbeek, "New Autogenous Lime-Based Grouts Used in the Conservation of Lime-Based Wall Paintings" by Piero Baglioni, Luigi Dei, Francesca Piqué, and Giuseppe Sarti, ASTM C-207-06 "Standard Specification for Hydrated Lime for Masonry Purposes," and ASTM C-144-11 "Standard Specification for Aggregate for Masonry Mortar."

14.3 – Concluding Remarks

That there are even any extant remnants of the historic polychromatic painted façade of the Mission San José de Tumacácori is simply extraordinary. The analysis that had been undertaken through this thesis has concluded that overall, the plaster stucco substrate is lime-rich and was composed of a mineralogically diverse array of aggregate. The painted ornamentation appears to not have been applied in a true fresco manner – indeed, the indication of a weathered surface and observed lime laitences indicate that time elapsed between stucco and pigment application finish layers. Samples that exhibited discrete layering generally possessed a primary thin white preparatory finish coat of gypsum over which the pigments were then applied. Perhaps the most curious observation that has resulted from this analysis is the question of whether certain façade elements were not necessarily painted, but rather stained. This hypothesis is supported by contextual research into other contemporaneous traditions of limewash staining and the application of organic resins in Spanish-Colonial edifices coupled with observations of the samples that exhibited these characteristics through the analytical process – however further research is necessary to confirm this supposition. Confirmed pigments used on the exterior include hematite (red), goethite (yellow), and gypsum (white), while evidence suggests that there were no large-scale campaigns of repainting to have ever been undertaken at Tumacácori.

Ultimately, despite the large technical component of this thesis, this investigation was undertaken with the scope that the conservation history and treatments will ultimately be used in a larger scheme of interpretation and education intended for the public. All acts of conservation are simultaneously acts of interpretation, and Tumacácori's façade stands as an excellent case in which to explore further collaborations with local community members and stakeholders. This is not unprecedented, as the 1992 collaboration to conserve the interior dome of Tumacácori with the nonprofit preservation group Patronato San Xavier and trained members of the Tohono O'odham tribe illustrate. The tenet of collaborative preservation has been particularly strong in the Southwest, and considerations of the Tumacácori façade treatment could be used to reinvigorate threads of advocacy and community-oriented conservation. Indeed, this historic foundation for collaboration extends beyond Arizona and even ties back to the University of Pennsylvania as well, aptly indicated by the 1997 Cultural Resource Management newsletter entitled "A Unity of Theory and Practice Bridging to the Past: The University of Pennsylvania and the NPS."[6]

Therefore, the fact that this site will be highlighted in the 2016 NPS centennial celebrations signifies a unique opportunity to use conservation and preservation as a vehicle to interpret the site for the diversity of the American public. Having weathered, both figuratively and literally, the forces of history and changing methodologies of preservation, the utter relative rarity of surviving Spanish-Colonial missions that have retained their original painted decoration punctuates the imperative to conserve Mission San José de Tumacácori's façade for the education and enjoyment of generations to come.

Notes

[1] Jon Harman, DStretch.com, Web.
[2] Angelyn Bass and Douglas Porter, "Preliminary Condition Assessment of the Architectural Finishes, South Façade Mission Church at Tumacácori National Historical Park 2013" National Parks Service (2013) pg 8.
[3] Bass and Porter, 9.
[4] Bass and Porter, 9.
[5] Chandra L. Reedy, *Thin-section Petrography of Stone and Ceramic Cultural Materials*, (London: Archetype, 2008) Print. pg 124.
[6] Cultural Resource Management, "A Unity of Theory and Practice Bridging to the Past" (National Parks Service U.S. Department of the Interior: 1997).

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1965 (paint job on barrel roof)

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1941 *Report of Inspection, Tumacacori National Monument*, WACC.

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1976 *Mission Guevavi: Excavations in the Convento*. The Kiva 42(2):135-75.

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1947 (Background info on getting Gettens)
1959 (Shelter over granary discussion)

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1949 *Tumacacori Interior Decorations.* WACC, Tucson.

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Tumacacori National Monument
1956 (Ruins stab, granary stab, silicon treatment)

1976 Cultural and Natural Resources Management Plan and Environmental Assessment, Tumcacori National Monument, Arizona

1980 Cultural and Natural Resource Management Plan, Archaeological Assessment and Management Recommendations, WACC

1980b (Mineralogical study of fired bricks)

1999 Draft: Replacement and Relocation Plan, Environmental Assessment, Maintenance and Administration Facilities, NPS

Vivian, R. G.

1954 (Rain damage to TUMA, general discussion)

1954b (data on silicones. Summarize findings on silicone and ethyl silicates, testing on school house)

1956 *Notes on the Structure Known as the Corridor*. WACC.

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Watson, Douglas S.

1931 *The Santa Fe Trail to California, 1849-1852: The Journal and Drawings of H. M. T. Powell.* The Book Club of California, San Francisco.

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1979 *A Magnetic Survey of Tumacacori National Monument*. WACC.

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1998 Adobe or Bust: An Examination of Selected Spanish Colonial Adobe Walls in the Tumacacori and Guevavi Missions

Willima,R.E

1976 The Application of Rock Melting to the Preservation of Archaeological Sites, Los Almos Scientific Laboratory of the university of California, Los Alamos, New Mexico

Zimtt, Werner S.

1993 Adobe Stabilization Test Walls at Tumacacori national Monument

<u>November 6, 2014: Memo of Documents Requested from WAAC</u>

From 11.03.14-11.06.14 Frank Matero visited WACC library and archives to review documents for the current CESU project to prepare a conservation history of Tumacacori and specifically the church exterior. Matthew Smith provided full support to assist in the access and review of a large amount of material. The following items (docs/folders) have been identified by red or yellow flags on documents and folders for copy/scan (flags on folders means entire contents required for repro). The list of documents follows:

TUMA

Box 1/Group 36 (Acc 00681/Cat 7651)

F2-Adm-Corr
F5-Adm-Corr
F9-Adm-Corr

Box 2

F14-Adm-Daily Diaries & Monthly Reports
F15- " "
F16- " "
F17
F20-Interp Files-Interp
F22-Interp-Architecture
F23-Interp-Sonoran Missions
F25-Interp-Pinkley's Handbook

Box 3

F29-Interp-Statistics
F30-Interp-PhotoInventiry (G.Grant)
F37-Facilities Repairs-Storm Damage
F33-ArchaeoFiles-Stab (all)
F35-Archaeo-Stab (all)

Box 33/Series 13.1/TUMA/File Untis 1-16

007-Crosby HP 1977

TUMA/Acc244/Box 1/10

#115

Cat #4622/4458-Pinkley Mission SJT, 1921
830/115/4662-1921, Repair & Restoration Work
825/117/4573-1947-J. Lancaster Stab
825/117/4467-1947-" "
825/129/4535-1960-Corresp (all)

Box 2/10/Acc84…

825/133/4555/4554-1930-Peterson
825/132/4553-1935-Atwell Inspection
830/116/4572-1947 (all)
825/116/4464-1947-Corresp (all)
825/116/4572-1947-E. Jackson-Stab
830/94/4574-1949-Steen-Stab (all)
405/94/4461-1949-Steen-Stab (all)
830/139/4661-1955-Corresp (all)
825/139/4661-1955-Corresp (all)
825/165/4473-1962 (all)
825/122/4534-1972 (all) 1/2
825/122/4534-1972 (all) 2/2
825/121/4530-1973 (all)

Misc unmarked box

019.1/13.1-TUMA Research Doc
016/13.1-Maintenance & Pres Proj 1955-95
008/13.1-Dome 1983-1986
825/129/4538-1960-(all)
825/130/4543-1961
Stab of Preh Adobe Arch-O/Bannon & Wilander, 1978
3432-Cattanach, Dec 1976 (corresp)

MSC Coll/Box 35

F817.T8P47-Report on Exam of Avail Evidence on Det-Percious & Norvelle
F817.T8T69-Torvea-Report on SJT
F817.T8U55-TUMA Cultural &Natural Resource Management Plan
F817.T8U55-TUMA Statement for Management

Notes:

Also at WACC:

Schneider-Hector, Dietmar. *Sundipped Memories of Frank Pinkley*. Percha Creek Press, NM, 2003.
-check to see if for sale

Rensch, H.E. *Chronology for Tumacacori N. M. with Bibliography*. USDI, Berkley CA:NPS, 1934.

Crosby, Tony. *Historic Structures Preservation Guide*, Tumacacori. Sept 1983.
-survey forms and procedures for survey and repair

DeLong, Scofield & Lefler B. Miller. *Architecture of the Sonora Missions Sonora Expedition, Oct 12-29, 1935*. USDI, NPS" Berkeley, CA, 1937.
-very good watercolor details of painted decoration and measured dwgs.

Drawings:

Torvea-1930s – in various reports

HABS 1975-77-Borchers, Ohio State Univ, photogrammetry-incomplete set at WACC-check LoC

Master Development Plan, Tumacacori National Monument
1938 (W.L.B. –W. Lyle Bennet?) & 1958.
1 sheet

The Master Plan, Tumacacori Natiobal Monument, Arizona.
Title + 10 sheets-1954-58

Vint approved both

Photos:
Need to check large inventory of Grant photos (see Xerox) from 1935, 1940, 1953.

Appendix A: Historic Photograph Set of Mission San José de Tumacácori's Façade

Tumacácori Historic Photos & Metadata
Revised October 29, 2014

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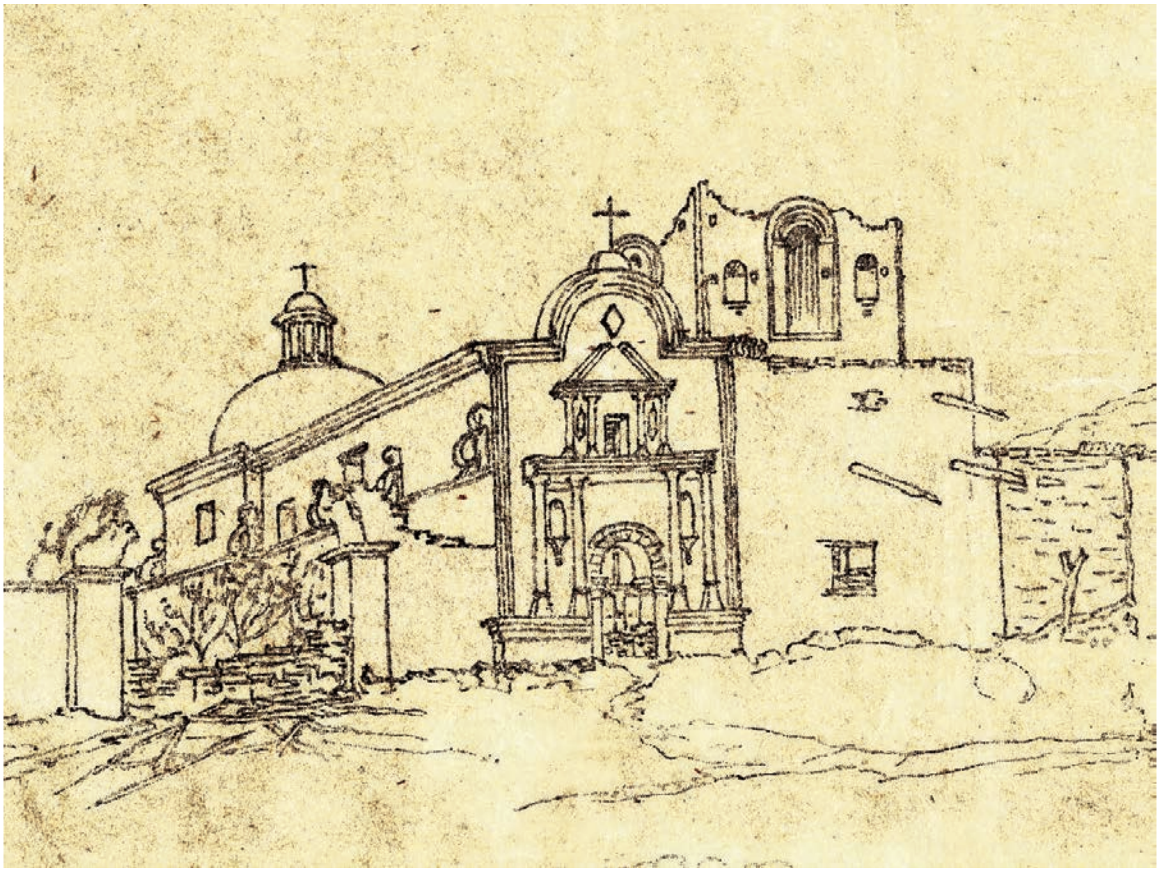
1849 Tumacácori Sketch



	Title	Tumacácori: H.M.T. Powell sketch ca 1849
	Credit	H.M.T. Powell
	Date	1849
	Description	H.M.T. Powell drew this sketch in his journal on the way to California
	Source	NPS website "Changing Face of Tumacácori"

	Title	"1_TUMA_PuebloTumacacoriSketch_550_cleaned_darklines_1849ish.tif"
	Credit	H.M.T. Powell
	Date	1849
	Description	Pueblo Tumacácori
	Source	Tumacácori Archives

1868 Tumacácori

	**Title**	Tumacácori 1868
	Credit	Unknown
	Date	1868
	Description	Light in the doorway suggests that the roof has already been disassembled but the choir loft is still standing
	Source	NPS website "Changing Face of Tumacácori"

1889 Tumacácori

	Title	Tumacácori 1889
	Credit	Unknown
	Date	1889
	Description	Damage can now be seen at the base of the doorway
	Source	NPS website “Changing Face of Tumacácori”

	Title	“church timeline001_1889.tif”
	Credit	-
	Date	1889
	Description	-United States Department of the Interior: National Parks Service -Classification No: 266.2791/Negative No: 1,260 -Subject: Old photo of mission church from front -Location: Tumacacori Nat Mon -Form 10-30 (7/57) Print File Card
	Source	Tumacácori Archives

1912 Tumacácori

	Title	Tumacácori 1912
	Credit	Unknown
	Date	1912
	Description	In the aftermath of an earthquake in 1890, the large rounded pediment came down from the top of the façade. Observe, too, the first bit of preservation efforts after Tumacácori's establishment as a national monument in 1908. A fence has been erected in front of the ruins (and a man is standing on the wall of the bell tower
	Source	NPS website "Changing Face of Tumacácori"

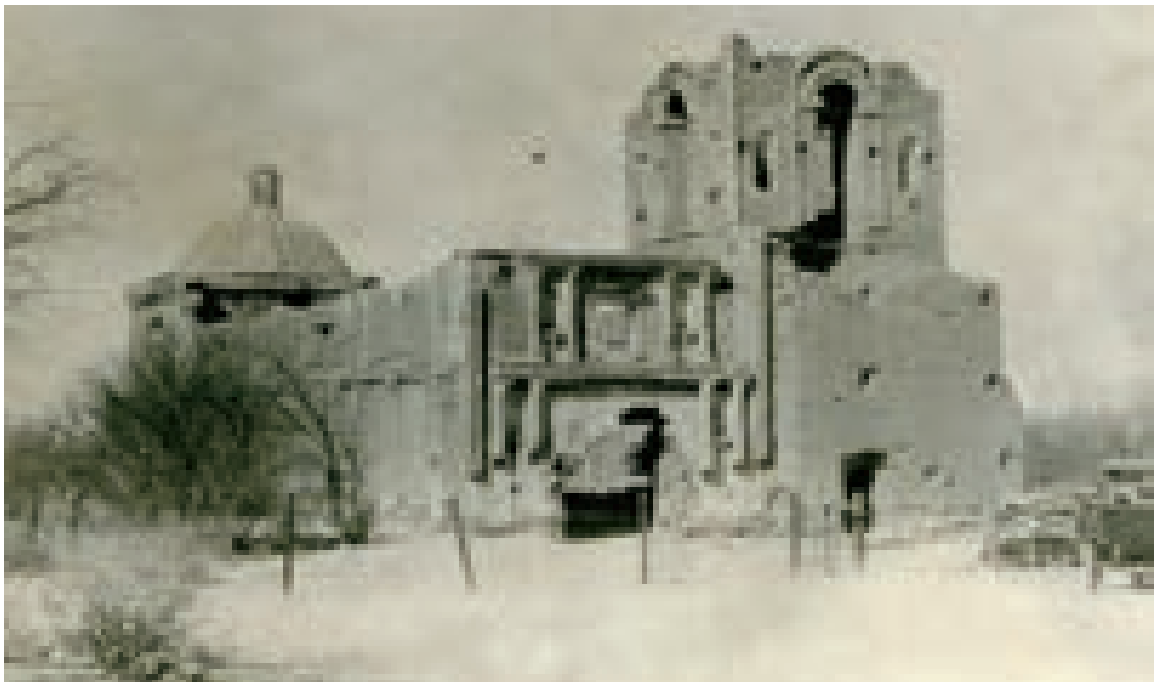
	Title	"church timeline 002_1912.tif"
	Credit	-
	Date	1912
	Description	-
	Source	Tumacácori Archives

1913 Tumacácori

	**Title**	Tumacácori 1913
	Credit	Unknown
	Date	1913
	Description	Extensive damage can be seen at the base of the doorway
	Source	NPS website "Changing Face of Tumacácori"

	**Title**	"church timeline003_1913"
	Credit	-
	Date	1913
	Description	-
	Source	Tumacácori Archives

1915 Tumacácori

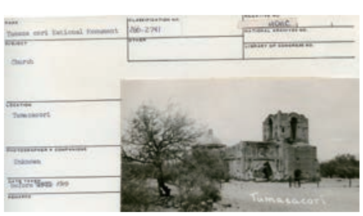


	Title	Tumacácori 1915
	Credit	Unknown
	Date	1915
	Description	Pallets near the vehicle in front of the fence suggest that preservation work has begun
	Source	NPS website “Changing Face of Tumacácori”

	Title	“church timeline0004_1915.tif”
	Credit	-
	Date	1915
	Description	-INT.-DUP. SEC., WASH., DC. -Classification No: 266.2791 -000194 -Negative No: 1667 -10-30 (Sept. 1953)/83083
	Source	NPS website “Changing Face of Tumacácori”

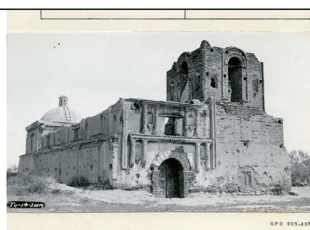
1916 Tumacácori

Title	Tumacácori 1916
Credit	NPS Photo
Date	1916
Description	-
Source	NPS website “Changing Face of Tumacácori”



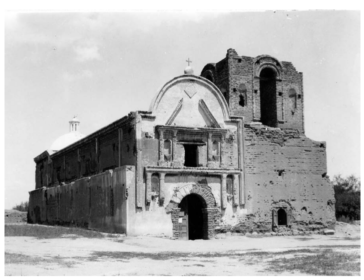
Title	“church timeline005_1916poss.tif”
Credit	Unknown
Date	Before [1919] (crossed out 1921)
Description	-Park: Tumacacori National Monument -Subject: Church -Location: Tumacacori -Photographer & Companions: Unknown -Date Taken: before 1919 -Classification No: 266-2791 -Negative No: 404C?
Source	Tumacácori Archives

1919 Tumacácori

	Title	Tumacácori 1919
	Credit	NPS Photo
	Date	1919
	Description	Doors, window shutters and adobe replacement work near the bell tower can be seen
	Source	NPS website "Changing Face of Tumacácori"

	Title	"church timeline006_1919.tif"
	Credit	
	Date	Probably early 20's
	Description	-Park: Tumacacori National Monument -Subject: Church before restoration -Location: Tumacacori -Photographer: Unknown -Date Taken: Unknown/Remarks: Probably early 20's -Classification No: 266-2791 -Negative No: No neg. -NPS 10-30 (8/68) National Visual Inventory Card -GPO 905.437
	Source	Tumacácori Archives

1922 Tumacácori



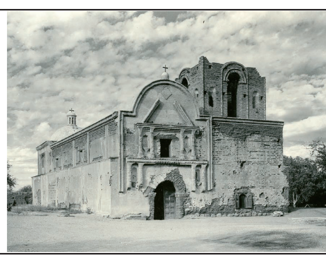
Title	Tumacácori 1922
Credit	NPS Photo
Date	1922
Description	The rounded pediment at the top of the façade has now been rebuilt
Source	NPS website “Changing Face of Tumacácori”

Title	“church timeline007_1922.tif”
Credit	-
Date	1920’s
Description	-Classification No.: 266.2791 -000281 -Negative No.: 73 WACC
Source	Tumacácori Archives

1927 Tumacácori

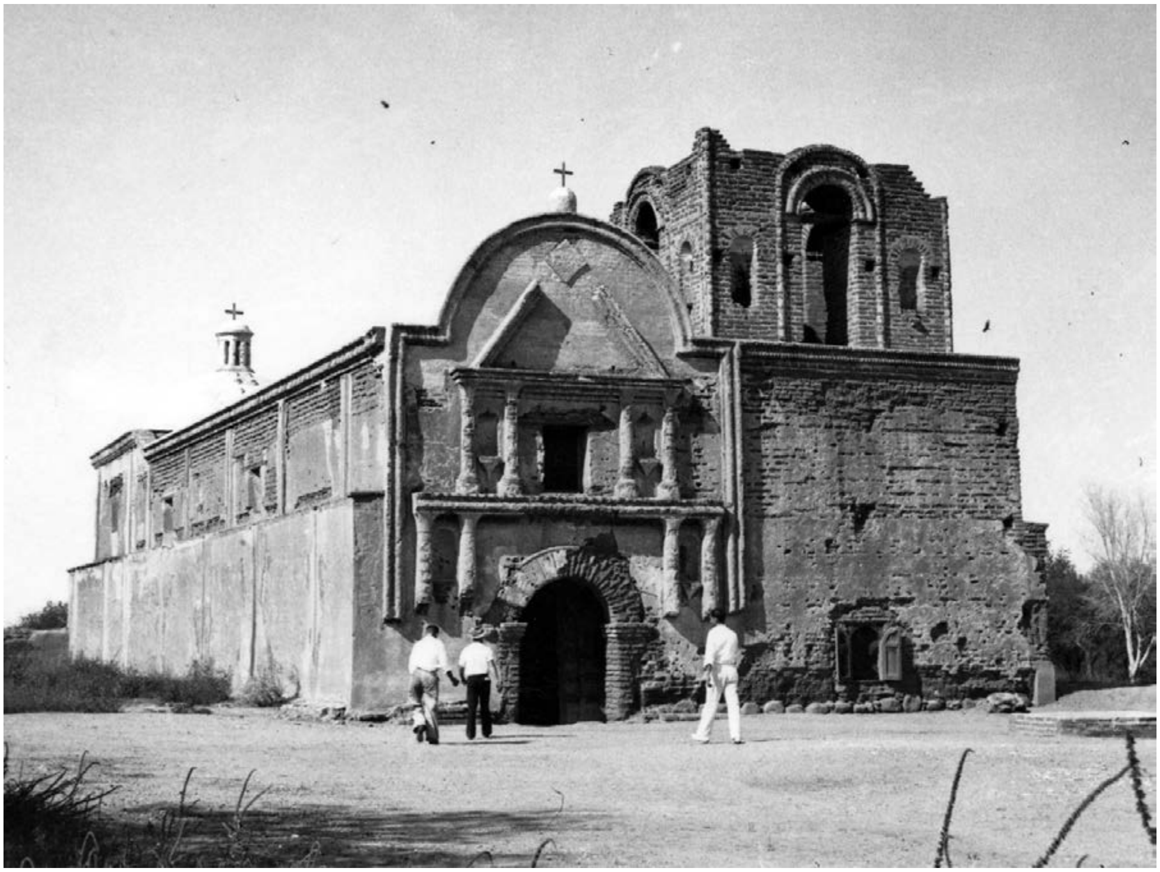
	Title	Tumacácori 1927
	Credit	NPS Photo
	Date	1927
	Description	Replacement adobes are piled near the front entrance
	Source	NPS website "Changing Face of Tumacácori"

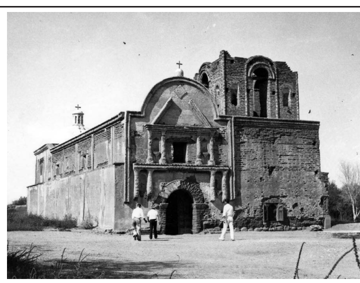
1930 Tumacácori

	**Title**	Tumacácori 1930
	Credit	NPS Photo
	Date	1930
	Description	The cornice below the bell tower has been squared off
	Source	NPS website “Changing Face of Tumacácori”

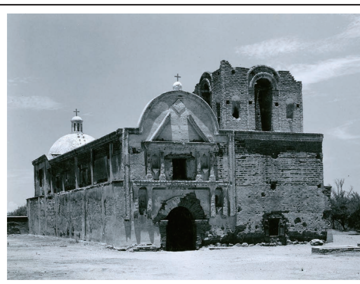
	**Title**	“church timeline009_1930.tif”
	Credit	-
	Date	c. 1930?
	Description	-Classification No.: 266.2791 -000353
	Source	Tumacácori Archives

1938 Tumacácori



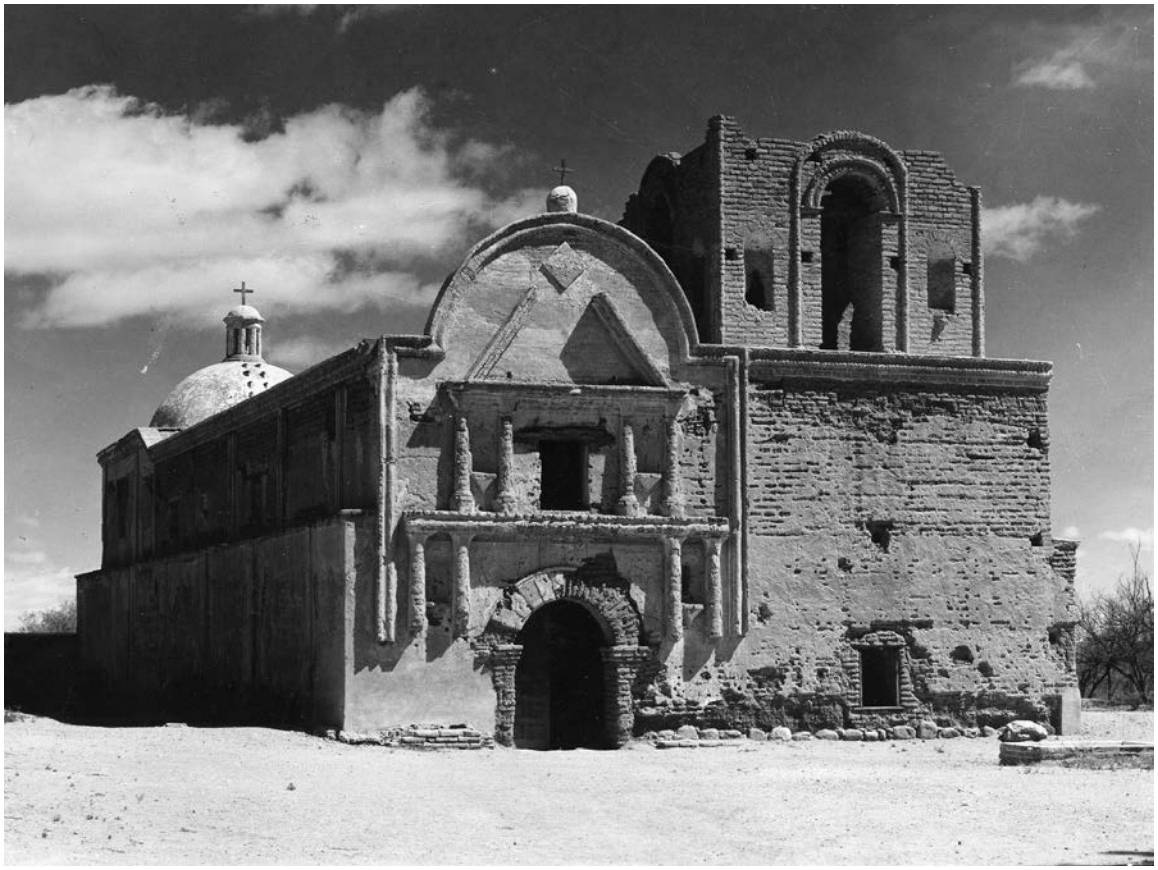
	Title	Tumacácori 1938
	Credit	NPS Photo
	Date	1938
	Description	-
	Source	NPS website “Changing Face of Tumacácori”

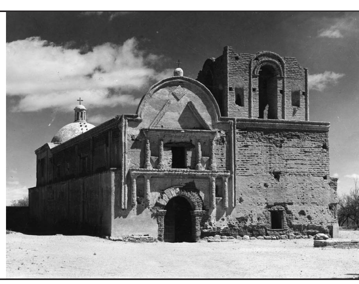
1940 Tumacácori

	**Title**	Tumacácori 1940
	Credit	NPS Photo
	Date	1940
	Description	-
	Source	NPS website "Changing Face of Tumacácori"

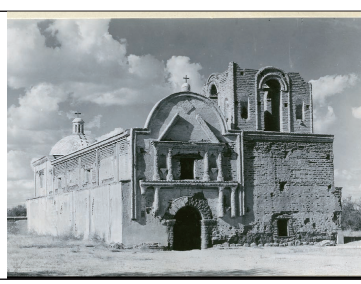
 	**Title**	"church timeline011_1940.tif"
	Credit	-
	Date	1920's
	Description	-INT.-DUP. SEC., WASH., D.C. -Classification No.: 266.2791 (1) Tum -000091 -Negative No.: none -83083
	Source	Tumacácori Archives

1944 Tumacácori



	Title	Tumacácori 1944
	Credit	NPS Photo
	Date	1944
	Description	-
	Source	NPS website “Changing Face of Tumacácori”

1945 Tumacácori

	Title	Tumacácori 1945
	Credit	NPS Photo
	Date	1945
	Description	-
	Source	NPS website “Changing Face of Tumacácori”

	Title	“church timeline013_1945.tif”
	Credit	-
	Date	1945
	Description	-Classification Nbr.: 266.2791 -000069 -Negative No.: 10320 WACC
	Source	Tumacácori Archives

1946 Tumacácori

	Title	Tumacácori 1946
	Credit	NPS Photo
	Date	1946
	Description	The first floor columns have been rebuilt to their original bases
	Source	NPS website “Changing Face of Tumacácori”

	Title	“church timeline014_1946.tif”
	Credit	-
	Date	-
	Description	-Classification No.: 266.2791 -0000383 -Negative No.: none
	Source	Tumacácori Archives

1947 Tumacácori

	Title	"church_timeline015_1947"
	Credit	-
	Date	1947
	Description	-
	Source	Tumacácori Archives

1953 Tumacácori

		
	Title	Tumacácori 1953
	Credit	NPS Photo
	Date	1953
	Description	-
	Source	NPS website "Changing Face of Tumacácori"

		
	Title	"church timeline016_1953.tif"
	Credit	-
	Date	1953
	Description	-Classification No.: 266.2791 -000456 -Negative No.: none -Mission Church – Tumacacori National Monument, Arizona 6-y-386 -INT.-DUP. SEC., WASH., D.C. -4814
	Source	Tumacácori Archives

1956 Tumacácori

	Title	Tumacácori 1956
	Credit	NPS Photo
	Date	1956
	Description	Interpretive wayside signs can be seen along the trail leading to the main entrance
	Source	NPS website "Changing Face of Tumacácori"

	Title	"church timeline017_1956.tif"
	Credit	-
	Date	1956
	Description	-Classification No.: 266.2791 -000456 -Negative No.: 560 -Interior Duplicating Section Washington D.C. -84540
	Source	Tumacácori Archives

1967 Tumacácori

	**Title**	Tumacácori 1967
	Credit	NPS Photo
	Date	1967
	Description	The grounds have been neatly mowed
	Source	NPS website “Changing Face of Tumacácori”

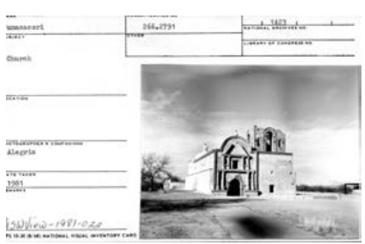
	**Title**	“church timeline018_1967.tif”
	Credit	Albert H. Schroeder
	Date	October 21, 1967
	Description	-Subject: Mission -Location: Tumacacori National Monument -Remarks: For publicity and record -[h]SWView-1967-013
	Source	Tumacácori Archives

1970 Tumacácori

	Title	Tumacácori 1970
	Credit	NPS Photo
	Date	1970
	Description	-
	Source	NPS website "Changing Face of Tumacácori"

	Title	"church timeline019_1970.tif"
	Credit	Staff
	Date	1970
	Description	-Park: Tumacacori -Subject: Mission San Jose de Tumacacori -Location: Tumacacori Nat'l Monument -Photo & Companions: Staff -Date Taken: 1970 -Remarks: ChSWView-1970-019 -Classification No: 266.2791 -Other: 21
	Source	Tumacácori Archives

1981 Tumacácori

	**Title**	“church timeline020_1981”
	Credit	[… Alegria]
	Date	1981
	Description	-Park: Tumacacori -Subject: Church -Photographer & Companions: [… Alegria] -Date Taken: 1981 -Remarks: ChSWView-1981-022 -Classification No.: 266.2791 -NPS 10-30 (8/68) National Visual Inventory Card
	Source	NPS website “Changing Face of Tumacácori”

2005 Tumacácori

<table>
<tr><td rowspan="5"></td><td>Title</td><td>Tumacácori 2005</td></tr>
<tr><td>Credit</td><td>NPS Photo</td></tr>
<tr><td>Date</td><td>2005</td></tr>
<tr><td>Description</td><td>Pallets near the vehicle in front of the fence suggest that preservation work has begun</td></tr>
<tr><td>Source</td><td>NPS website “Changing Face of Tumacácori”</td></tr>
</table>

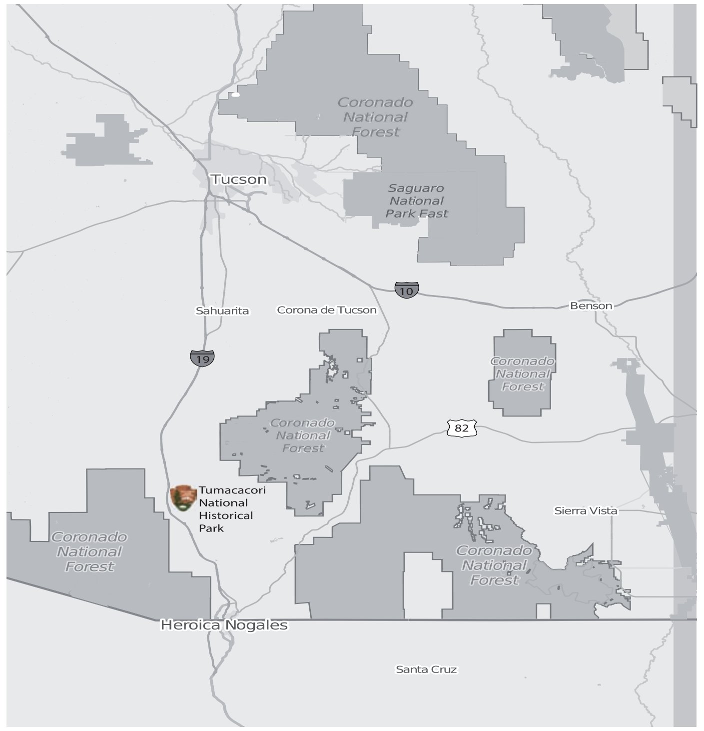
2012 Tumacácori

	Title	Tumacácori 2012
	Credit	NPS Photo
	Date	2012
	Description	Visitors enjoy a paved trail leading toward the main entrance
	Source	NPS website "Changing Face of Tumacácori"

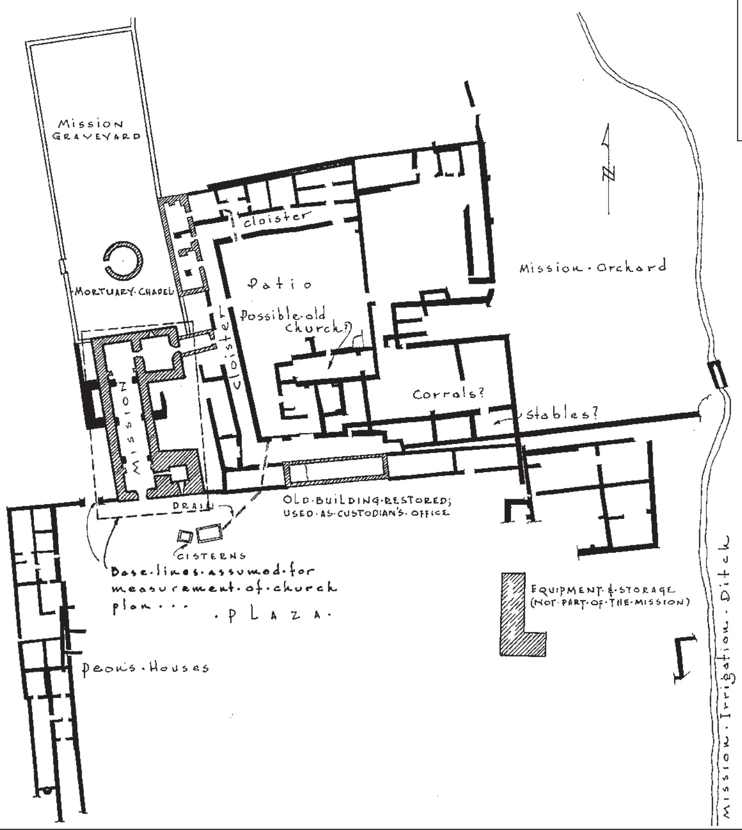
Appendix B: Sample Location Map Set (January 2015)

MISSION SAN JOSÉ DE TUMACÁCORI FACADE
TUMACÁCORI NATIONAL HISTORICAL PARK
NATIONAL PARK SERVICE, ARIZONA

LOCATION OF TUMACÁCORI NATIONAL HISTORIC PARK



MISSION SAN JOSÉ DE TUMACÁCORI SITE PLAN (HABS)



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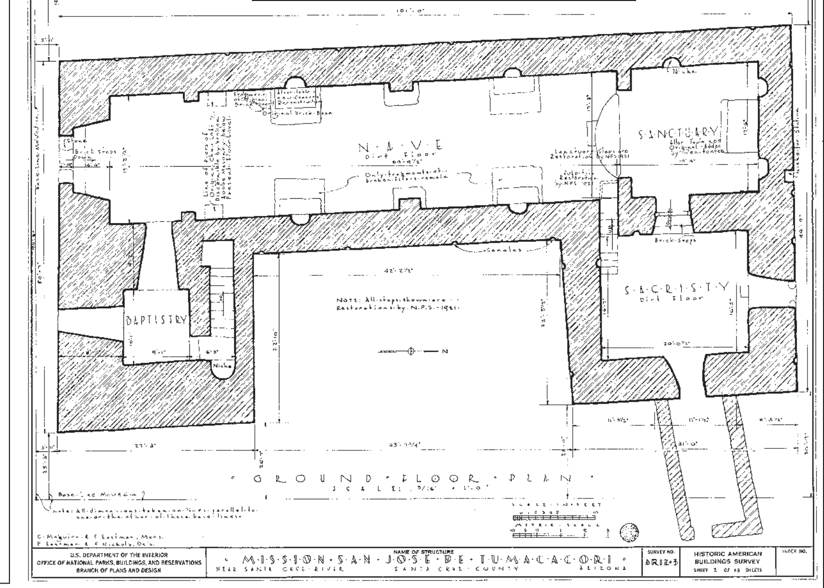
HABS CHURCH PLAN



SHEET IDENTIFICATION: TUMA-CS

SHEET DESCRIPTION: COVER SHEET

SITE CODE / LOCATION: TUMA

SITE VISIT: JANUARY 2015

DELINEATORS: John Hinchman, Jocelyn Chan

SPONSORED BY: NATIONAL PARK SERVICE, Tumacácori National Historical Park, AZ

FUNDING FROM: COLORADO PLATEAU COOPERATIVE ECOSYSTEM STUDIES UNIT

MISSION SAN JOSÉ DE TUMACÁCORI FACADE
Tumacácori National Historical Park, Arizona

Frank G Matero - Project Director, University of Pennsylvania
John Hinchman - Project Supervisor, University of Pennsylvania
Jocelyn Chan - Field Team, University of Pennsylvania

ARCHITECTURAL CONSERVATION LABORATORY
GRADUATE PROGRAM IN HISTORIC PRESERVATION SCHOOL OF DESIGN UNIVERSITY OF PENNSYLVANIA

Orthorectified photomontage created from photographs taken January 8, 2015 by John Hinchman (University of Pennsylvania, Architectural Conservation Laboratory) Photographs were then fit to photogrammetric HABS documentation photographed by Perry, Myra and Christina Borchers (September 20, 1975), plotted by Perry E. Borchers (February 1976 at Ohio State University), and delineated by Hugo Mario Romero-Ramirez (March 1976)

- ● (red) - *samples identified as original finishes*
- ● (blue) - *samples identified as repair campaigns*

Each sample is approximately 5/8 inch (or 15 mm) in diameter
Locator icon size is not to scale.

SCALE IN FEET 0 5 10 15 20 25 30 35 40 45 50

SHEET IDENTIFICATION:
TUMA-AX.0

SHEET DESCRIPTION:
SAMPLE LOCATION MAP

SITE CODE / LOCATION:
TUMA

SITE VISIT:
JANUARY 2015

DELINEATORS:
John Hinchman
Jocelyn Chan

SPONSORED BY:
NATIONAL PARK SERVICE
Tumacácori National Historical Park, AZ

FUNDING FROM:
COLORADO PLATEAU COOPERATIVE
ECOSYSTEM STUDIES UNIT

MISSION SAN JOSÉ DE TUMACÁCORI FACADE
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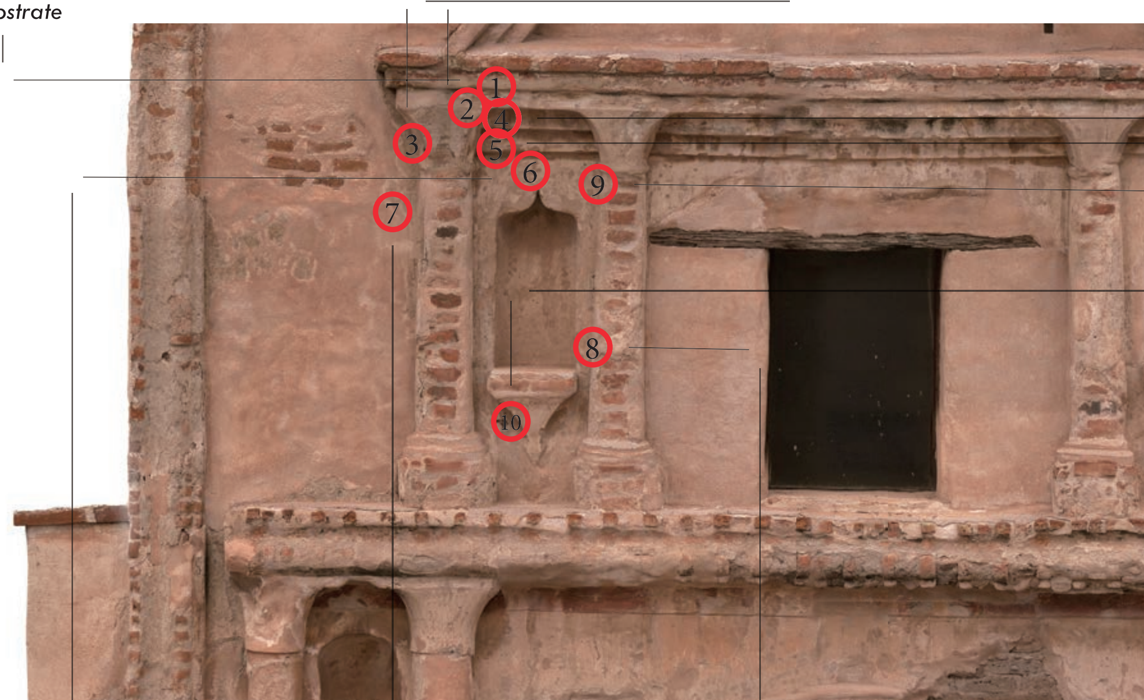
TUMA_1
Red on white undercoat, fired brick substrate

TUMA_2
White, substrate unknown

TUMA_3
White, brick substrate

TUMA_4
White, substrate unknown

TUMA_5
Yellow, substrate unknown



Photographs show location of samples acquired while the colored rectangles indicate approximate area of sampling.

- samples identified as original finishes (red circle)

- samples identified as repair campaigns (blue circle)

TUMA_6
Yellow, substrate unknown

TUMA_7
Yellow, substrate unknown

TUMA_8
White, substrate unknown

TUMA_9
Yellow on white, substrate unknown

TUMA_10
Yellow on white, brick substrate

SHEET IDENTIFICATION:
TUMA-AX.1

SHEET DESCRIPTION:
SAMPLES TUMA_1-TUMA_10

SITE CODE / LOCATION:
TUMA

SITE VISIT:
JANUARY 2015

DELINEATORS:
John Hinchman
Jocelyn Chan

SPONSORED BY:
NATIONAL PARK SERVICE
Tumacácori National Historical Park, AZ

FUNDING FROM:
COLORADO PLATEAU COOPERATIVE
ECOSYSTEM STUDIES UNIT

MISSION SAN JOSÉ DE TUMACÁCORI FACADE
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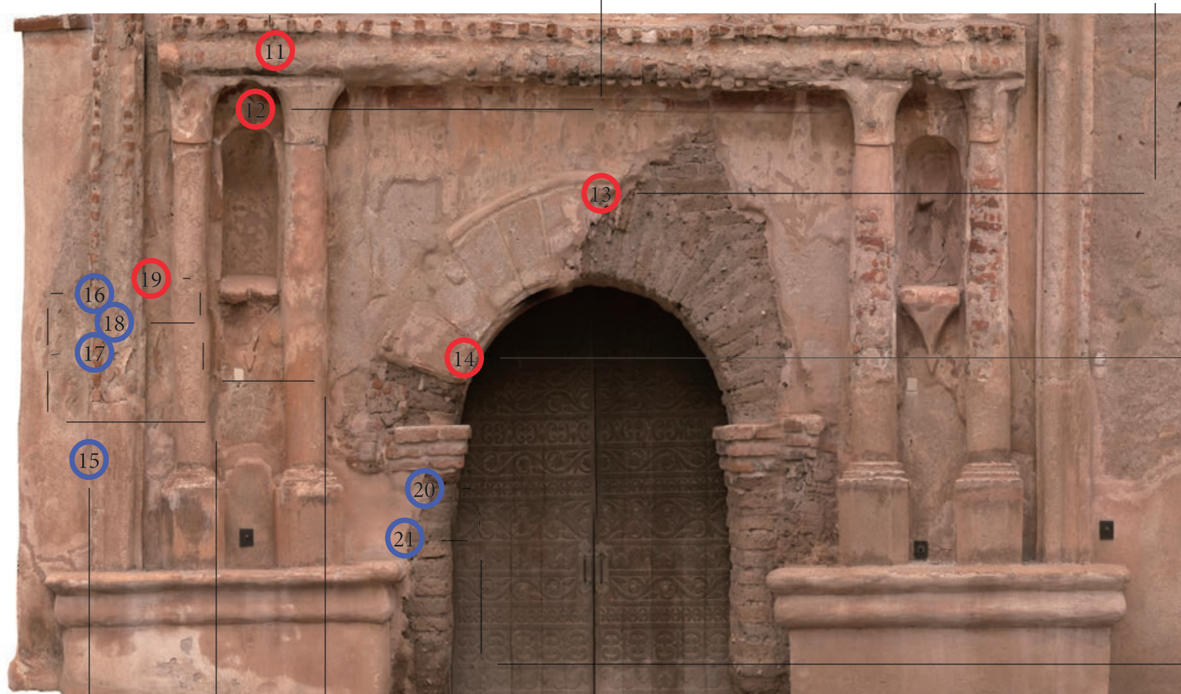
GRADUATE PROGRAM IN HISTORIC PRESERVATION SCHOOL OF DESIGN UNIVERSITY OF PENNSYLVANIA

TUMA_11
Yellow, 1st scratch coat ~1/8", 2nd scratch coat ~1/4", 3rd coat limewash, 4th coat color

TUMA_12
Red, substrate unknown

TUMA_13
Yellow and white, both extradose molding and scored joint

TUMA_14
Dark orange voussoir with pencilled white joints and black border



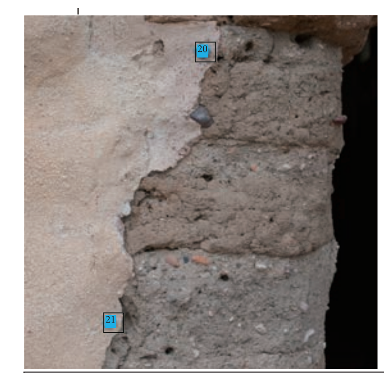
Photographs show location of samples acquired while the colored rectangles indicate approximate area of sampling.

- *samples identified as original finishes* (red circle)
- *samples identified as repair campaigns* (blue circle)

TUMA_15
Repair

TUMA_16
May be similar to TUMA_15
TUMA_17
Repair to TUMA_15

TUMA_18
Repair to TUMA_15
TUMA_19
Original finish



TUMA_20
Pink repair directly on rebuilt adobe
TUMA_21
Pink repair directly on rebuilt adobe

SHEET IDENTIFICATION:
TUMA-AX.2

SHEET DESCRIPTION:
SAMPLES TUMA_11-TUMA_21

SITE CODE / LOCATION:
TUMA

SITE VISIT:
JANUARY 2015

DELINEATORS:
John Hinchman
Jocelyn Chan

SPONSORED BY:
NATIONAL PARK SERVICE
Tumacácori National Historical Park, AZ

FUNDING FROM:
COLORADO PLATEAU COOPERATIVE
ECOSYSTEM STUDIES UNIT

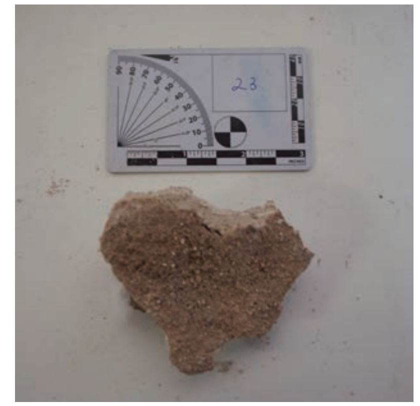
MISSION SAN JOSÉ DE TUMACÁCORI FACADE
Tumacácori National Historical Park, Arizona

Frank G Matero - Project Director, University of Pennsylvania
John Hinchman - Project Supervisor, University of Pennsylvania
Jocelyn Chan - Field Team, University of Pennsylvania

ARCHITECTURAL CONSERVATION LABORATORY
GRADUATE PROGRAM IN HISTORIC PRESERVATION SCHOOL OF DESIGN UNIVERSITY OF PENNSYLVANIA

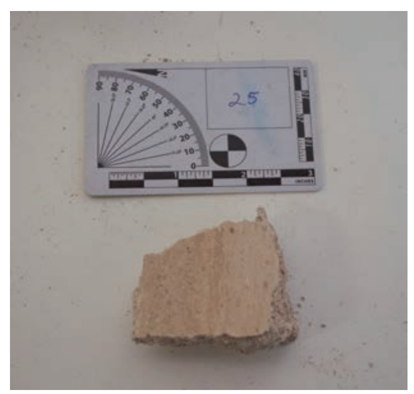
Samples from collection of lower right column fragments.
Sample descriptions by Alex Lim (National Parks Service)

TUMA_22
#1 substrate behind column wall"



TUMA_23
"#4 substrate/repair"

TUMA_24
"#6 substrate/repair"



TUMA_25
"#2 finish"

TUMA_26
"#7 finish"

TUMA_27
"#10 finish"

TUMA_28
"#11 finish"

TUMA_29
"#12 finish"

TUMA_30
"#13 finish"

SHEET IDENTIFICATION:
TUMA-AX.3

SHEET DESCRIPTION:
SAMPLES TUMA_22-TUMA_30

SITE CODE / LOCATION:
TUMA

SITE VISIT:
JANUARY 2015

SPONSORED BY:
NATIONAL PARK SERVICE
Tumacácori National Historical Park, AZ

FUNDING FROM:
COLORADO PLATEAU COOPERATIVE
ECOSYSTEM STUDIES UNIT

DELINEATORS:
John Hinchman
Jocelyn Chan

MISSION SAN JOSÉ DE TUMACÁCORI FACADE
Tumacácori National Historical Park, Arizona

Frank G Matero - Project Director, University of Pennsylvania
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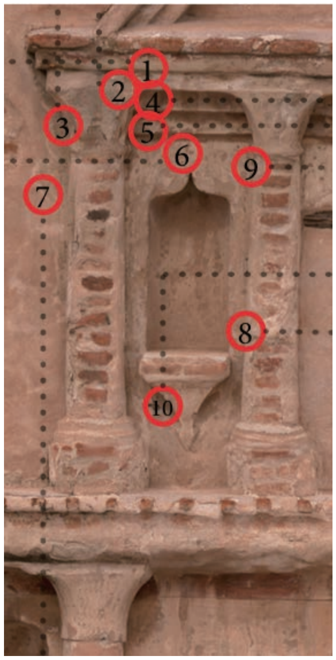
GRADUATE PROGRAM IN HISTORIC PRESERVATION   SCHOOL OF DESIGN   UNIVERSITY OF PENNSYLVANIA

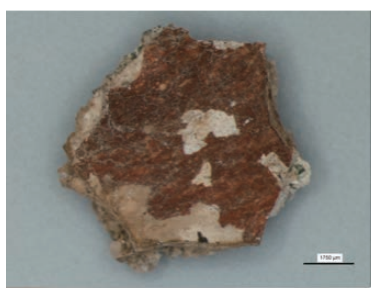
Appendix C: Cross-Section Stratigraphy Data Sets

Sample Location for TUMA_01 (Red)

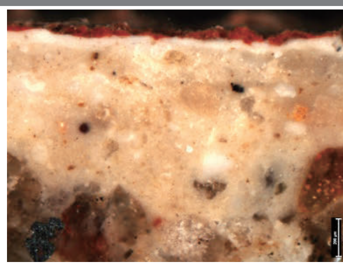
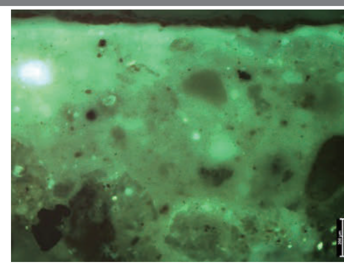
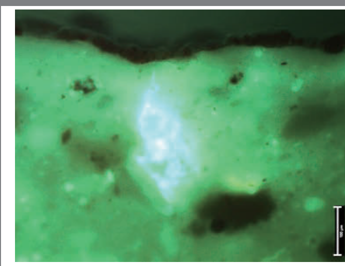
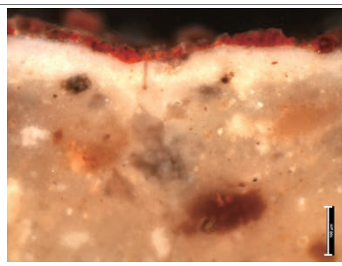
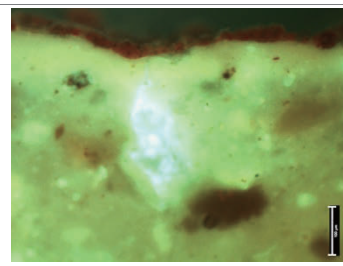
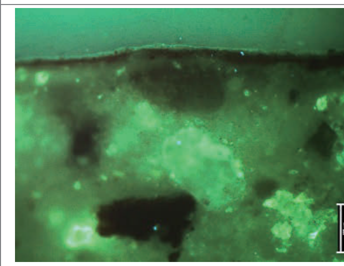


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_01
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Upper left broken cornice

Microscopic Analysis of TUMA_1 (Red)

		
	Unmounted, 1.6x total magnification	Cross section, 2.0x total magnification
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	Red on white undercoat, fired brick substrate	Red on white preparatory layer with initial plaster scratch coat visible. Initial coat contains a variety of large inclusions.

Stratigraphic Analysis of TUMA_01 (Red)

Stratigraphic Analysis of TUMA_01 (Red)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

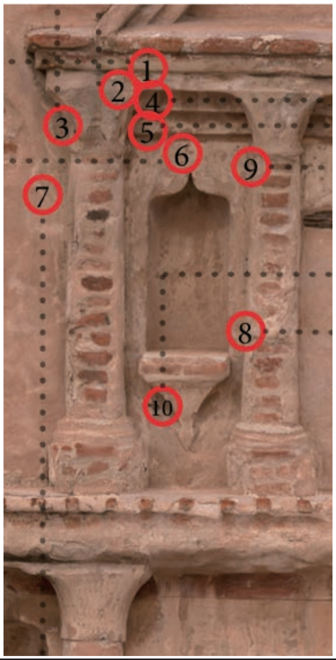
Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Upper left broken cornice	F. Matero, J. Chan	1/9/15	J. Chan
Microscope	Light Source	Filters	Camera
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular mag	Trinocular mag	Objective mag	Zoom
10.0x	1.0x	4.0x, 10.0x.	-

NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thin preparatory white finish layer
- Layer 2: bright red pigmented finish, discrete particles visible suggesting inorganic pigment

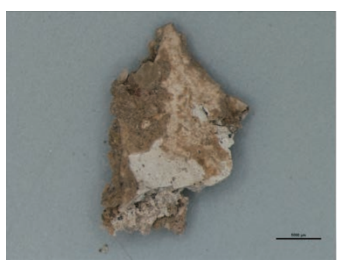
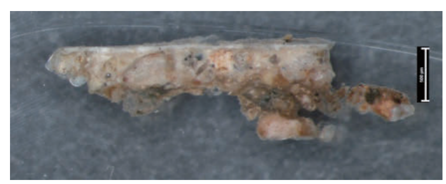
- Very clear, discrete layers
- Can see what may potentially be indication of lime laitance (more visible in ultraviolet light)
- Good candidate for subsequent analyses be used for subsequent analyses as representative red pigment sample

Sample Location for TUMA_02 (White)

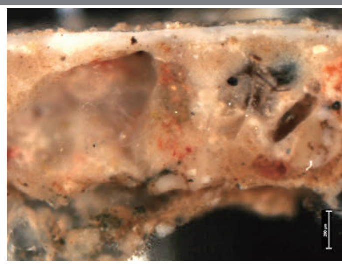
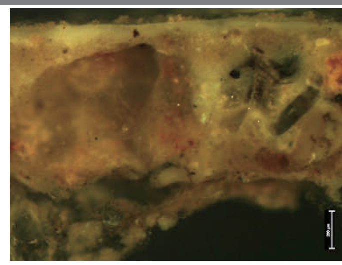
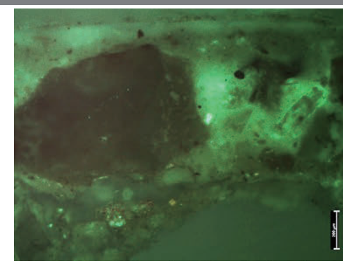
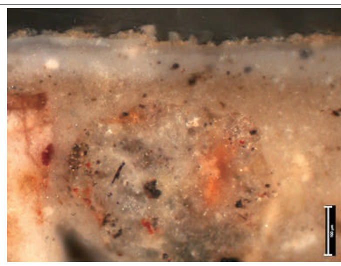
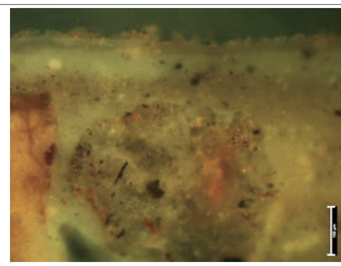
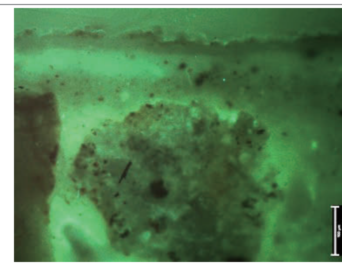


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_02
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Upper left frieze

Microscopic Analysis of TUMA_02 (White)

		
	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	White, substrate unknown	White preparatory layer, sample has lost a lot of the finish. Yellowish cream intermittent?

Stratigraphic Analysis of TUMA_02 (White)

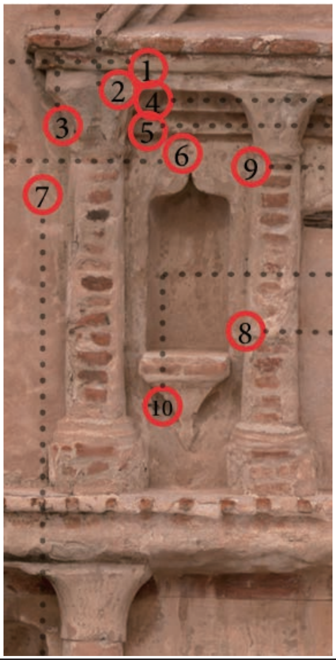
Stratigraphic Analysis of TUMA_02 (White)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Upper left frieze	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

NOTES

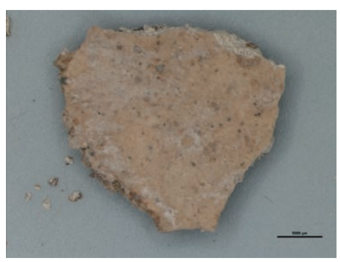
- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thin preparatory white finish layer
- Layer 2: yellowish cream inconsistent
- Distressed finish layer

Sample Location for TUMA_03

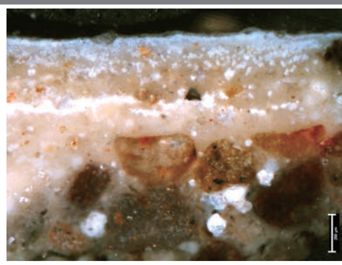
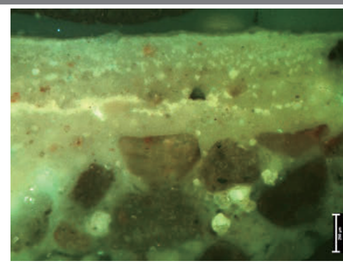
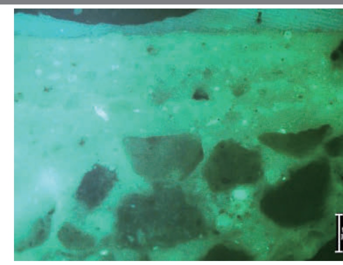
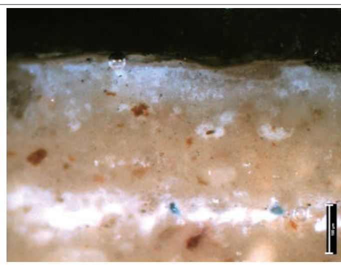
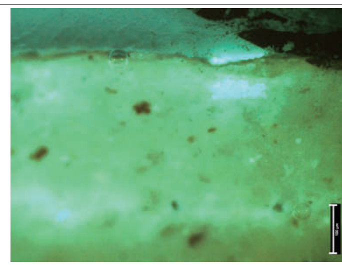
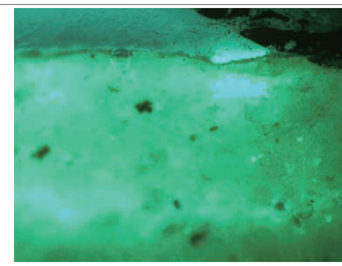


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_03
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Upper, outer left capital (west side)

Microscopic Analysis of TUMA_03

		
	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	White, brick substrate	Thick white preparatory layer, white finish layer

Stratigraphic Analysis of TUMA_03 (White)

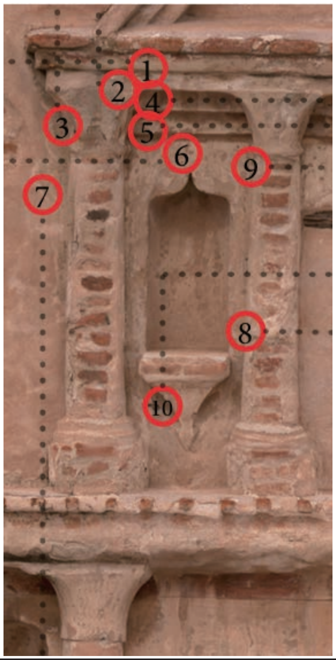
Stratigraphic Analysis of TUMA_03 (White)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Upper, outer left capital (west side)	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

NOTES

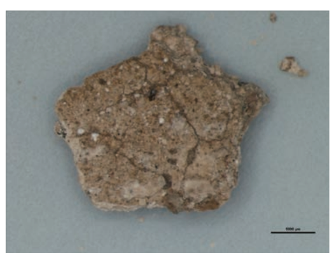
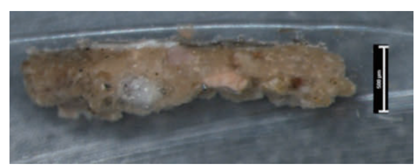
- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thick preparatory white finish layer
- Layer 2: orange-yellow pigmented finish, discrete particles visible suggesting inorganic pigment; some red pigment particles visible in upper finish layer
- Very clear, discrete layering

Sample Location for TUMA_04 (White)

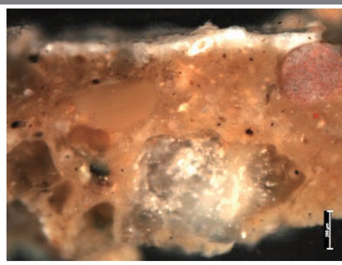
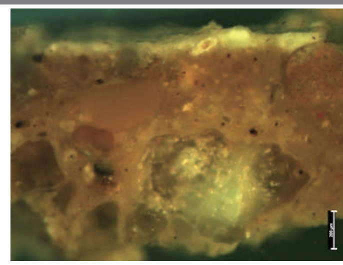
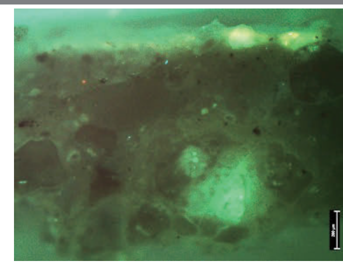
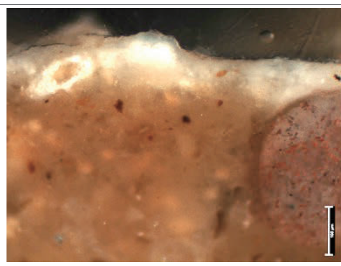
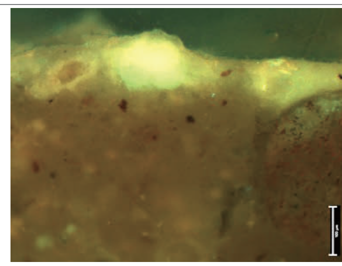
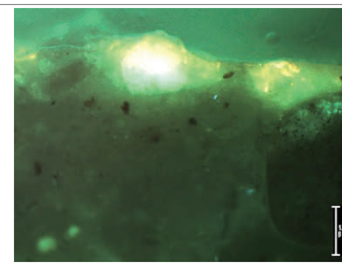


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_04
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Upper left frieze

Microscopic Analysis of TUMA_04 (White)

		
	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	White, substrate unknown	Not as good as other samples, missing a lot of surface. Does not appear to be in the same plane appears cream colored

Stratigraphic Analysis of TUMA_04 (White)

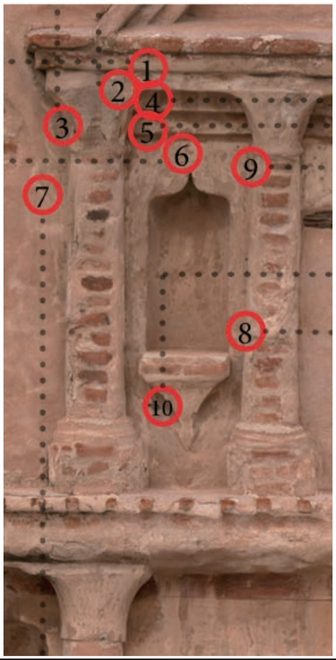
Stratigraphic Analysis of TUMA_04 (White)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Upper left frieze	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

NOTES

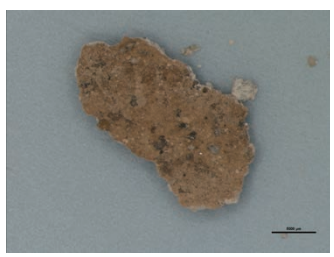
- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thick preparatory white finish layer
- Layer 2: orange-yellow pigmented finish, discrete particles visible suggesting inorganic pigment; some red pigment particles visible in upper finish layer
- Distressed finish layer

Sample Location for TUMA_06 (Yellow)



Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_06
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Upper face (left) above nicho

Microscopic Analysis of TUMA_06 (Yellow)

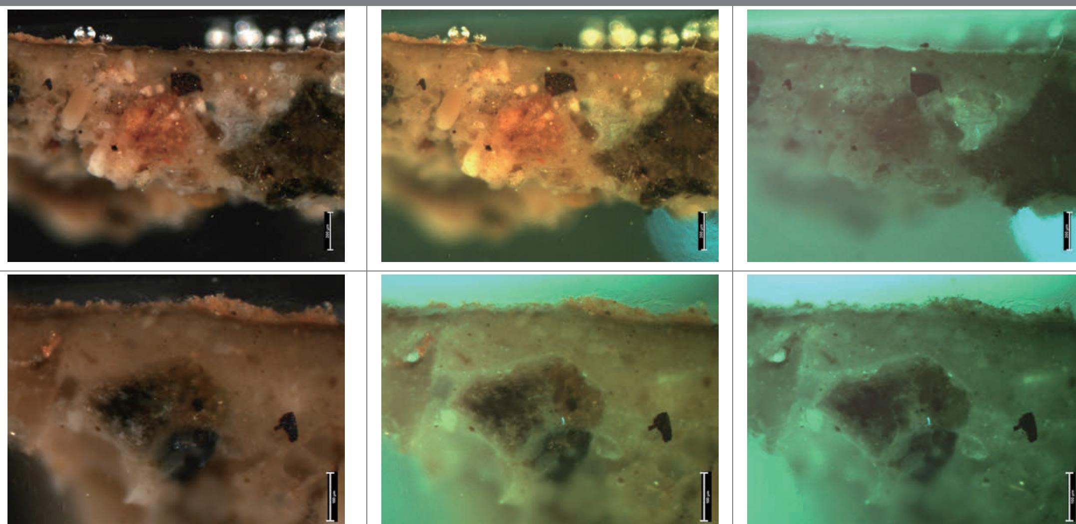
		
	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	Yellow, substrate unknown	Very thick yellow layer, bubbles on surface, yellow does not appear to be applied on a preparatory layer

Stratigraphic Analysis of TUMA_06 (Yellow)

STRATIGRAPHIC ANALYSIS OF TUMA_06 (YELLOW)

	VISIBLE	ULTRAVIOLET/VISIBLE	ULTRAVIOLET

40X / 100X



MICROSCOPY METADATA

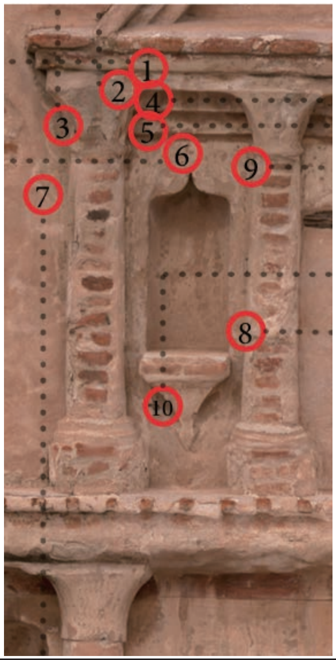
LOCATION	SAMPLED BY	SAMPLED ON	ANALYZED BY
Upper fact (left) above nicho	F. Matero, J. Chan	1/9/15	J. Chan
MICROSCOPE	**LIGHT SOURCE**	**FILTERS**	**CAMERA**
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
OCULAR MAG	**TRINOCULAR MAG**	**OBJECTIVE MAG**	**ZOOM**
10.0X	1.0X	4.0X, 10.0X.	-

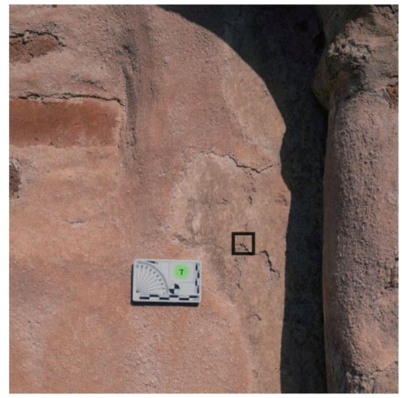
NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: brownish-yellow layer across entirety of sample that does not appear to be applied on preparatory layer or as a discrete surface (particles seem integral to plaster substrate)
- Layer 2: some bright yellow pigment left on surface that appears more consistent with other applied pigment particles suggesting inorganic nature

- Brownish-yellow layer appears more organic
- To be used for subsequent analyses as sample of potential limewash staining (e.g. to test for application of ferrous sulfate) or application of organic layer

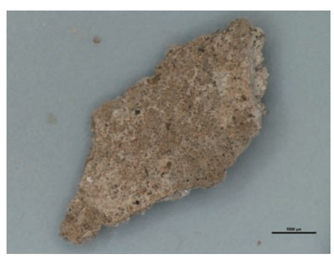
Sample Location for TUMA_07 (Yellow)



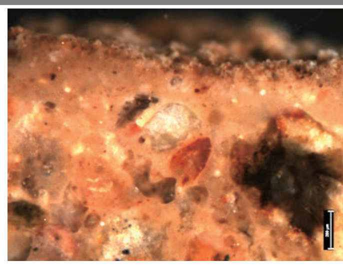
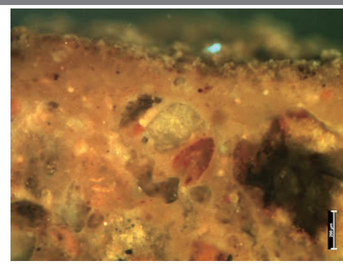
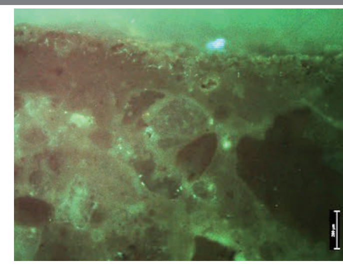
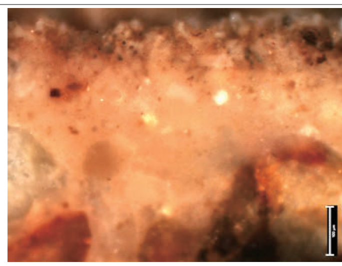
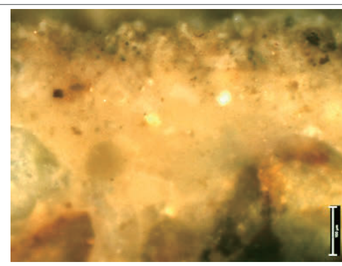
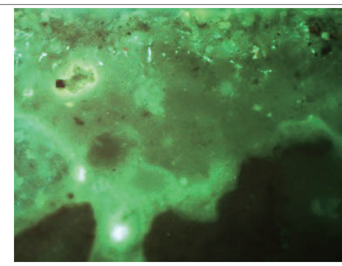


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_07
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Upper left face, left of outer left column

Microscopic Analysis of TUMA_07 (Yellow)

		
	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	Yellow, substrate unknown	Yellow thick layer

Stratigraphic Analysis of TUMA_07 (Yellow)

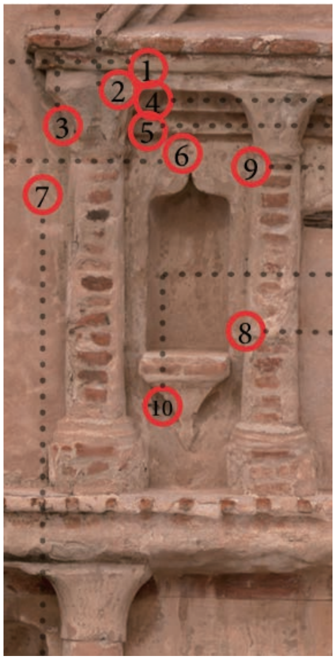
Stratigraphic Analysis of TUMA_07 (Yellow)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Upper left face, left of outer left column	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

NOTES

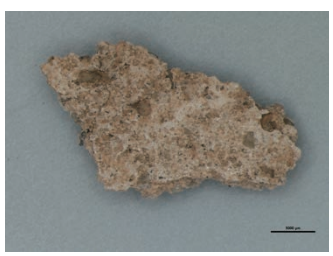
- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: brownish-yellow with mixed particles, does not appear to be on a preparatory layer
- Similar to TUMA_06 to test for application of a stain?

Sample Location for TUMA_08 (White)

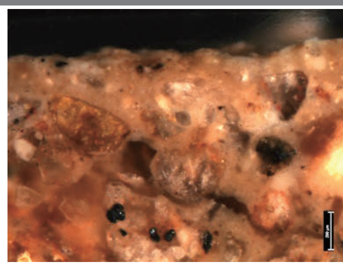
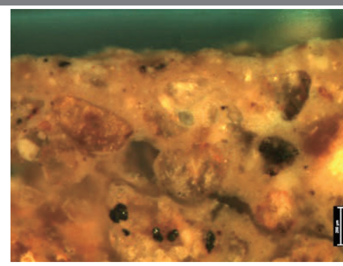
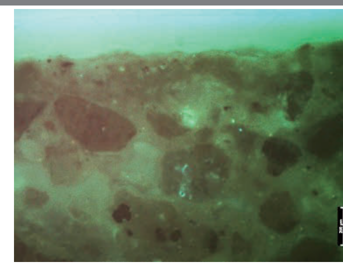
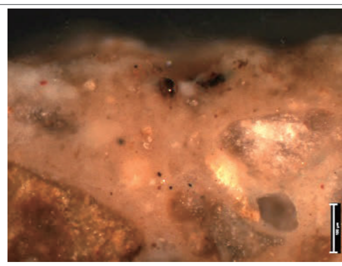
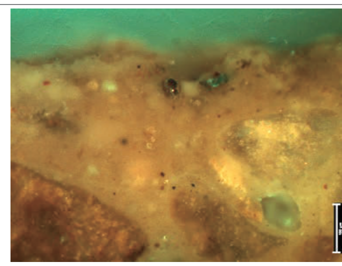
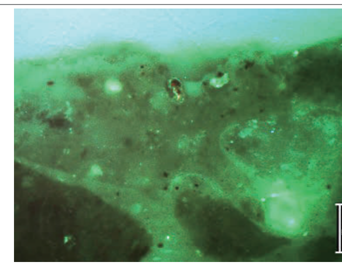


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_08
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Lower column shaft, right side of upper left nicho

Microscopic Analysis of TUMA_08 (White)

		
	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	White, substrate unknown	Appears there was a white finish, gone? Distressed surface

Stratigraphic Analysis of TUMA_08 (White)

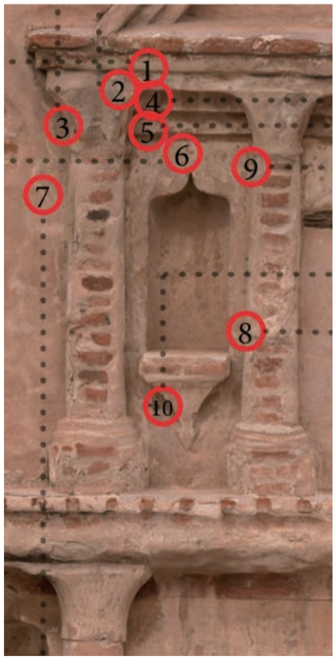
Stratigraphic Analysis of TUMA_08 (White)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			
Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Lower column shaft, right side of upper left nicho	F. Matero, J. Chan	1/9/15	J. Chan
Microscope	Light Source	Filters	Camera
Nikon Alphaphot-2	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, 10.0x.	-

NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: intermittent white particles

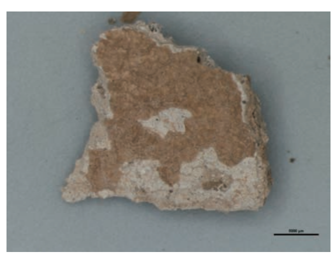
- Appears there was a white finish but now gone, very distressed sample

Sample Location for TUMA_09 (Yellow)

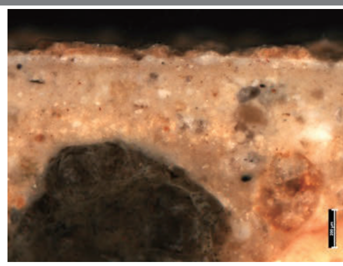
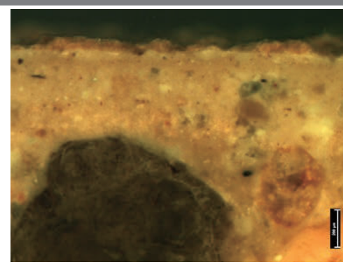
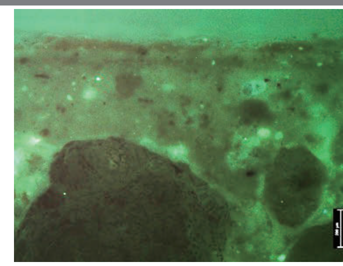
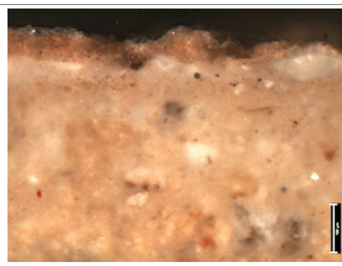
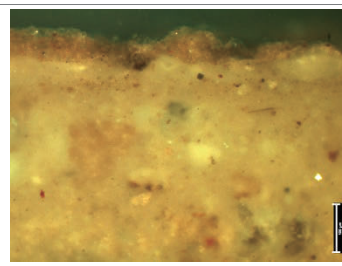
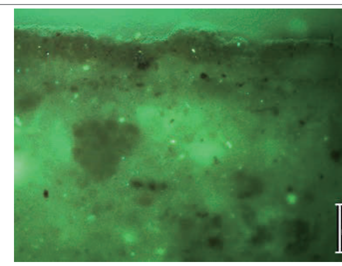


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_09
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Upper column shaft, right side of upper left nicho

Microscopic Analysis of TUMA_09 (Yellow)

		
	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	Yellow on white, substrate unknown	Paste of substrate, white, yellow, small red and black particles in mixture bulk. Discrete layers.

Stratigraphic Analysis of TUMA_09 (Yellow)

Stratigraphic Analysis of TUMA_09 (Yellow)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

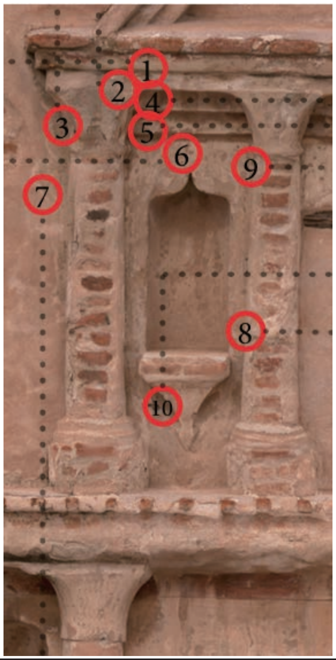
Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Upper column shaft, right side of upper left nicho	F. Matero, J. Chan	1/9/15	J. Chan
Microscope	Light Source	Filters	Camera
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular mag	Trinocular mag	Objective mag	Zoom
10.0x	1.0x	4.0x, 10.0x.	-

NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thin white preparatory layer
- Layer 2: yellow pigmented layer with red and black particles

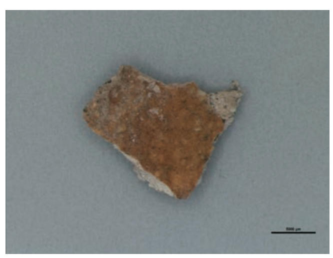
- Discrete layering

Sample Location for TUMA_11 (Yellow)



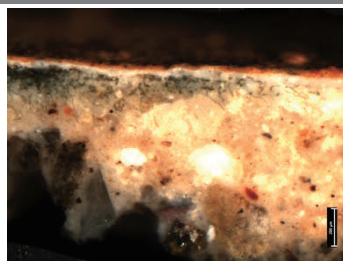
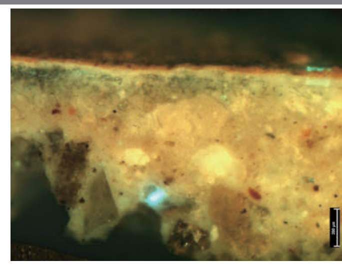
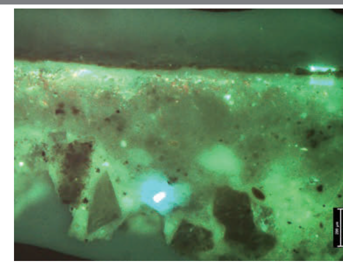
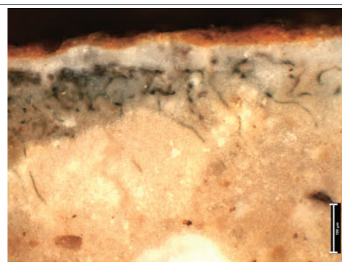
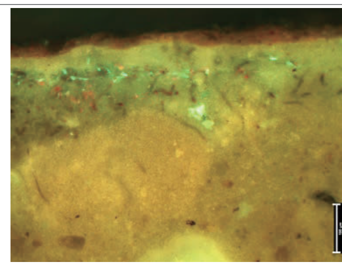
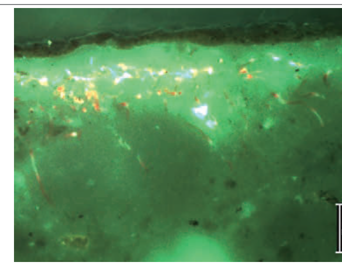
Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_11
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Lower left cornice

Microscopic Analysis of TUMA_11 (White)



	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	Yellow, first scratch coat appro. 1/8”, 2nd scratch coat approx ¼”, 3rd coat thick limewash, 4th coat color	Very clear, pigmented with red and yellow on white preparatory layer. White layer appears to be on a very weathered white substrate, black appears to be biological microflora

Stratigraphic Analysis of TUMA_11 (Yellow)

Stratigraphic Analysis of TUMA_11 (Yellow)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata

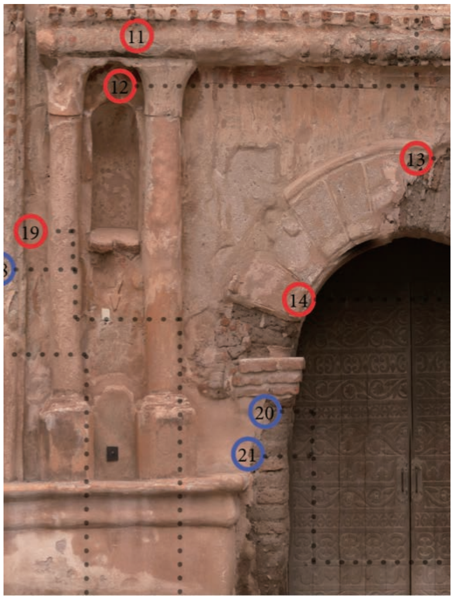
Location	Sampled By	Sampled On	Analyzed By
Lower left cornice	F. Matero, J. Chan	1/9/15	J. Chan
Microscope	**Light Source**	**Filters**	**Camera**
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular mag	**Trinocular mag**	**Objective mag**	**Zoom**
10.0x	1.0x	4.0x, 10.0x.	-

NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thick preparatory white finish layer
- Layer 2: orange-yellow pigmented finish, discrete particles visible suggesting inorganic pigment; some red pigment particles visible in upper finish layer

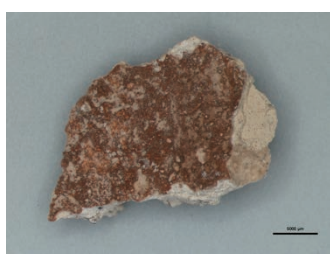
- Very clear, discrete layering
- White preparatory finish layer appears to be on very weathered white substrate, suggested that it was applied atop an already dried surface
- Black tendrils appear to be some type of biological microflora

Sample Location for TUMA_12 (Red)

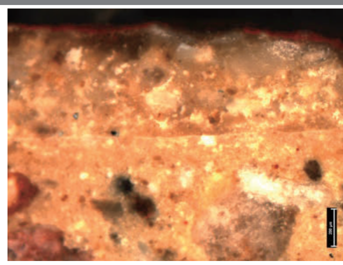
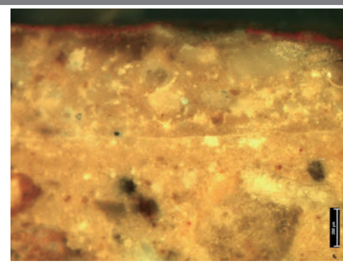
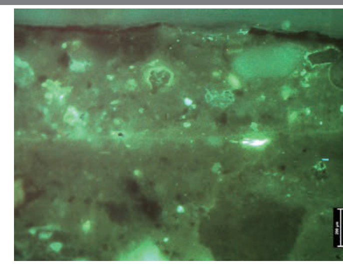
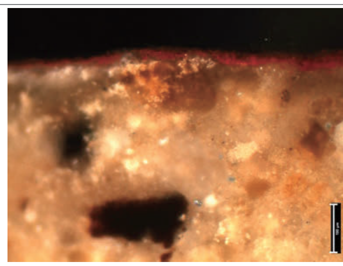
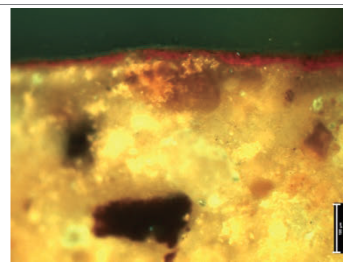
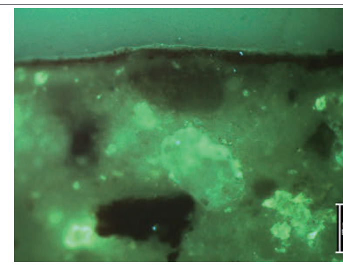


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_12
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Lower left face above nicho

Microscopic Analysis of TUMA_12 (Red)

		
	Unmounted, 1.6x total magnification	Cross section, 2.0x total magnification
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	Red, substrate unknown	Red on white preparatory, very clear – can see lines suggesting lime laitance

Stratigraphic Analysis of TUMA_12 (Red)

Stratigraphic Analysis of TUMA_12 (Red)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

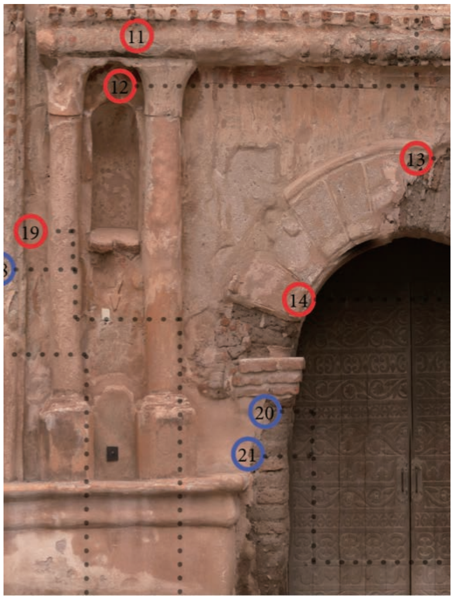
Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Lower left face above nicho	F. Matero, J. Chan	1/9/15	J. Chan
Microscope	Light Source	Filters	Camera
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular mag	Trinocular mag	Objective mag	Zoom
10.0x	1.0x	4.0x, 10.0x.	-

NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thin preparatory white finish layer
- Layer 2: bright red pigmented finish, discrete particles visible suggesting inorganic pigment

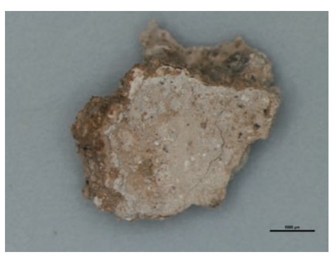
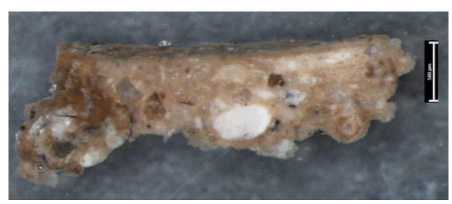
- Very clear, discrete layers
- Can see what may potentially be indication of lime laitance (more visible in ultraviolet light)
- Will be used for subsequent analyses as representative red pigment sample

Sample Location for TUMA_13A (White)

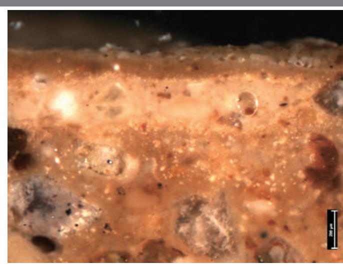
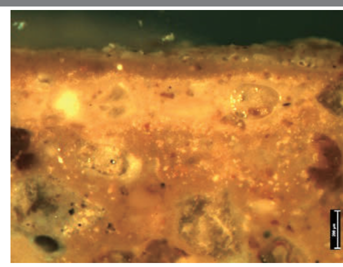
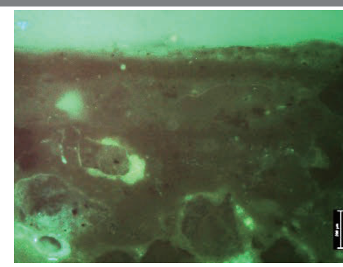
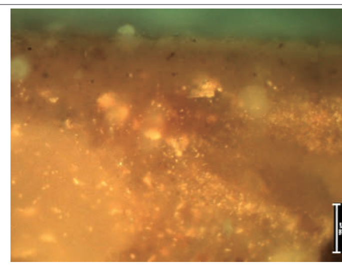
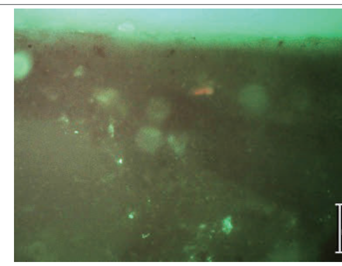


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_13A
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Scored joint of extradose above voussoirs – TUMA13A is white finish of joint

Microscopic Analysis of TUMA_13A (White)

		
	Unmounted, 1.6x total magnification	Cross section, 2.0x total magnification
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	TUMA_13A is white of scored joint (TUMA_13B yellow of extradose molding)	Very thin white layer on top of yellow layer

Stratigraphic Analysis of TUMA_13A (White)

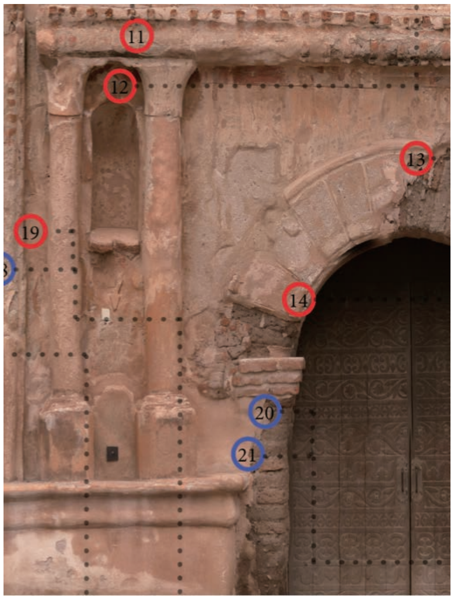
Stratigraphic Analysis of TUMA_13A (White)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Scored joint of extradose above voussoirs (TUMA_13A is white finish of joint)	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-
NOTES			

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thin preparatory yellow finish layer
- Layer 2: very thin white finish layer

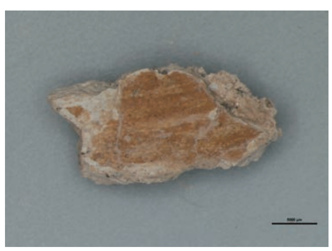
- TUMA_13A is from the scored joint of the extradose above voussoirs (match to TUMA_13B)

Sample Location for TUMA_13B (Yellow)

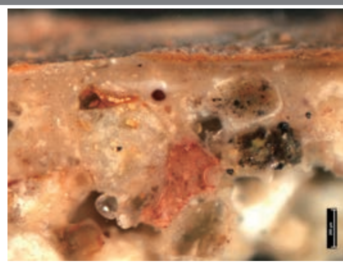
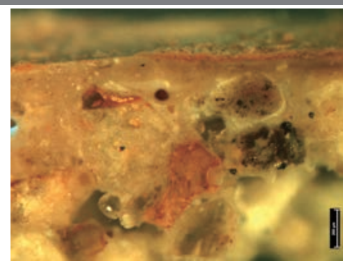
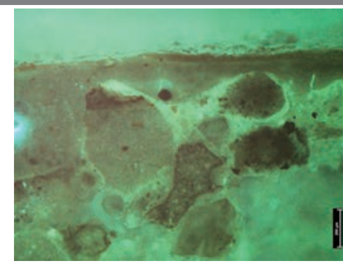
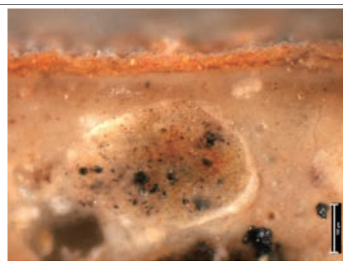
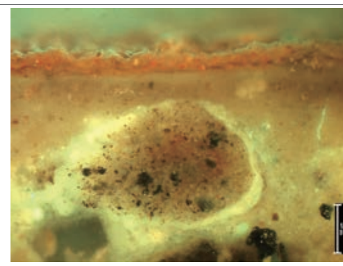
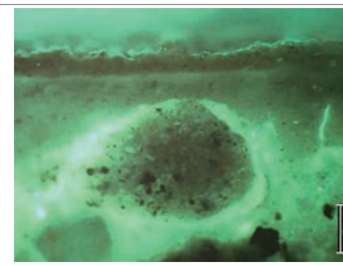


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_13B
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Scored joint of extradose above voussoirs – TUMA13B is yellow finish of extradose molding

Microscopic Analysis of TUMA_13B (Yellow)

		
	Unmounted, 1.6x total magnification	Cross section, 2.0x total magnification
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	TUMA_13A is white of scored joint (TUMA_13B yellow of extradose molding)	Thin preparatory layer, yellow layer mixed with red pigment

Stratigraphic Analysis of TUMA_13B (Yellow)

Stratigraphic Analysis of TUMA_13B (Yellow)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

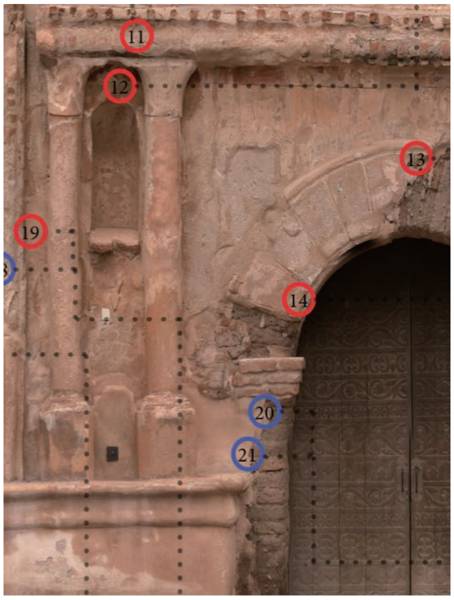
Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Scored joint of extradose above voussoirs (TUMA_13B is yellow finish of extradose molding)	F. Matero, J. Chan	1/9/15	J. Chan
Microscope	Light Source	Filters	Camera
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular mag	Trinocular mag	Objective mag	Zoom
10.0x	1.0x	4.0x, 10.0x.	-

NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thin preparatory white finish layer
- Layer 2: pigmented yellow finish layer (some red particles visible within pigment matrix)

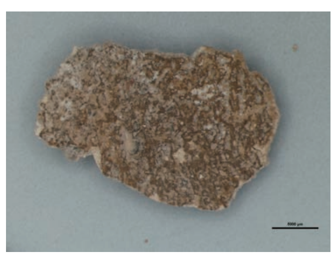
- TUMA_13B is yellow finish of extradose molding (compare to TUMA_13A, the white of scored joint)

Sample Location for TUMA_14 (Orange)

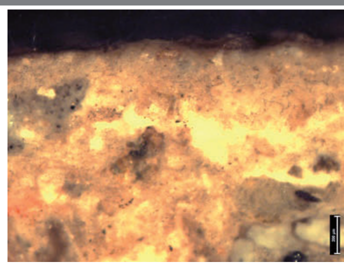
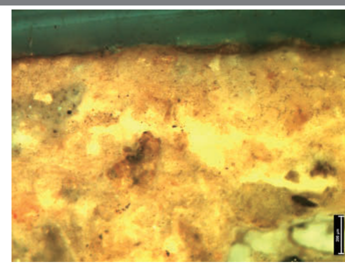
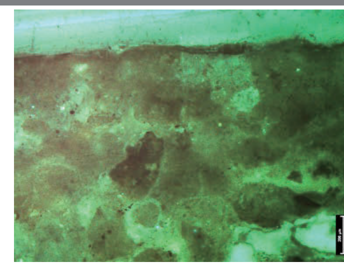
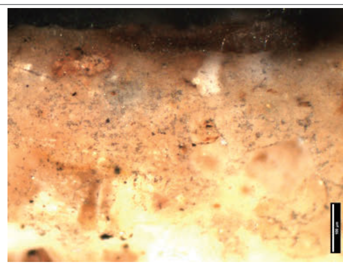
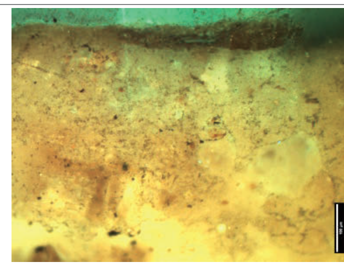
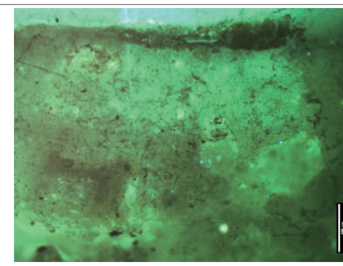


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_14
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Intradose voussoir

Microscopic Analysis of TUMA_14 (Orange)

		
	Unmounted, 1.6x total magnification	Cross section, 2.0x total magnification
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	Dark orange voussoir with penciled white joints and black border	Layer appears distressed, pigment darker than in other examples. Presence of what appears yellow stained upper zone

Stratigraphic Analysis of TUMA_14 (Orange)

Stratigraphic Analysis of TUMA_14 (Orange)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

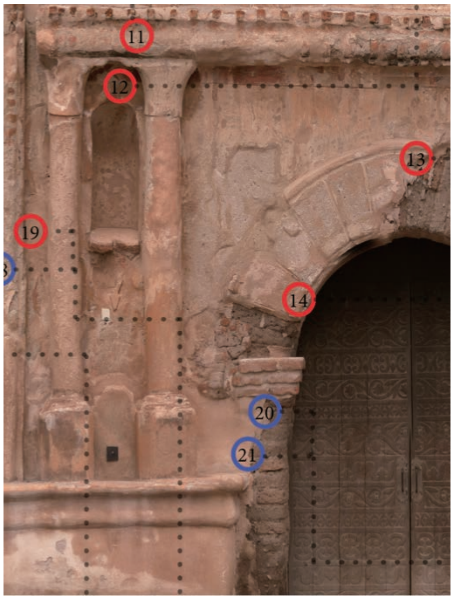
Microscopy Metadata

Location	Sampled By	Sampled On	Analyzed By
Intradose voussoir	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

NOTES

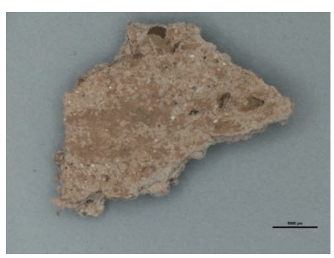
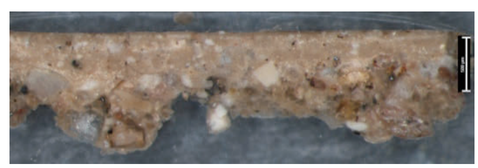
- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: brownish-yellow layer across entirety of sample that does not appear to be applied on preparatory layer or as a discrete surface – potentially similar to TUMA_06
- Colored layer appears distressed
- Black particles are likely residue from carbon paint applied during SEM-EDS, may be instructive to retake photographs with new cross-section off billet

Sample Location for TUMA_19 (Yellow)

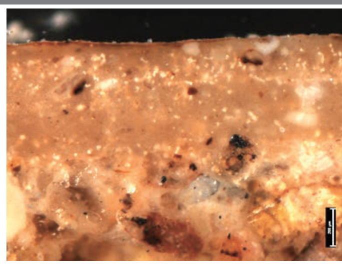
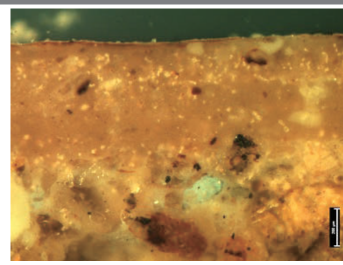
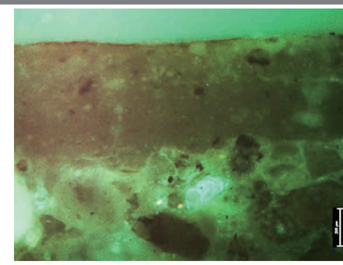
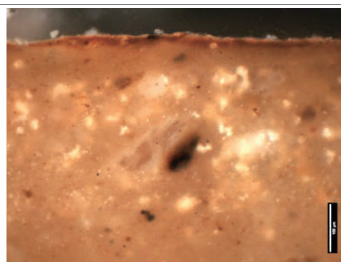
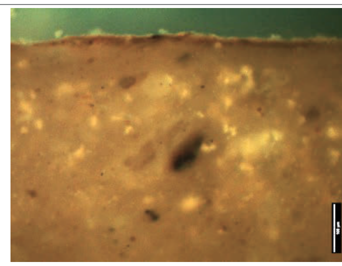
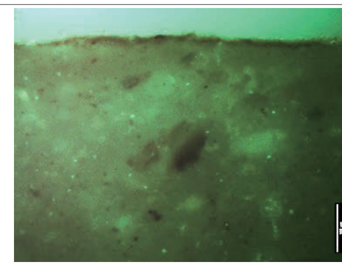


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	January 9, 2015
Sample name	TUMA_14
Sampled by	Frank Matero, Jocelyn Chan (Penn ACL)
Sample location	Lower left return of inner edge of outer surround

Microscopic Analysis of TUMA_19 (Yellow)

		
	Unmounted, 1.6x total magnification	Cross section, 2.0x total magnification
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	Somewhat distressed surface, yellow and cream pigments	

Stratigraphic Analysis of TUMA_19 (Yellow)

Stratigraphic Analysis of TUMA_19 (Yellow)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
Lower left return of inner edge of outer surround	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

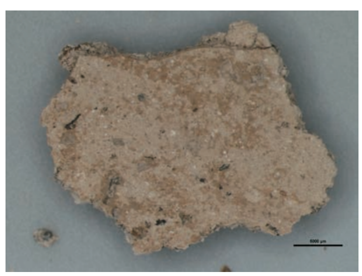
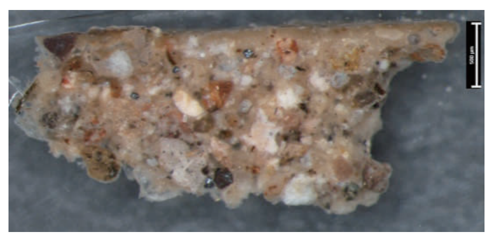
NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: some areas of inconsistent cream preparatory layer – appears to be more dispersed and less of a discrete layer
- Layer 2: distressed, inconsistent yellow pigment
- Colored layer appears distressed

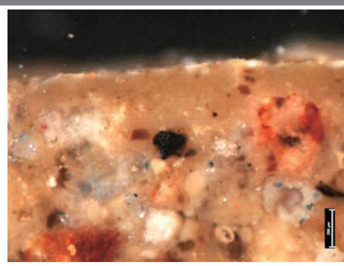
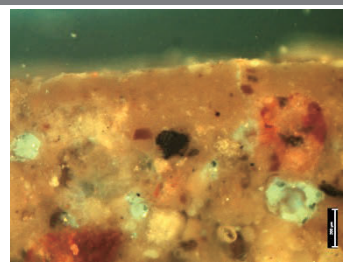
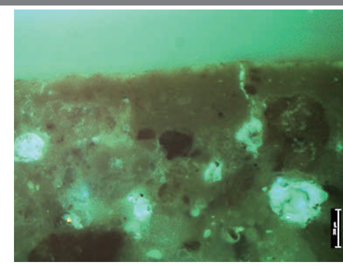
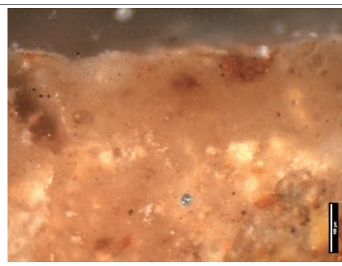
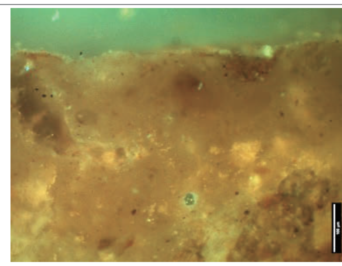
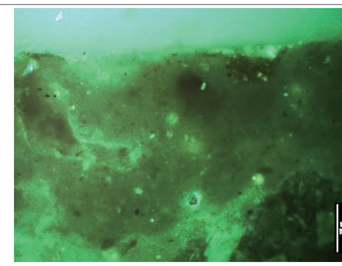
Sample Location for TUMA_25 (White)

Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	Unknown
Sample name	TUMA_25
Sampled by	Alex Lim (NPS)
Sample location	From collection of fallen fragments (potentially lower right column)

Microscopic Analysis of TUMA_25 (White)

		
	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description		

Stratigraphic Analysis of TUMA_25 (White)

Stratigraphic Analysis of TUMA_25 (White)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
From collection of fallen fragments (potentially lower right column)	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

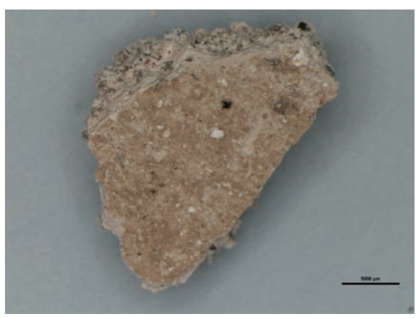
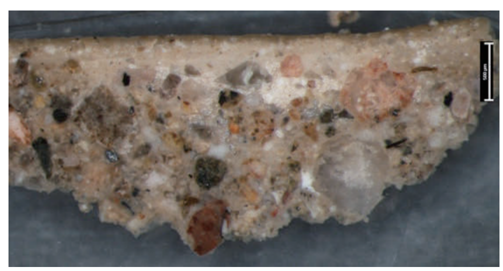
NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thick cream layer
- Layer 2: some yellowish pigment particles but otherwise not discrete layering?
- Good example of thicker preparatory layer, sample sent for thin-section

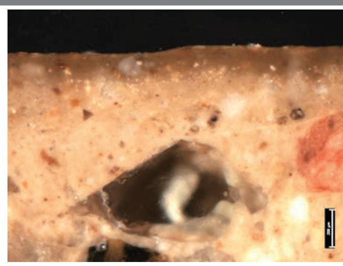
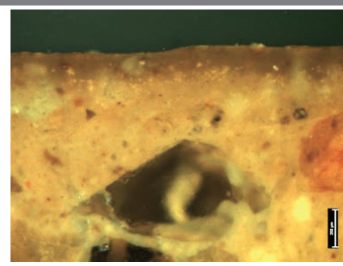
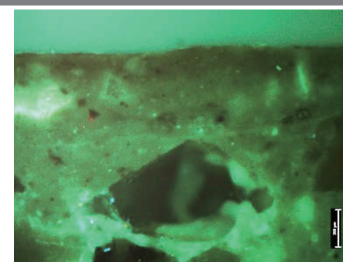
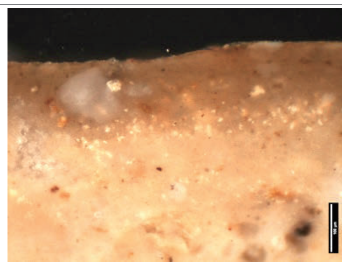
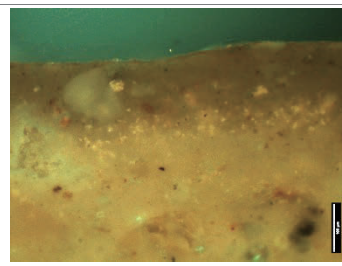
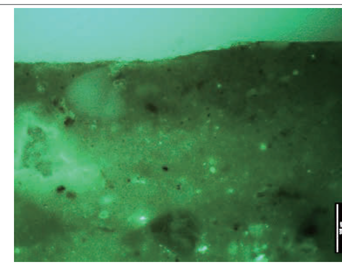
Sample Location for TUMA_26 (Yellow)

Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	Unknown
Sample name	TUMA_26
Sampled by	Alex Lim (NPS)
Sample location	From collection of fallen fragments (potentially lower right column)

Microscopic Analysis of TUMA_26 (Yellow)

		
	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	Yellow-cream layer, not as brightly pigmented as other yellow examples	Discrete layering with yellow-cream finish – laitance visible under UV

Stratigraphic Analysis of TUMA_26 (Yellow)

Stratigraphic Analysis of TUMA_26 (Yellow)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
From collection of fallen fragments (potentially lower right column)	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

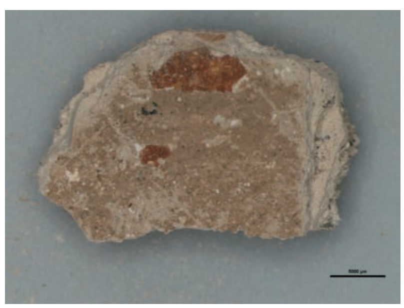
NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: cream preparatory paste
- Layer 2: yellow finish seems to be thick and not applied on the thin white preparatory layer

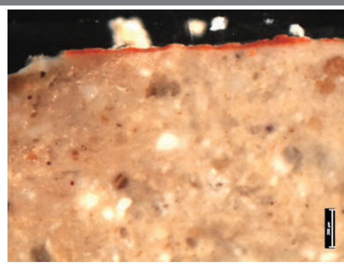
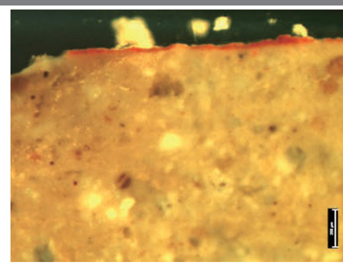
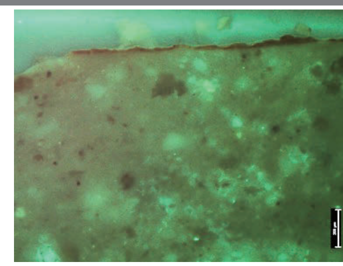
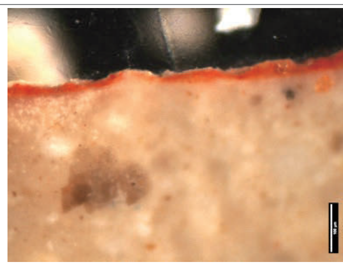
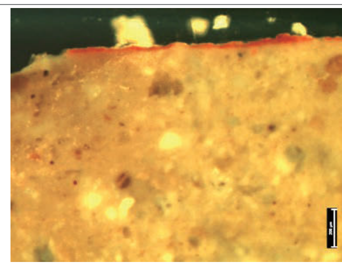
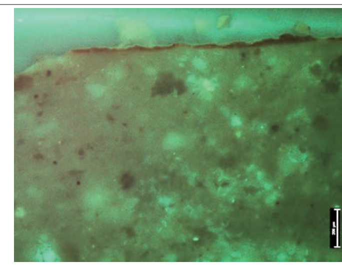
Sample Location for TUMA_27 (Red)

Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	Unknown
Sample name	TUMA_27
Sampled by	Alex Lim (NPS)
Sample location	From collection of fallen fragments (potentially lower right column)

Microscopic Analysis of TUMA_27 (Red)

		
	Unmounted, 1.6x total magnification	Cross section, 2.0x total magnification
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description		

Stratigraphic Analysis of TUMA_27 (Red)

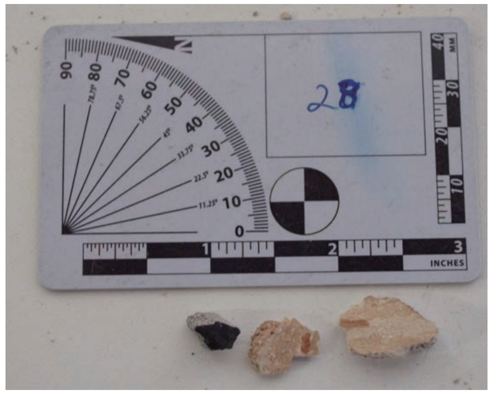
Stratigraphic Analysis of TUMA_27 (Red)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
From collection of fallen fragments (potentially lower right column)	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

NOTES

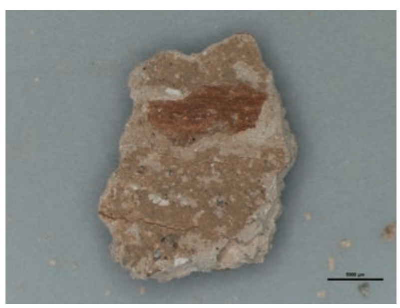
- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thick cream-white preparatory layer
- Layer 2: traces of orange-red pigment, brightly pigmented like in other cases of red finish

Sample Location for TUMA_28 (Red)

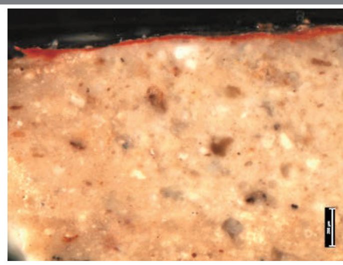
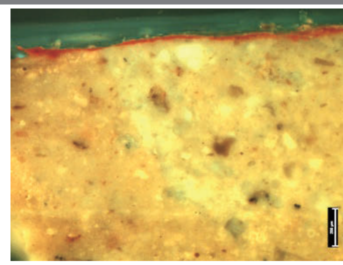
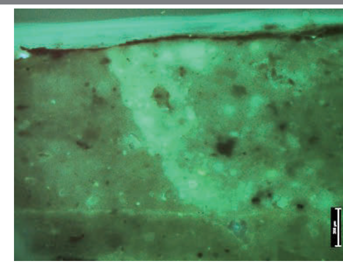
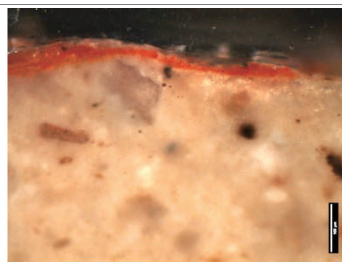
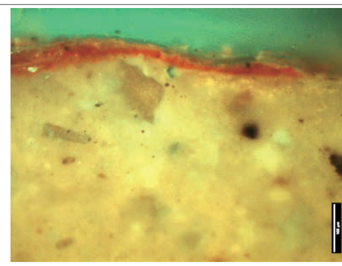
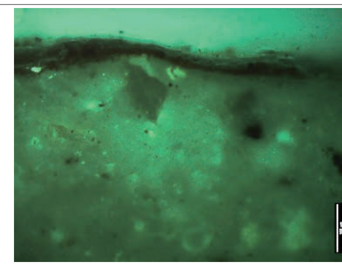


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	Unknown
Sample name	TUMA_28
Sampled by	Alex Lim (NPS)
Sample location	From collection of fallen fragments (potentially lower right column)

Microscopic Analysis of TUMA_28 (Red)

		
	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description	Red finish on weathered preparatory	Traces of red over thick white preparatory layer – lime laitance visible in UV

Stratigraphic Analysis of TUMA_28 (Red)

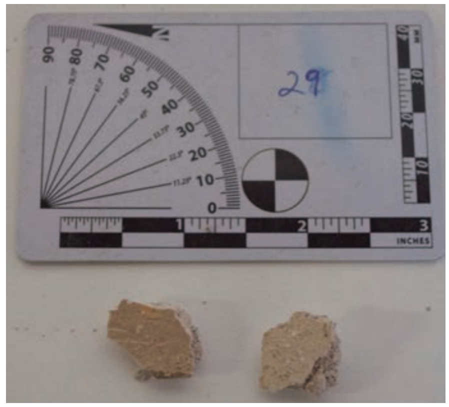
Stratigraphic Analysis of TUMA_28 (Red)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
From collection of fallen fragments (potentially lower right column)	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

NOTES

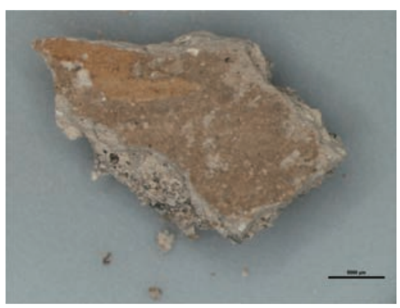
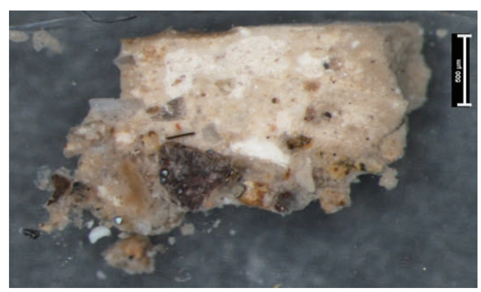
- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: thick cream-white preparatory layer
- Layer 2: traces of red pigment, brightly pigmented like in other cases of red finish
- Lime laitance visible in UV

Sample Location for TUMA_29 (Yellow)

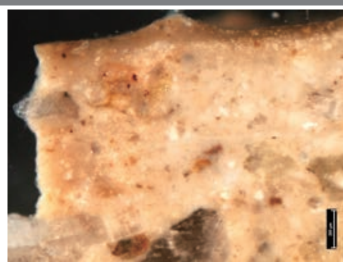
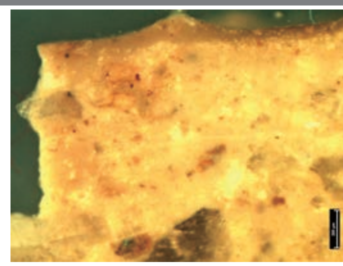
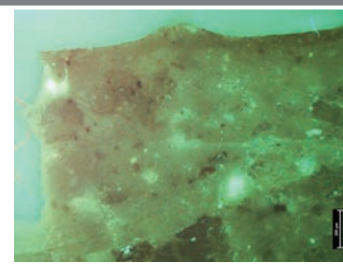
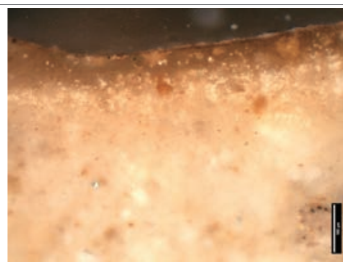
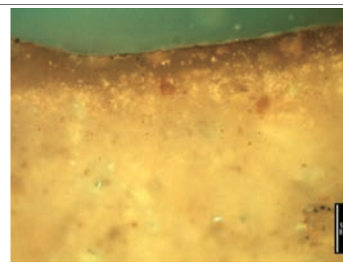
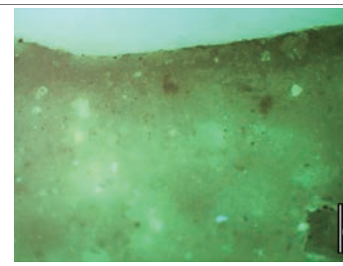


Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	Unknown
Sample name	TUMA_29
Sampled by	Alex Lim (NPS)
Sample location	From collection of fallen fragments (potentially lower right column)

Microscopic Analysis of TUMA_29 (Yellow)

		
	Unmounted, 1.6x total magnification	**Cross section, 2.0x total magnification**
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description		

Stratigraphic Analysis of TUMA_29 (Yellow)

Stratigraphic Analysis of TUMA_29 (Yellow)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
From collection of fallen fragments (potentially lower right column)	F. Matero, J. Chan	1/9/15	J. Chan
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, 10.0x.	-

NOTES

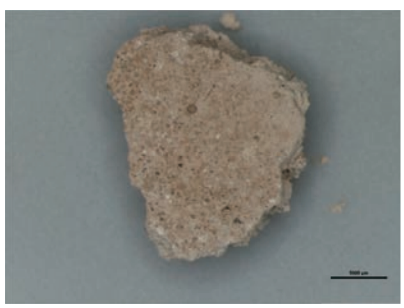
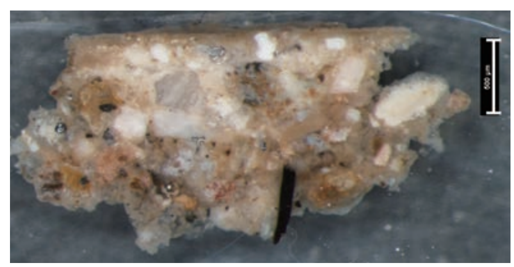
- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: cream-white preparatory layer
- Layer 2: traces of yellow pigment

- Lime laitance visible in UV

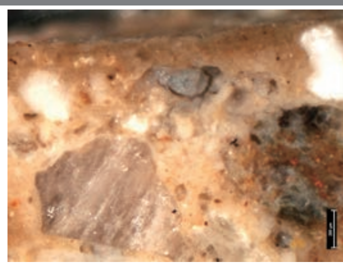
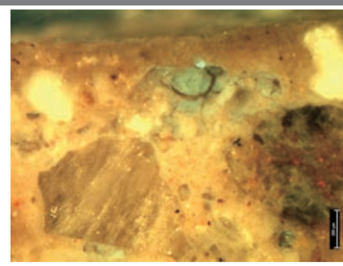
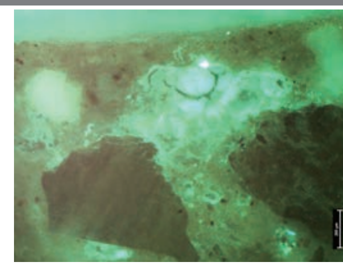
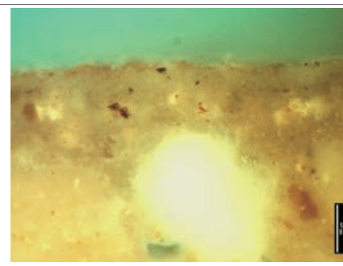
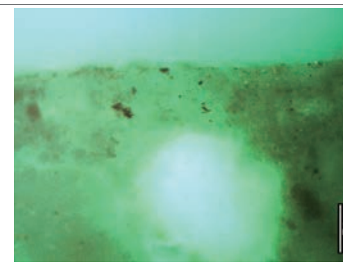
Sample Location for TUMA_30 (White)

Site	Mission San José de Tumacácori façade, Tucson Arizona
Sampling date	Unknown
Sample name	TUMA_30
Sampled by	Alex Lim (NPS)
Sample location	From collection of fallen fragments (potentially lower right column)

Microscopic Analysis of TUMA_30 (White)

		
	Unmounted, 1.6x total magnification	Cross section, 2.0x total magnification
Examination date	February 22, 2015	March 22, 2015
Analyzed by	Jocelyn Chan	Jocelyn Chan
Microscope & Software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software	Leica MZ16a stereoscope Nikon DS Fi-1 camera with NIS Elements BR software
Description		

Stratigraphic Analysis of TUMA_30 (White)

Stratigraphic Analysis of TUMA_30 (White)			
	Visible	Ultraviolet/Visible	Ultraviolet
40x			
100x			

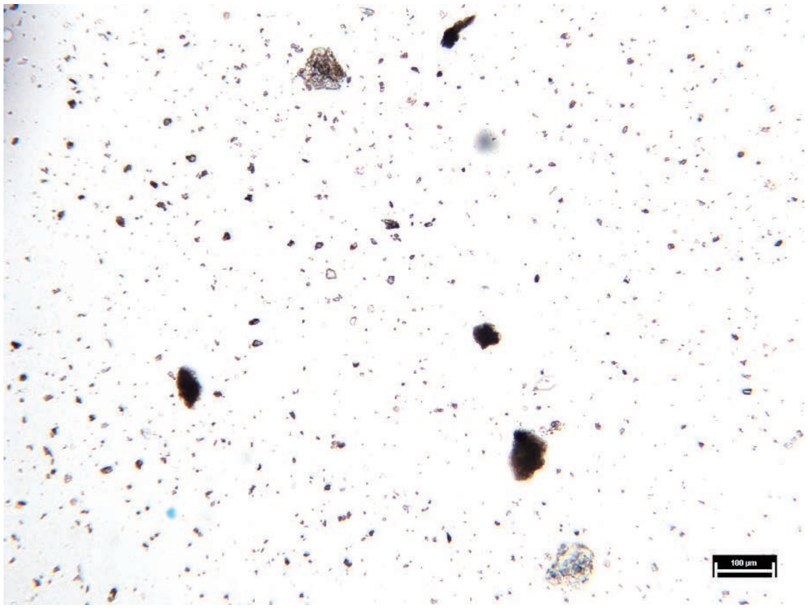
Microscopy Metadata			
Location	Sampled By	Sampled On	Analyzed By
From collection of fallen fragments (potentially lower right column)	F. Matero, J. Chan	1/9/15	J. Chan
Microscope	Light Source	Filters	Camera
Nikon Alphaphot-2	Visible (fiber optics), UV (mercury lamp)	Daylight	Nikon DS Fi-1 camera NIS Elements BR software
Ocular mag	Trinocular mag	Objective mag	Zoom
10.0x	1.0x	4.0x, 10.0x.	-

NOTES

- Substrate: coarse aggregate paste with extremely varied mineral constituents
- Layer 1: cream-white layer that appears darkened/weathered – potentially a preparatory layer?

Appendix D: Particle Dispersions

Particle Dispersion of TUMA_01 (Red) in PPL and XPL at 100x



SAMPLE TUMA_01
PARTICLE DISPERSION – PPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
SAMPLED: 1/9/15

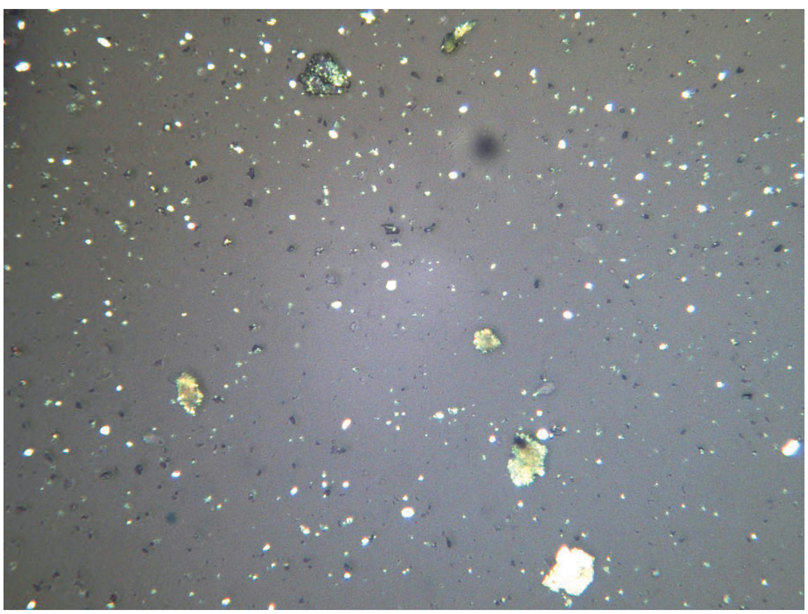
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Olympus CX31
OCULAR MAG: 10 x

OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a



SAMPLE TUMA_01
PARTICLE DISPERSION – XPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
SAMPLED: 1/9/15

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

MICROSCOPE: Olympus CX31
OCULAR MAG: 10 x

OBJECTIVE: 20x
ZOOM: n/a

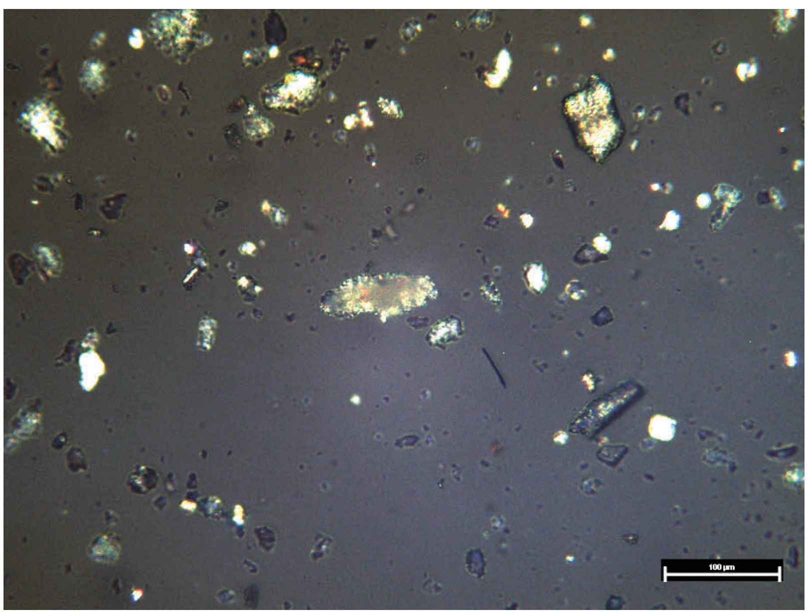
TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

-Dull red coarse grain particles
-High birefringence
-Mixture of grain sizes, some more opaque red
-Several clear particles that appear to be quartz coated in red pigment, similar to hematite standard in Pigment Compendium

Particle Dispersion of TUMA_01 (Red) in PPL and XPL at 200x

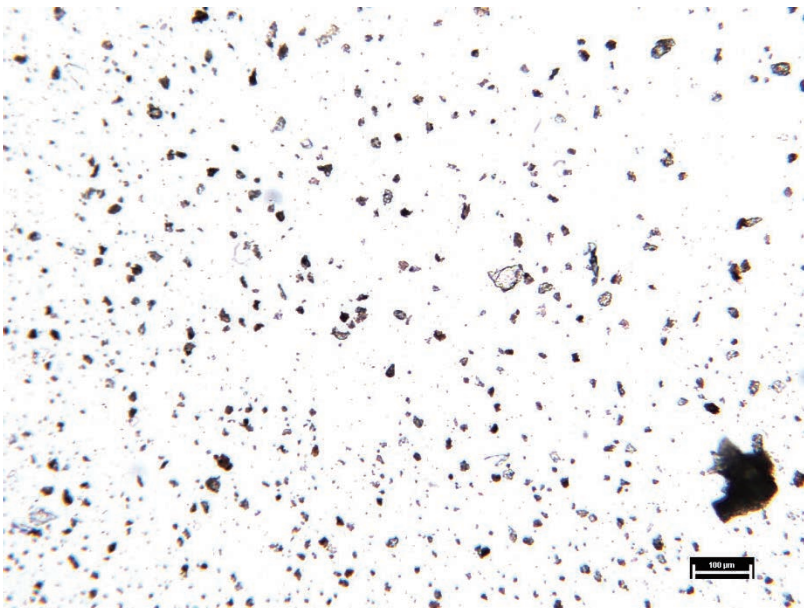
SAMPLE TUMA_01 PARTICLE DISPERSION – PPL	
ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) SAMPLED: 1/9/15	
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software	
MICROSCOPE: Olympus CX31 OCULAR MAG: 10 x	
OBJECTIVE: 20x ZOOM: n/a	
TRINOCULAR MAG: 0.6x LIGHT SOURCE: halogen	
FILTERS: daylight COLOR TEMP: n / a	



SAMPLE TUMA_01 PARTICLE DISPERSION – XPL	
ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) SAMPLED: 1/9/15	
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software	
MICROSCOPE: Olympus CX31 OCULAR MAG: 10 x	
OBJECTIVE: 20x ZOOM: n/a	
TRINOCULAR MAG: 0.6x LIGHT SOURCE: halogen	
FILTERS: daylight COLOR TEMP: n / a	

-Dull red coarse grain particles
-High birefringence
-Mixture of grain sizes, some more opaque red
-Angular crystalline particles mixed with smaller more rounded red particles
-Several clear particles that appear to be quartz coated in red pigment, similar to hematite standard

Particle Dispersion of TUMA_12 (Red) in PPL and XPL at 100x



SAMPLE TUMA_12
PARTICLE DISPERSION – PPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
SAMPLED: 1/9/15

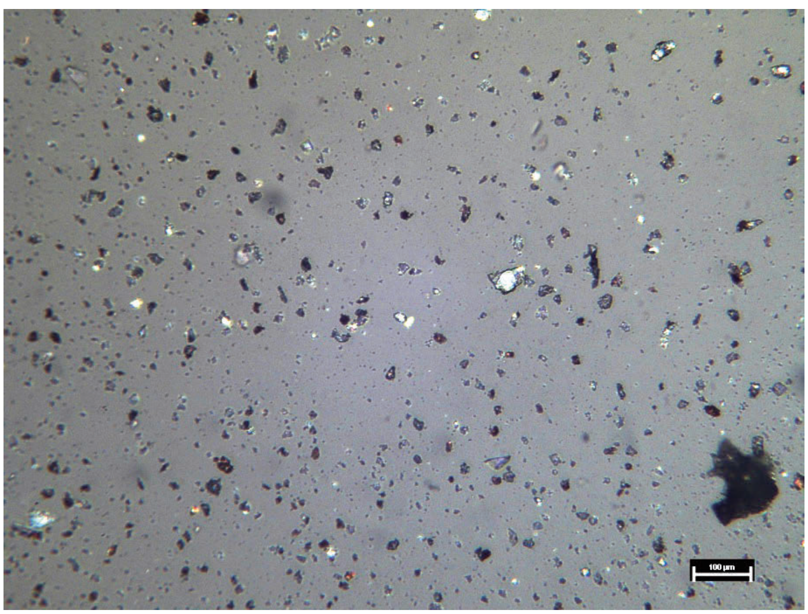
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Olympus CX31
OCULAR MAG: 10 x

OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a



SAMPLE TUMA_12
PARTICLE DISPERSION – XPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
SAMPLED: 1/9/15

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

MICROSCOPE: Olympus CX31
OCULAR MAG: 10 x

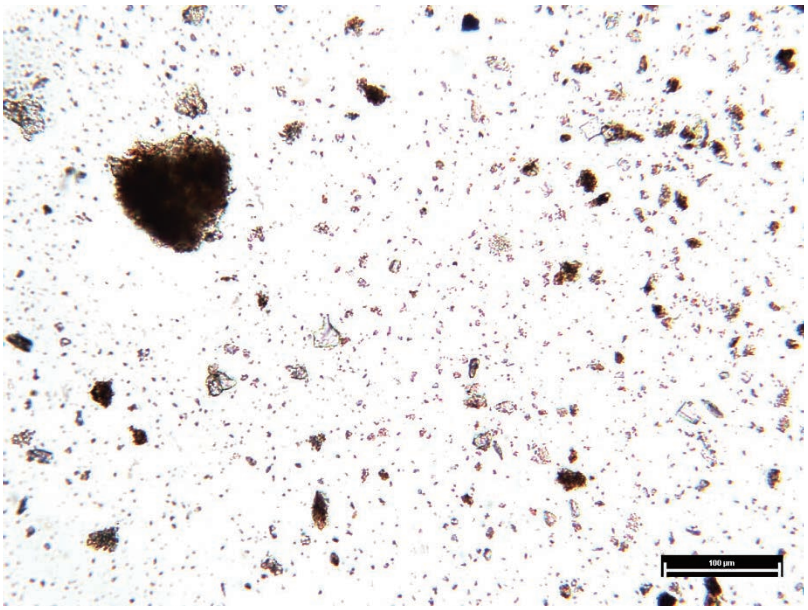
OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

-Dull red coarse grain particles
-High birefringence
-Mixture of grain sizes, some more opaque red
-Seems consistent with sample TUMA_01

Particle Dispersion of TUMA_12 (Red) in PPL and XPL at 200x



SAMPLE TUMA_12
PARTICLE DISPERSION – PPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
SAMPLED: 1/9/15

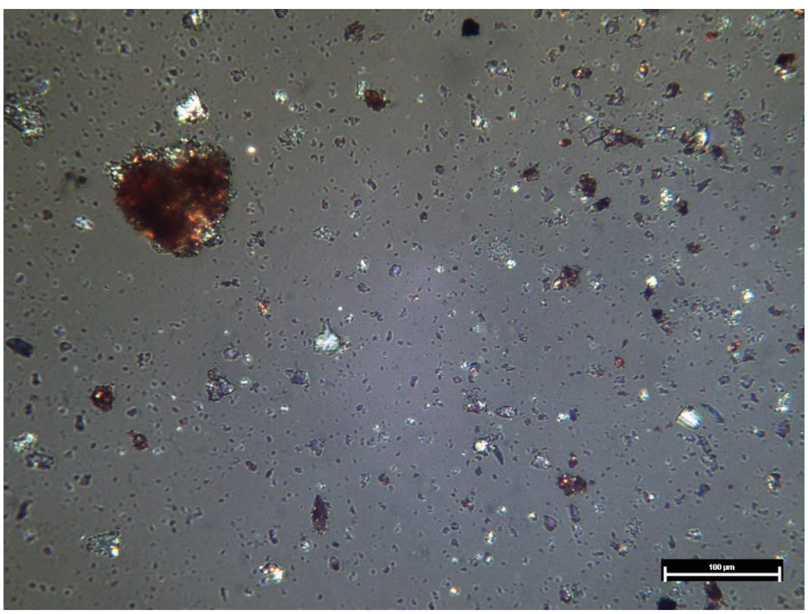
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Olympus CX31
OCULAR MAG: 10 x

OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a



SAMPLE TUMA_12
PARTICLE DISPERSION – XPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
SAMPLED: 1/9/15

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

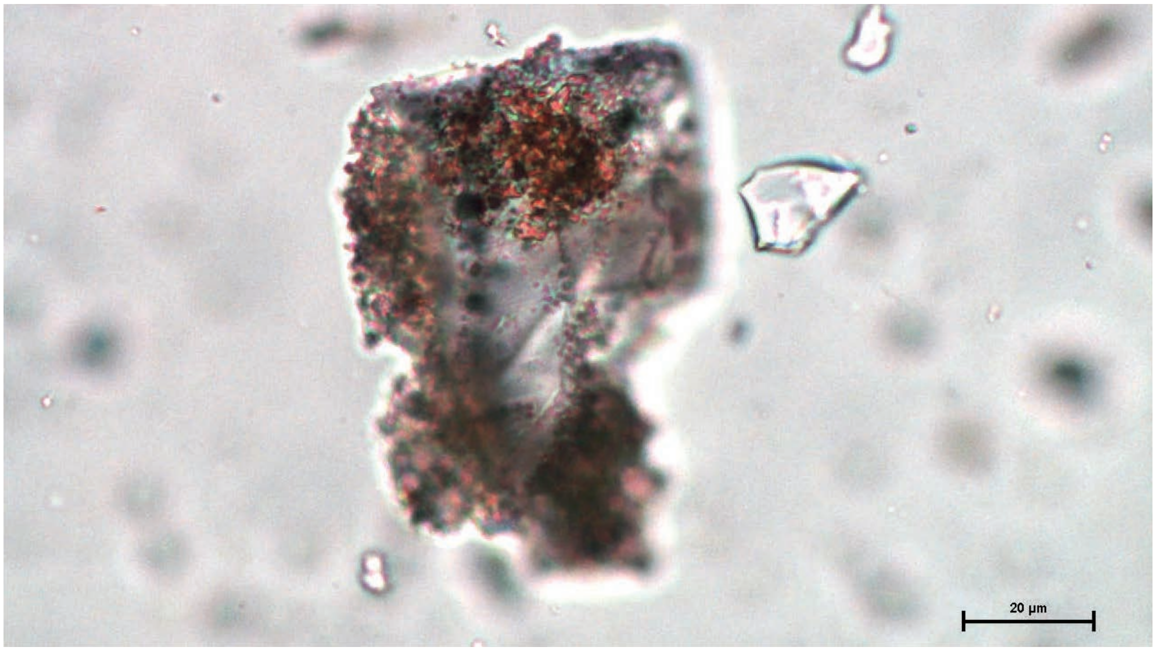
MICROSCOPE: Olympus CX31
OCULAR MAG: 10 x

OBJECTIVE: 20x
ZOOM: n/a

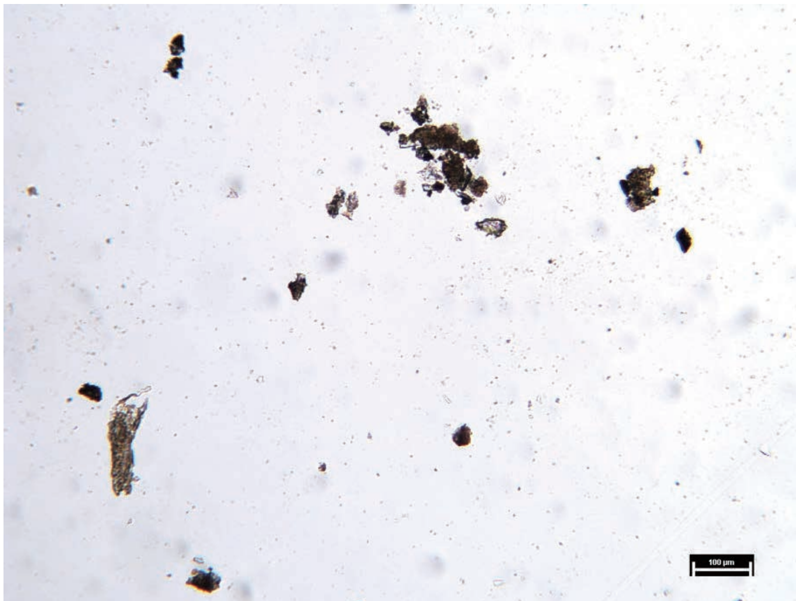
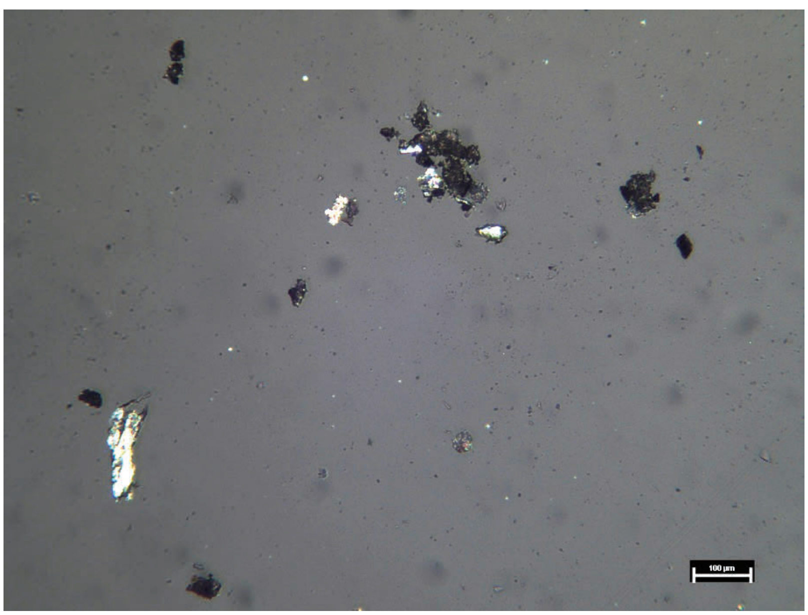
TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

-Dull red coarse grain particles
-High birefringence
-Mixture of grain sizes, some more opaque red
-Several clear particles that appear to be quartz coated in red pigment, similar to hematite standard in Pigment Compendium

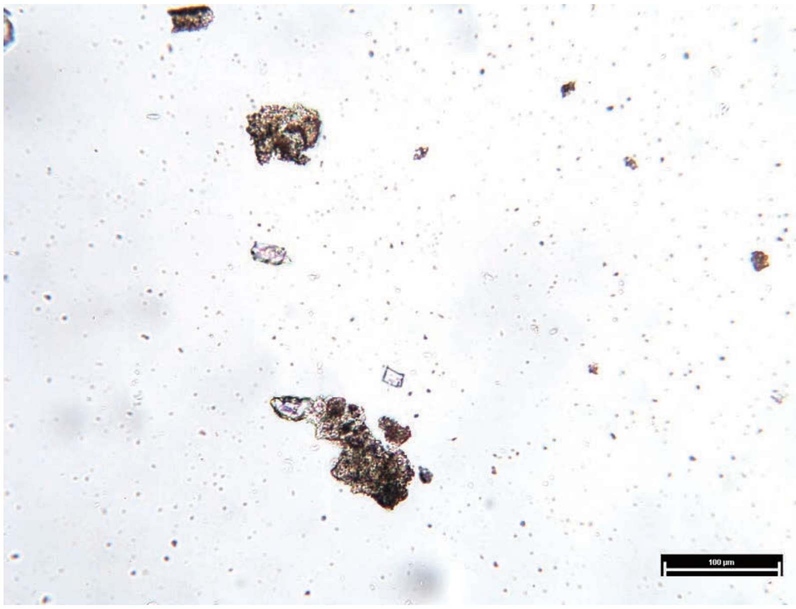


Two particles both from TUMA_12 at 400x magnification showing what appears to be quartz crystals covered in a red globular pigment – this is consistent with standards shown in Pigment Compendium

Particle Dispersion of TUMA_06 (Yellow) in PPL and XPL at 100x	
	SAMPLE TUMA_06 PARTICLE DISPERSION – PPL ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) RECEIVED: 4/6/15 IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x OBJECTIVE: 20x ZOOM: n/a TRINOCULAR MAG: 0.6x LIGHT SOURCE: halogen FILTERS: daylight COLOR TEMP: n / a
	SAMPLE TUMA_06 PARTICLE DISPERSION – XPL ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) RECEIVED: 4/6/15 IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x OBJECTIVE: 20x ZOOM: n/a TRINOCULAR MAG: 0.6x LIGHT SOURCE: halogen FILTERS: daylight COLOR TEMP: n / a

-Dull yellow-brown coarse grain particles
-High birefringence
-Mixture of grain sizes, some more opaque
-Not as well dispersed as other yellow samples
-More cases of pigments that perhaps were not well ground or dispersed enough in preparation

Particle Dispersion of TUMA_06 (Yellow) in PPL and XPL at 200x



SAMPLE TUMA_06
PARTICLE DISPERSION – PPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

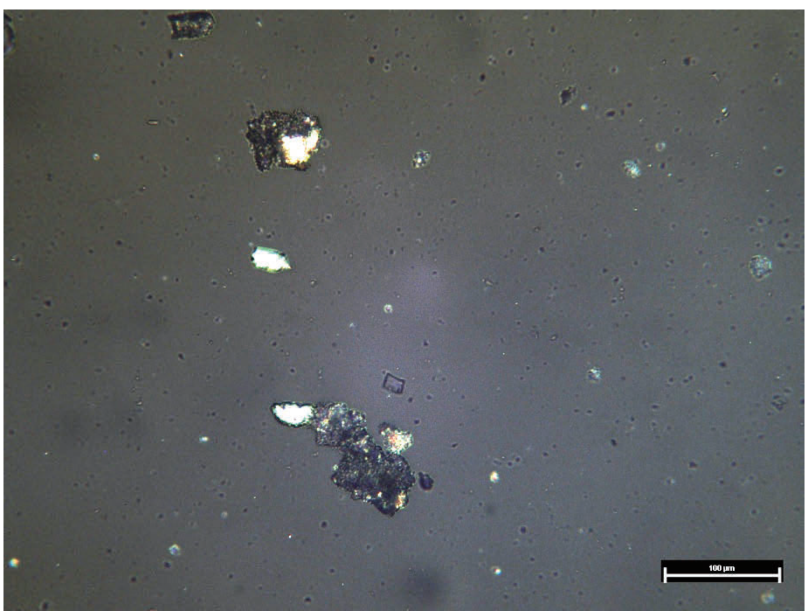
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a



SAMPLE TUMA_06
PARTICLE DISPERSION – XPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

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

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

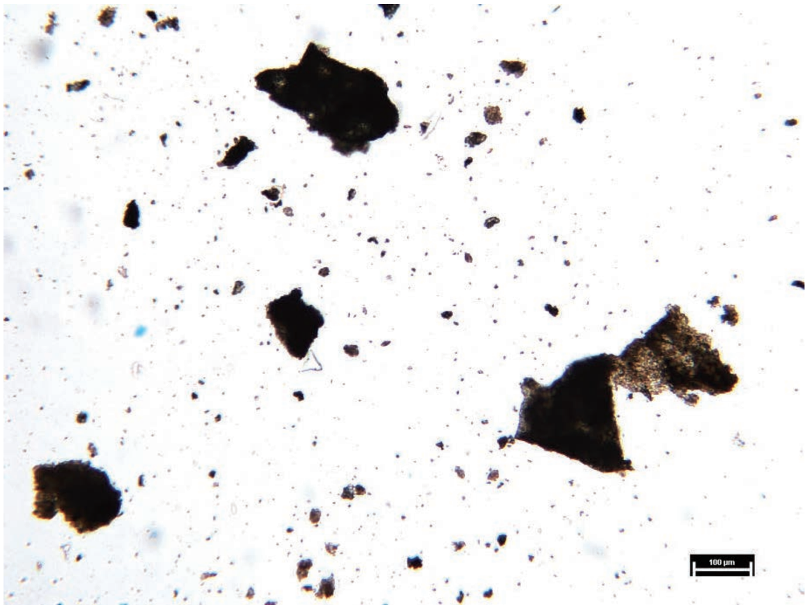
OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

-Dull yellow-brown coarse grain particles
-High birefringence
-Mixture of grain sizes, some more opaque
-Not as well dispersed as other yellow samples
-More cases of pigments that perhaps were not well ground or dispersed enough in preparation

PARTICLE DISPERSION OF TUMA_09 (YELLOW) IN PPL AND XPL AT 100X



<u>SAMPLE TUMA_09</u>
<u>PARTICLE DISPERSION – PPL</u>

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

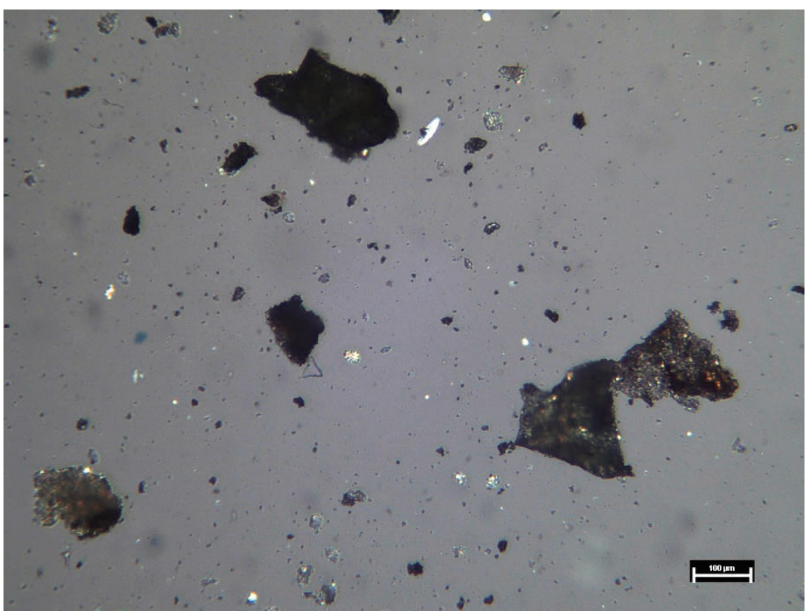
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a



<u>SAMPLE TUMA_09</u>
<u>PARTICLE DISPERSION – XPL</u>

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

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

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

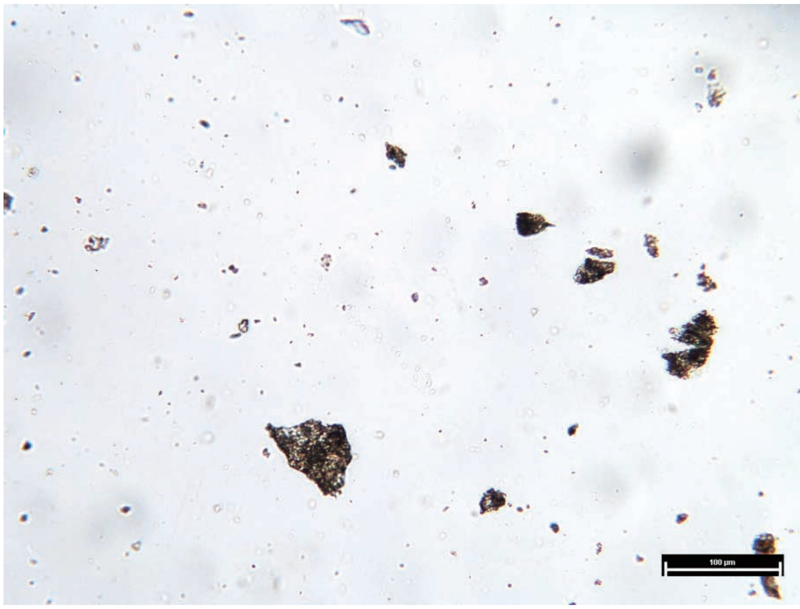
OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

-Dull yellow-brown coarse grain particles
-High birefringence
-Mixture of grain sizes, more opaques or large chunks of pigment noted than in other samples
-Presence of some red particles within the dispersion
-Appear similar to goethite standard in <u>Pigment Compendium</u>

Particle Dispersion of TUMA_09 (Yellow) in PPL and XPL at 200x



SAMPLE TUMA_09
PARTICLE DISPERSION – PPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

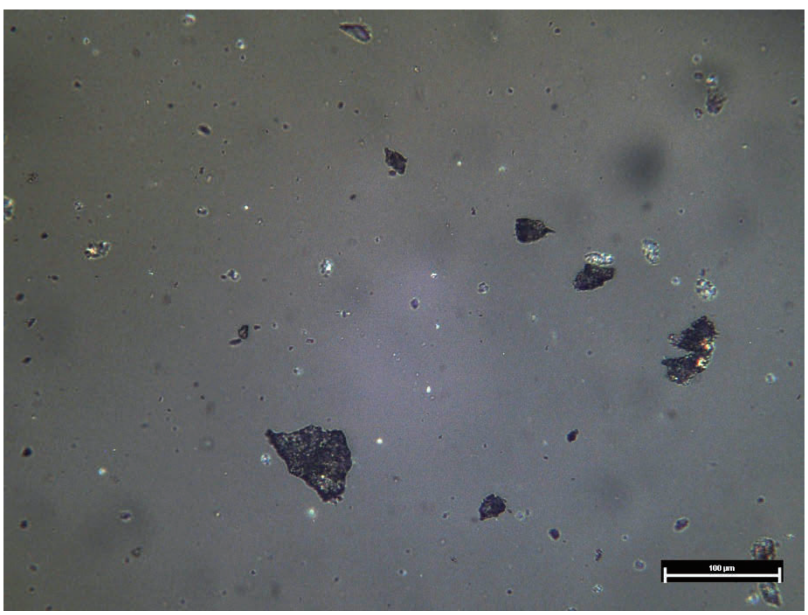
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a



SAMPLE TUMA_09
PARTICLE DISPERSION – XPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

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

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

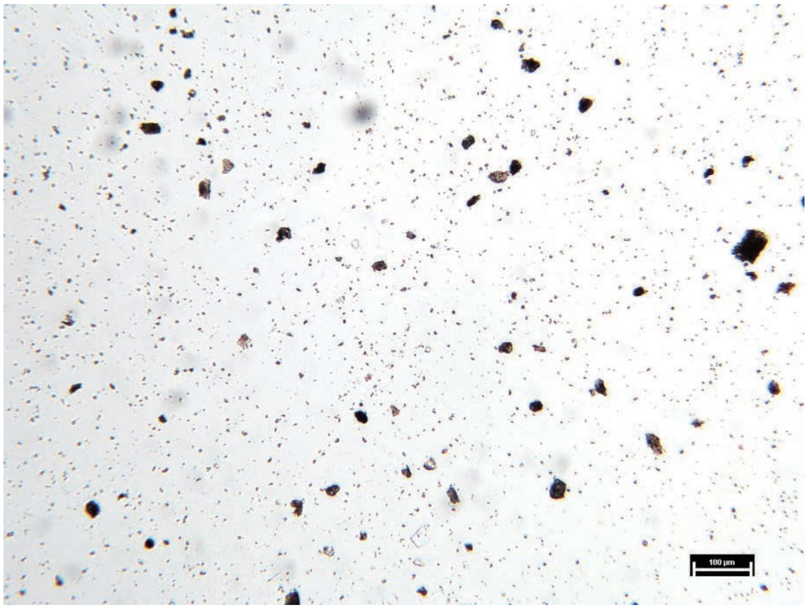
OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

-Dull yellow-brown coarse grain particles
-High birefringence
-Mixture of grain sizes, more opaques or large chunks of pigment noted than in other samples
-Presence of some red particles within the dispersion
-Appear similar to goethite standard in Pigment Compendium

Particle Dispersion of TUMA_11 (Yellow) in PPL and XPL at 100x



<u>SAMPLE TUMA_11</u>
<u>PARTICLE DISPERSION – PPL</u>

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

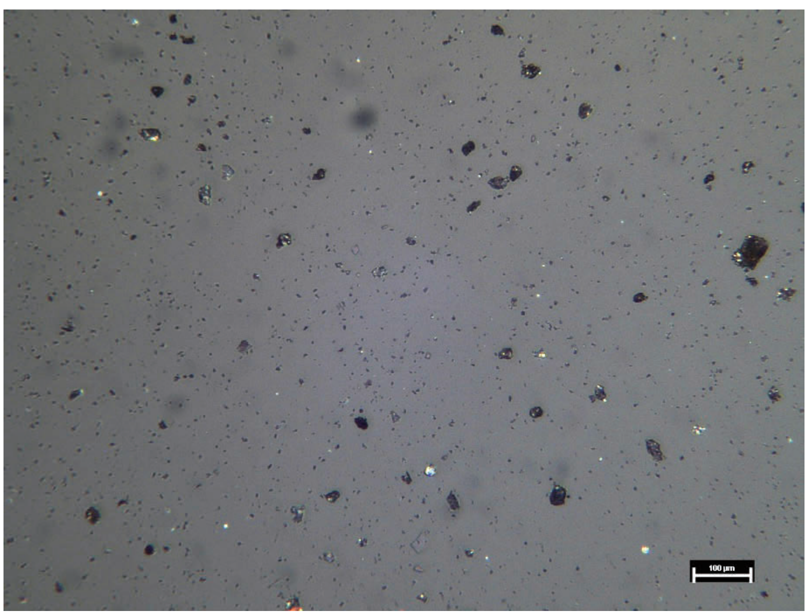
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a



<u>SAMPLE TUMA_11</u>
<u>PARTICLE DISPERSION – XPL</u>

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

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

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

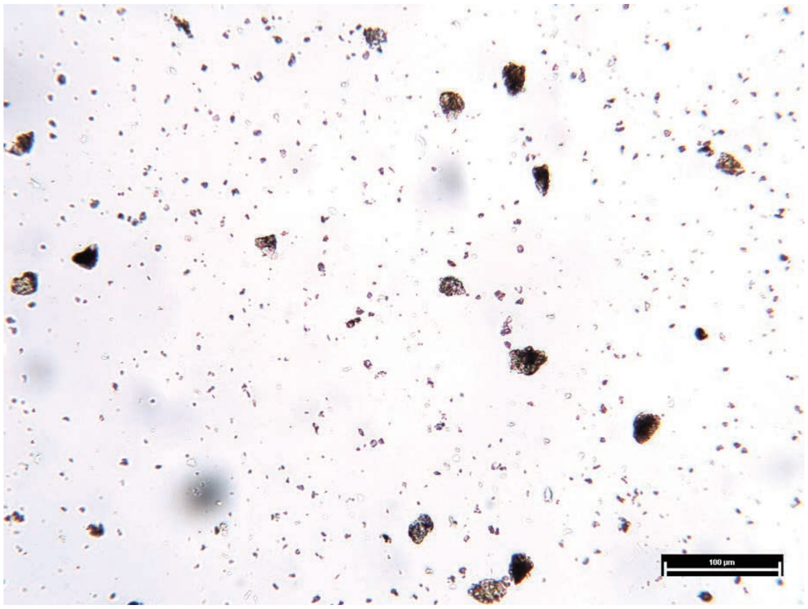
OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

-Dull yellow-brown coarse grain particles, mixture of grain sizes, some more opaque
-High birefringence
- Most well dispersed sample of the three yellow samples
-Presence of some red particles within the dispersion
-Appear similar to goethite standard in <u>Pigment Compendium</u>

Particle Dispersion of TUMA_11 (Yellow) in PPL and XPL at 200x



SAMPLE TUMA_11
PARTICLE DISPERSION – PPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

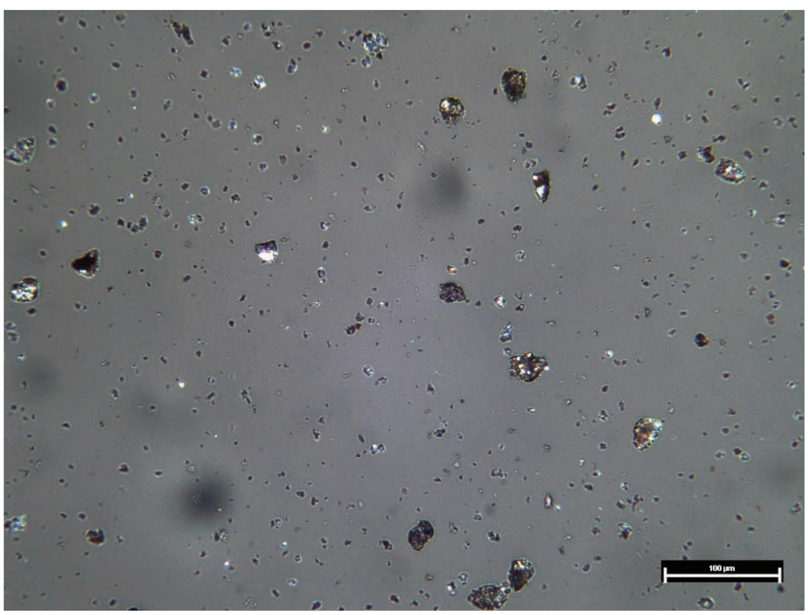
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

OBJECTIVE: 20x
ZOOM: n/a

TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a



SAMPLE TUMA_11
PARTICLE DISPERSION – XPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

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

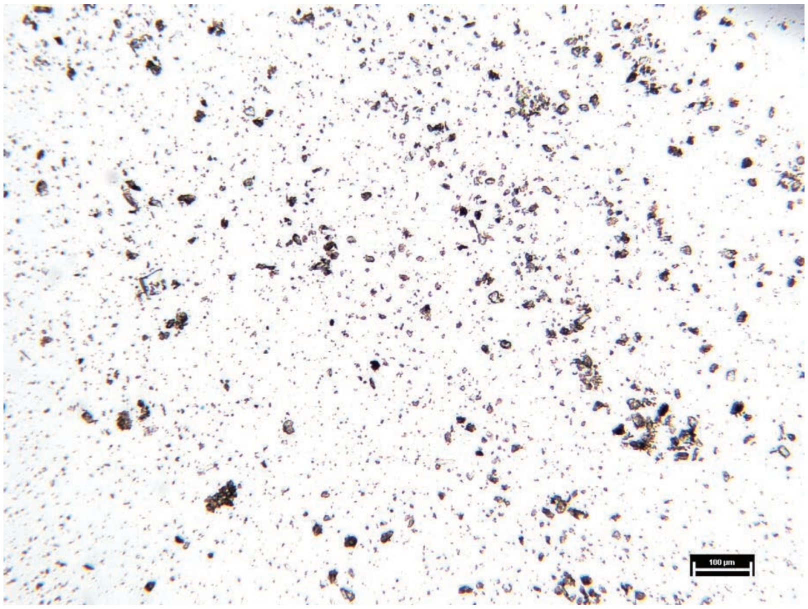
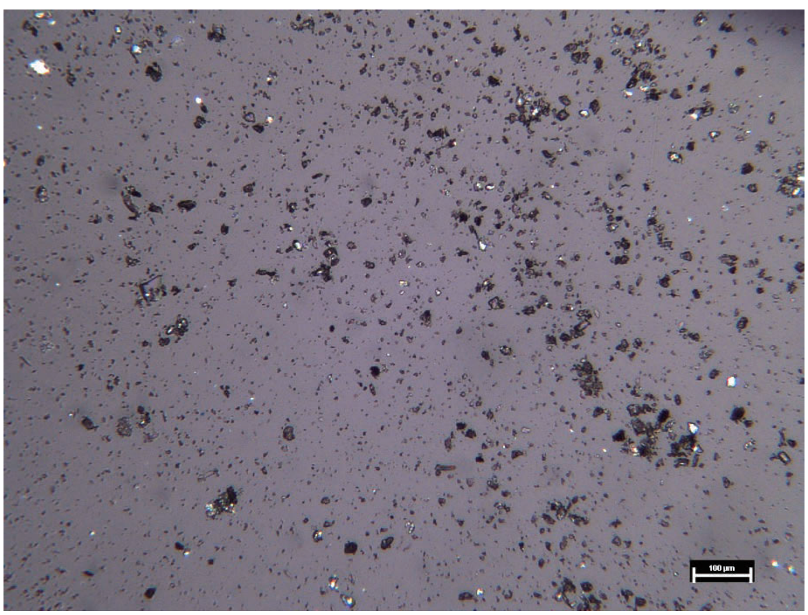
MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

OBJECTIVE: 20x
ZOOM: n/a

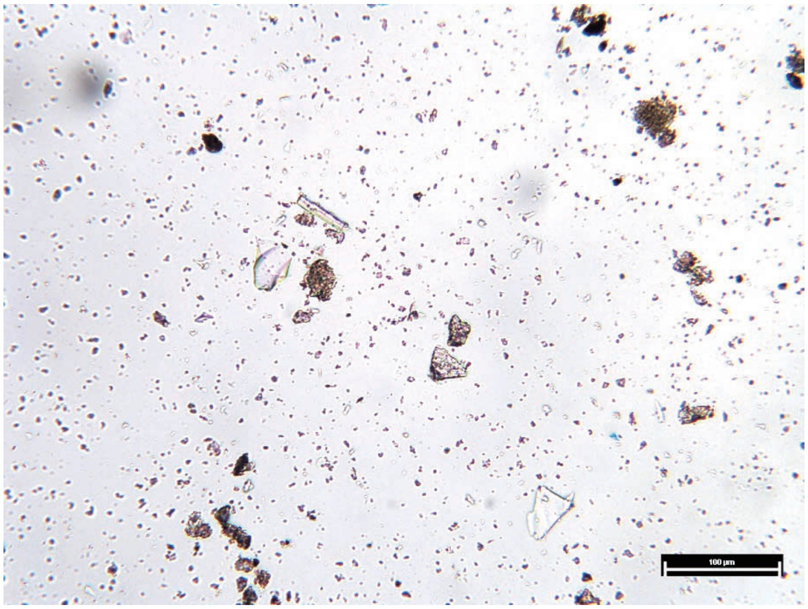
TRINOCULAR MAG: 0.6x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

-Dull yellow-brown coarse grain particles, mixture of grain sizes, some more opaque
-High birefringence
- Most well dispersed sample of the three yellow samples
-Presence of some red particles within the dispersion
-Appear similar to goethite standard in Pigment Compendium

PARTICLE DISPERSION OF TUMA_03 (WHITE) IN PPL AND XPL IN 100X	
	SAMPLE TUMA_03 PARTICLE DISPERSION – PPL ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) RECEIVED: 4/6/15 IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x OBJECTIVE: 4x ZOOM: n/a TRINOCULAR MAG: 1.0x LIGHT SOURCE: halogen FILTERS: daylight COLOR TEMP: n / a
	SAMPLE TUMA_03 PARTICLE DISPERSION – XPL ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) RECEIVED: 4/6/15 IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x OBJECTIVE: 4x ZOOM: n/a TRINOCULAR MAG: 1.0x LIGHT SOURCE: halogen FILTERS: daylight COLOR TEMP: n / a
-Irregularly shaped white/clear crystals -High birefringence -Mixture of grain sizes - More angular than TUMA_25 -Similar to chalk standard in Pigment Compendium, potential presence of microfossils?	

Particle Dispersion of TUMA_03 (White) in PPL and XPL in 200x



<u>SAMPLE TUMA_03</u>
<u>PARTICLE DISPERSION – PPL</u>

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

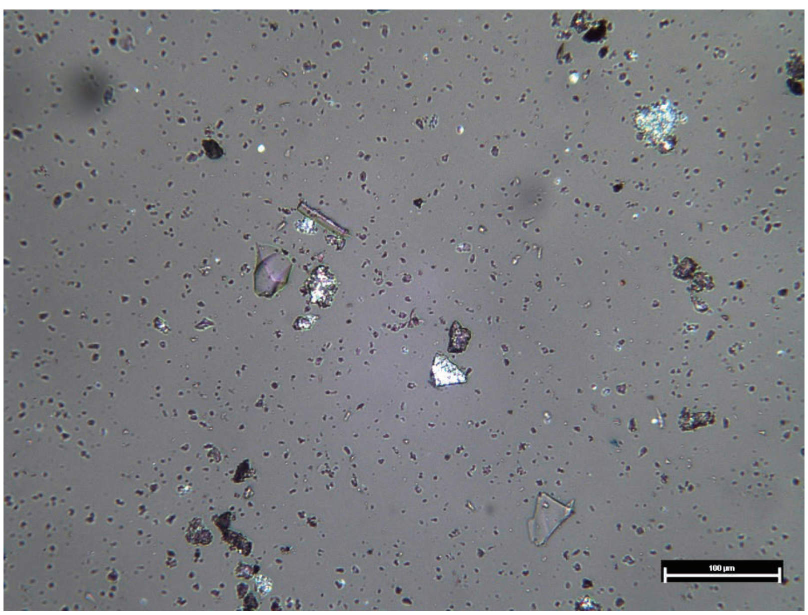
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

OBJECTIVE: 4x
ZOOM: n/a

TRINOCULAR MAG: 1.0x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a



<u>SAMPLE TUMA_03</u>
<u>PARTICLE DISPERSION – XPL</u>

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

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

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

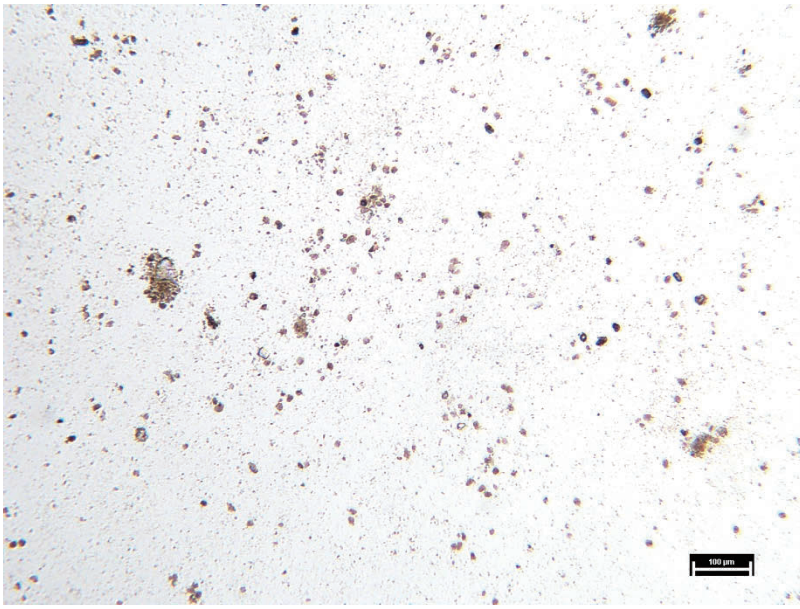
OBJECTIVE: 4x
ZOOM: n/a

TRINOCULAR MAG: 1.0x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

-Irregularly shaped white/clear crystals, mixture of grain sizes
-High birefringence
- More angular than TUMA_25
-Similar to chalk standard in <u>Pigment Compendium,</u> potential presence of microfossils?

PARTICLE DISPERSION OF TUMA_25 (WHITE) IN PPL AND XPL IN 100X



SAMPLE TUMA_25
PARTICLE DISPERSION – PPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

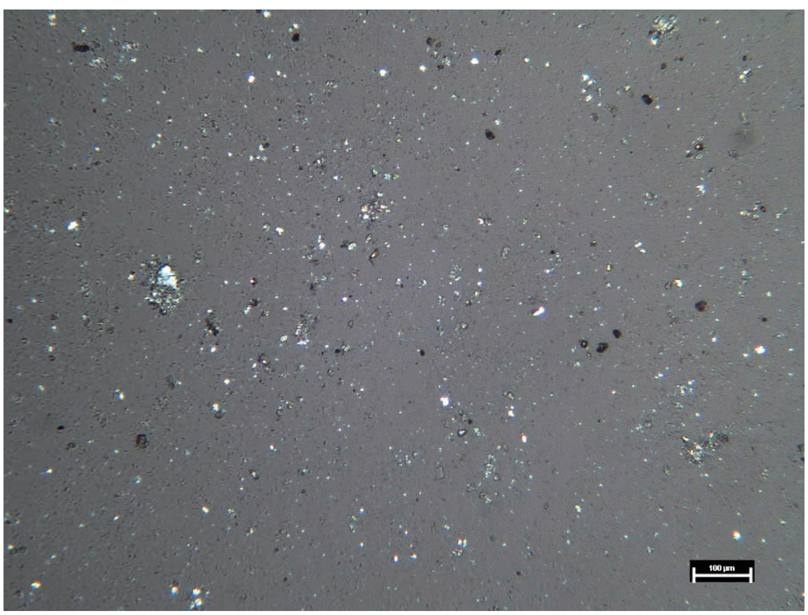
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

OBJECTIVE: 4x
ZOOM: n/a

TRINOCULAR MAG: 1.0x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a



SAMPLE TUMA_25
PARTICLE DISPERSION – XPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona)
RECEIVED: 4/6/15

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

MICROSCOPE: Nikon Alphaphot-2
OCULAR MAG: 10 x

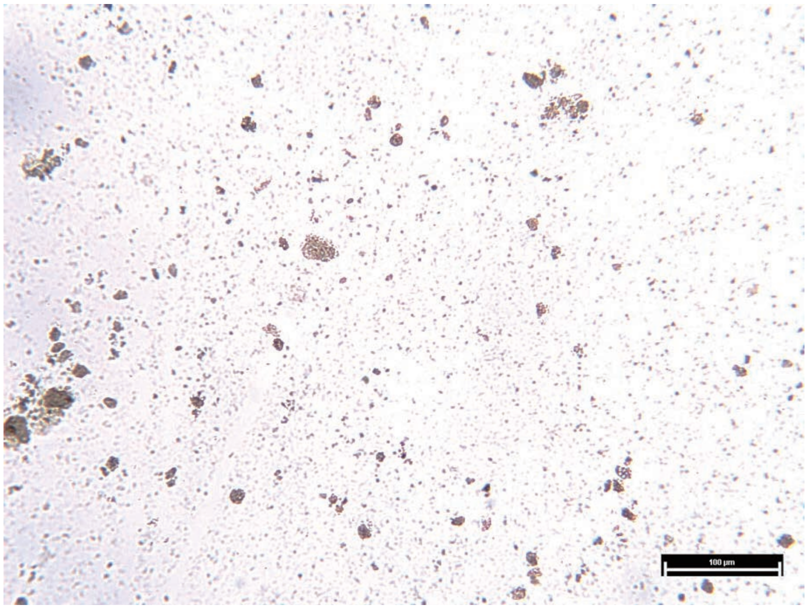
OBJECTIVE: 4x
ZOOM: n/a

TRINOCULAR MAG: 1.0x
LIGHT SOURCE: halogen

FILTERS: daylight
COLOR TEMP: n / a

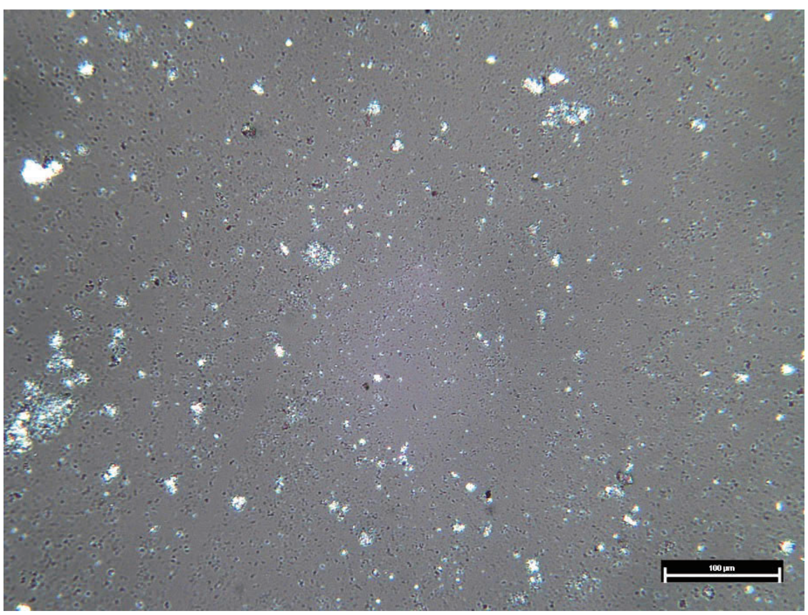
-Irregularly shaped white/clear crystals, mixture of grain sizes
-High birefringence
-More well dispersed than TUMA_03
-Similar to chalk standard in Pigment Compendium, potential presence of microfossils?

Particle Dispersion of TUMA_25 (White) in PPL and XPL in 200x



SAMPLE TUMA_25
PARTICLE DISPERSION – PPL

ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) **RECEIVED: 4/6/15**	
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software	
MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x	
OBJECTIVE: 4x ZOOM: n/a	
TRINOCULAR MAG: 1.0x LIGHT SOURCE: halogen	
FILTERS: daylight COLOR TEMP: n / a	



SAMPLE TUMA_25
PARTICLE DISPERSION – XPL

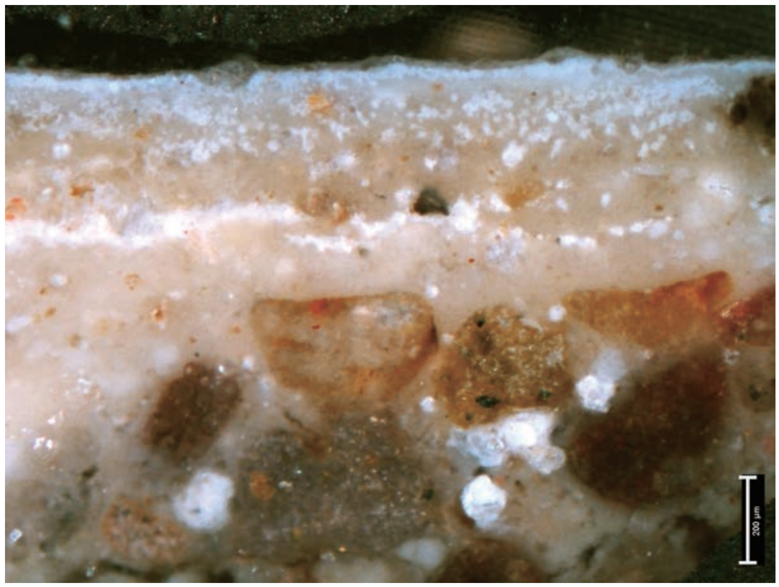
ORIGIN: Mission San José de Tumacácori, Tumacácori National Historical Park (Arizona) **RECEIVED: 4/6/15**	
IMAGING: Nikon DS-Fi1 camera with NIS Elements BR software	
MICROSCOPE: Nikon Alphaphot-2 OCULAR MAG: 10 x	
OBJECTIVE: 4x ZOOM: n/a	
TRINOCULAR MAG: 1.0x LIGHT SOURCE: halogen	
FILTERS: daylight COLOR TEMP: n / a	

-Irregularly shaped white/clear crystals, mixture of grain sizes
-High birefringence
-More well dispersed than TUMA_03
-Similar to chalk standard in Pigment Compendium, potential presence of microfossils?

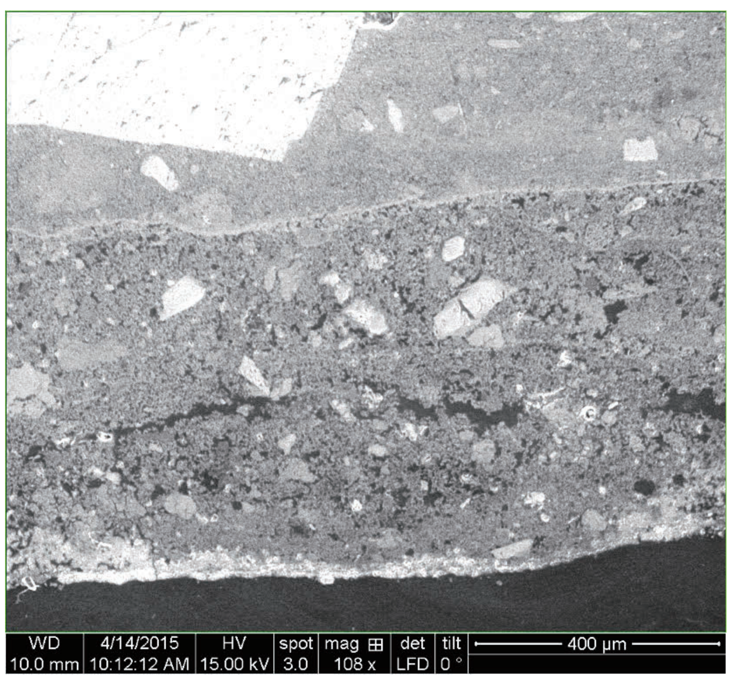
Appendix E: SEM-EDS Data Sets

Laboratory for Research on the Structure of Matter, University of Pennsylvania
TUMA_03 SEM-EDS Data

When comparing with data sets acquired at the Winterthur SRAL, it was noted in subsequent runs that it appeared perhaps some of the samples of the Penn run were labeled incorrectly.

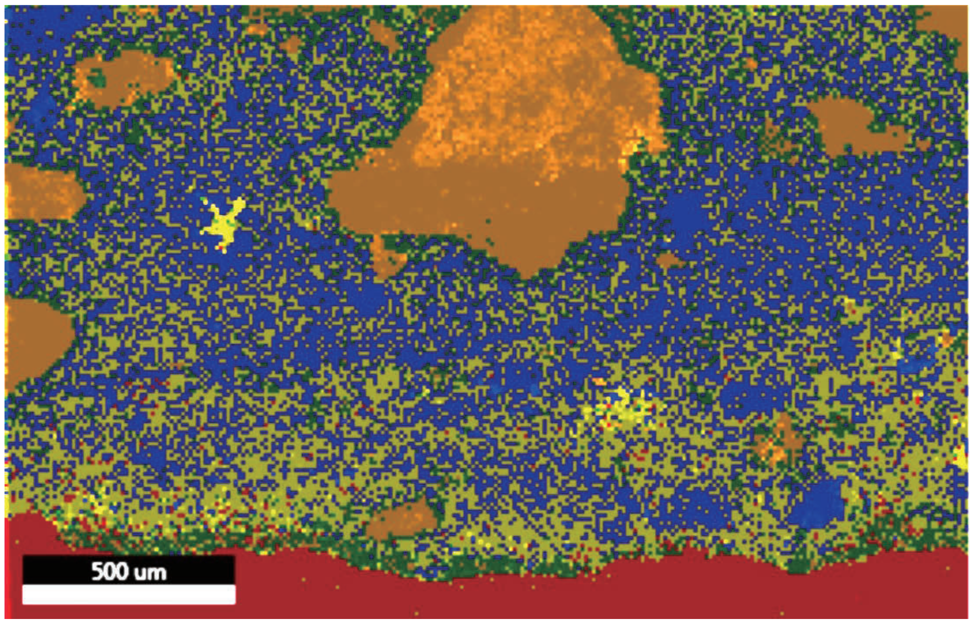


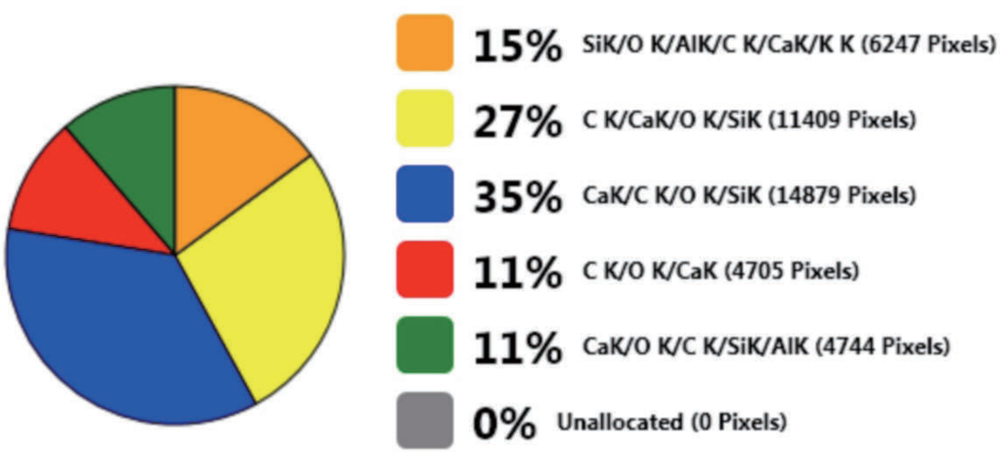
TUMA_03 in visible light at 40x

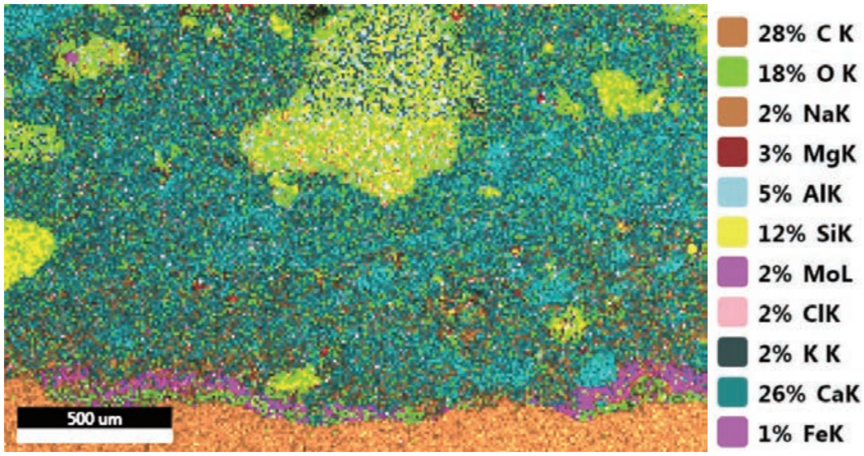


TUMA_03 backscattered electron image from SEM (note sample is finish layer down)

TUMA_03 Elemental Mapping

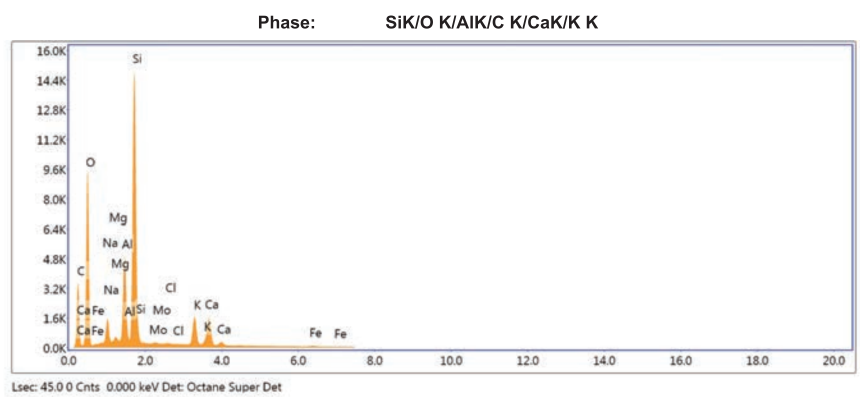






TUMA_03 EDS Spectra (1 of 5)

kV: 15 Mag: 60 Takeoff: 34 Live Time(s): 45 Amp Time(µs): 1.92 Resolution:(eV)135.3



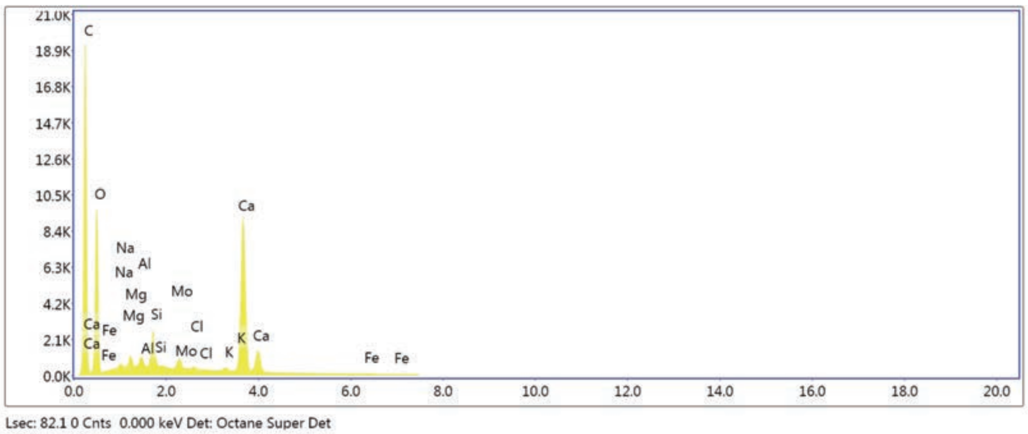
eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	25.56	37.25	975	9.86	0.06	1.08	0.96	0.23	1.00
O K	37.73	41.27	3099.6	8.87	0.10	1.03	0.98	0.26	1.00
NaK	2.37	1.81	435.5	7.38	0.01	0.93	1.01	0.52	1.01
MgK	0.28	0.20	81.6	11.31	0.00	0.94	1.02	0.67	1.01
AlK	5.72	3.71	1846	3.99	0.04	0.91	1.02	0.79	1.01
SiK	18.49	11.52	6052.2	3.20	0.14	0.93	1.03	0.84	1.01
MoL	0.26	0.05	33.8	32.64	0.00	0.69	1.22	0.99	1.02
ClK	0.11	0.06	25.8	35.67	0.00	0.86	1.04	0.91	1.02
K K	3.98	1.78	762.7	3.26	0.03	0.85	1.05	0.97	1.03
CaK	5.11	2.23	797.7	3.03	0.04	0.87	1.05	0.97	1.02
FeK	0.38	0.12	22.7	28.24	0.00	0.77	1.06	1.00	1.10

TUMA_03 EDS Spectra (2 of 5)

kV: 15 Mag: 60 Takeoff: 34 Live Time(s): 82.1 Amp Time(μs): 1.92 Resolution:(eV)135.

Phase: C K/CaK/O K/SiK



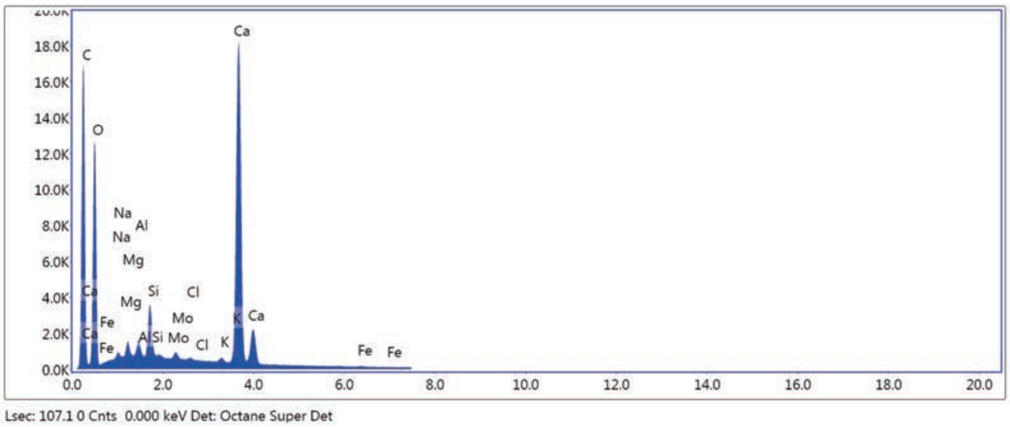
eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	40.60	54.40	3040.6	6.29	0.22	1.06	0.97	0.52	1.00
O K	35.48	35.70	1764.5	9.64	0.07	1.01	0.99	0.19	1.00
NaK	0.24	0.17	34.8	16.38	0.00	0.92	1.01	0.47	1.00
MgK	0.50	0.33	118.8	8.12	0.00	0.93	1.02	0.64	1.01
AlK	0.52	0.31	138.8	6.56	0.00	0.89	1.02	0.77	1.01
SiK	1.64	0.94	474.4	3.89	0.01	0.91	1.03	0.86	1.01
MoL	1.18	0.20	149.8	9.07	0.01	0.68	1.22	1.10	1.04
ClK	0.20	0.09	43	17.54	0.00	0.85	1.04	0.98	1.05
K K	0.30	0.12	54.9	12.83	0.00	0.84	1.05	1.00	1.11
CaK	19.17	7.70	2650.3	1.99	0.17	0.86	1.06	1.01	1.02
FeK	0.17	0.05	8.8	55.97	0.00	0.75	1.06	1.00	1.08

TUMA_03 EDS Spectra (3 of 5)

kV: 15 Mag: 60 Takeoff: 34 Live Time(s): 107.1 Amp Time(μs): 1.92 Resolution:(eV)135.3

Phase: CaK/C K/O K/SiK



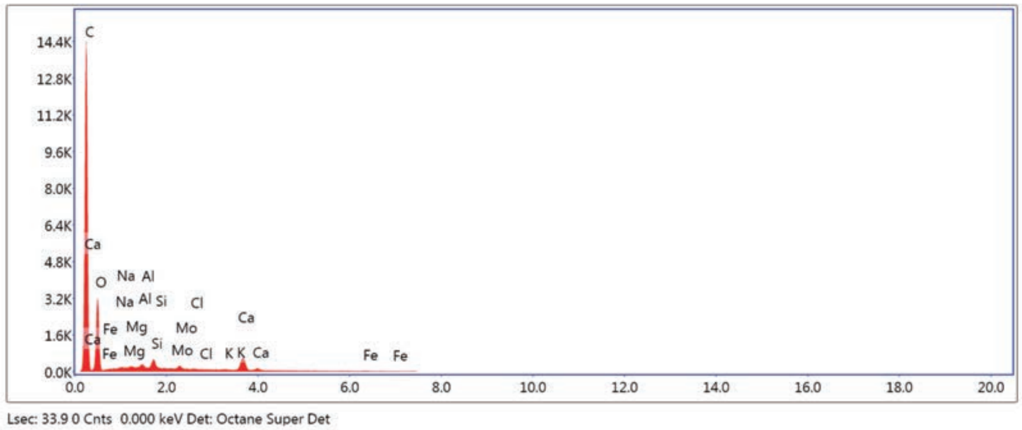
eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	28.99	42.75	2018.9	6.64	0.15	1.08	0.96	0.49	1.00
O K	38.05	42.12	1772.2	9.70	0.07	1.03	0.98	0.18	1.00
NaK	0.27	0.21	35.5	15.33	0.00	0.93	1.00	0.45	1.00
MgK	0.53	0.39	119.7	7.89	0.00	0.95	1.01	0.61	1.01
AlK	0.57	0.38	146.5	6.35	0.00	0.91	1.02	0.74	1.01
SiK	1.81	1.14	506.4	3.91	0.01	0.93	1.02	0.84	1.02
MoL	0.57	0.11	71.3	13.70	0.00	0.69	1.21	1.09	1.05
ClK	0.16	0.08	35.3	20.65	0.00	0.86	1.04	0.97	1.06
K K	0.28	0.12	51.8	11.14	0.00	0.86	1.05	1.00	1.16
CaK	28.64	12.66	3885.8	1.88	0.25	0.87	1.05	1.01	1.01
FeK	0.12	0.04	6	56.38	0.00	0.77	1.06	0.99	1.07

TUMA_03 EDS Spectra (4 of 5)

kV: 15 Mag: 60 Takeoff: 34 Live Time(s): 33.9 Amp Time(μs): 1.92 Resolution:(eV)135.3

Phase: C K/O K/CaK



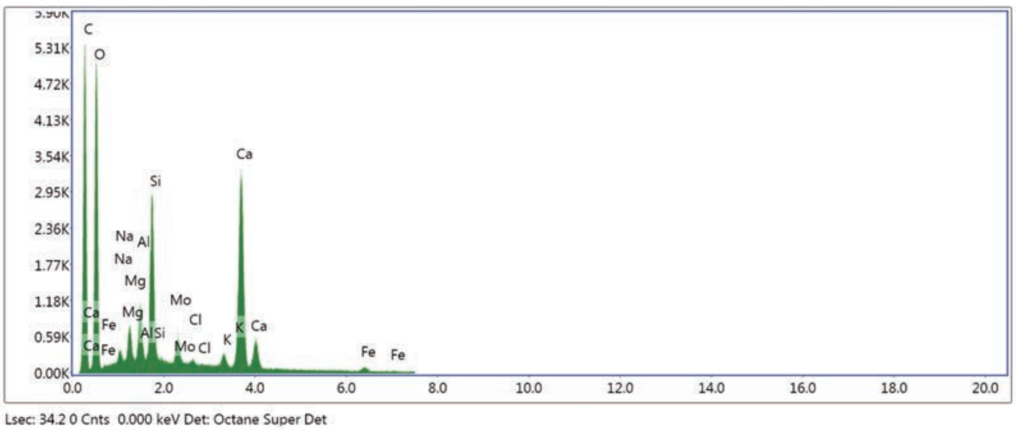
eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	64.93	73.34	5612.9	5.04	0.43	1.03	0.99	0.65	1.00
O K	28.70	24.34	1397.5	9.77	0.05	0.98	1.01	0.20	1.00
NaK	0.27	0.16	39.7	19.01	0.00	0.88	1.03	0.54	1.00
MgK	0.26	0.14	61.4	13.16	0.00	0.89	1.03	0.70	1.00
AlK	0.45	0.23	118.6	7.80	0.00	0.86	1.04	0.82	1.01
SiK	0.87	0.42	244.6	5.10	0.01	0.88	1.04	0.90	1.01
MoL	0.74	0.10	87.9	16.45	0.01	0.65	1.23	1.13	1.04
ClK	0.13	0.05	27.1	31.56	0.00	0.81	1.06	1.00	1.03
K K	0.24	0.08	39.2	19.63	0.00	0.81	1.06	1.02	1.06
CaK	3.25	1.10	424.4	3.78	0.03	0.82	1.07	1.02	1.03
FeK	0.17	0.04	8.6	58.34	0.00	0.72	1.07	1.01	1.17

TUMA_03 EDS Spectra

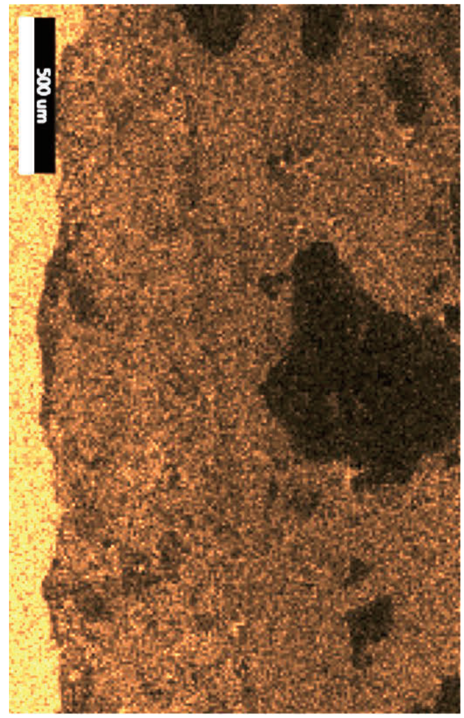
kV: 15 Mag: 60 Takeoff: 34 Live Time(s): 34.2 Amp Time(μs): 1.92 Resolution:(eV)135.3

Phase: CaK/O K/C K/SiK/AlK

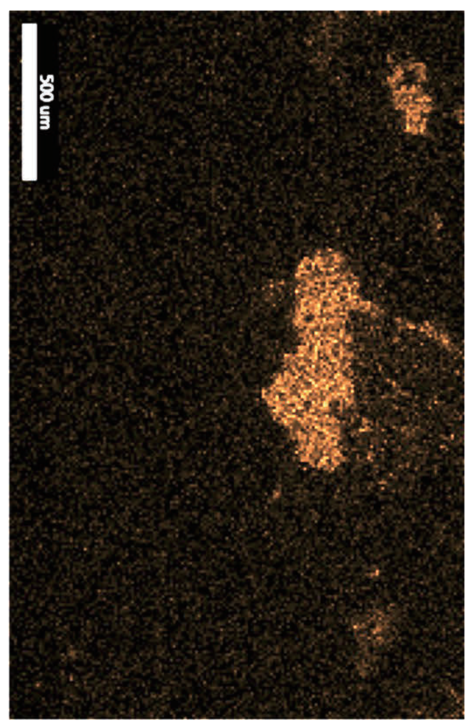


eZAF Smart Quant Results

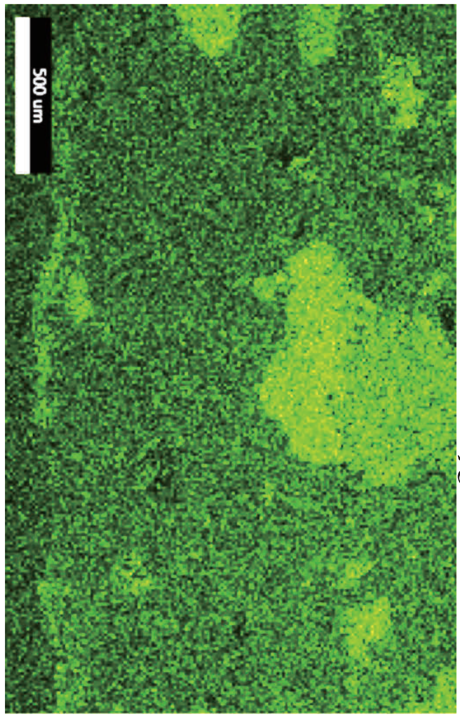
Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	34.02	47.38	2021.3	7.86	0.14	1.07	0.96	0.40	1.00
O K	38.03	39.76	2195.6	9.57	0.08	1.02	0.98	0.21	1.00
NaK	0.52	0.38	77.3	14.38	0.00	0.92	1.01	0.47	1.00
MgK	1.09	0.75	268.9	7.26	0.01	0.94	1.01	0.64	1.01
AlK	1.72	1.07	474	5.38	0.01	0.90	1.02	0.76	1.01
SiK	5.02	2.99	1484	3.63	0.04	0.92	1.03	0.84	1.01
MoL	1.74	0.30	220.3	9.94	0.01	0.69	1.22	1.07	1.03
ClK	0.24	0.11	52.8	21.65	0.00	0.85	1.04	0.95	1.04
K K	0.82	0.35	149.5	10.50	0.01	0.85	1.05	0.99	1.08
CaK	15.90	6.64	2266.7	2.20	0.14	0.86	1.05	1.00	1.02
FeK	0.90	0.27	47.3	18.83	0.01	0.76	1.06	1.00	1.08



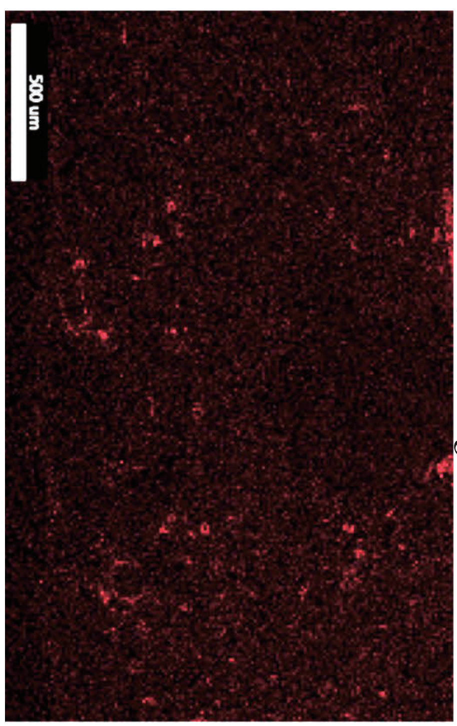
TUMA_03 EDS Calcium



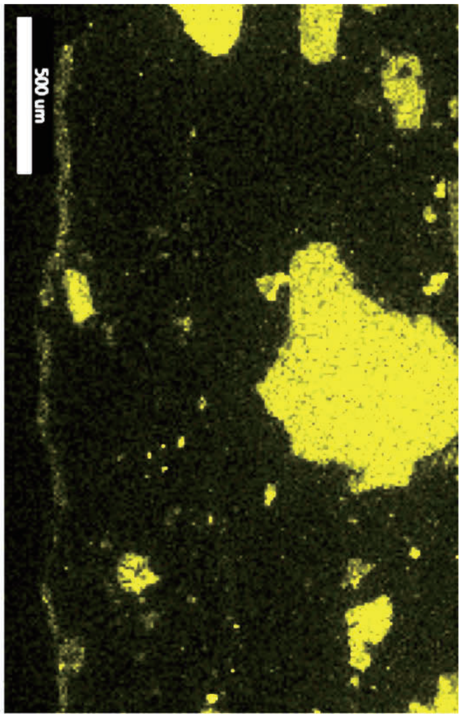
TUMA_03 EDS Sodium



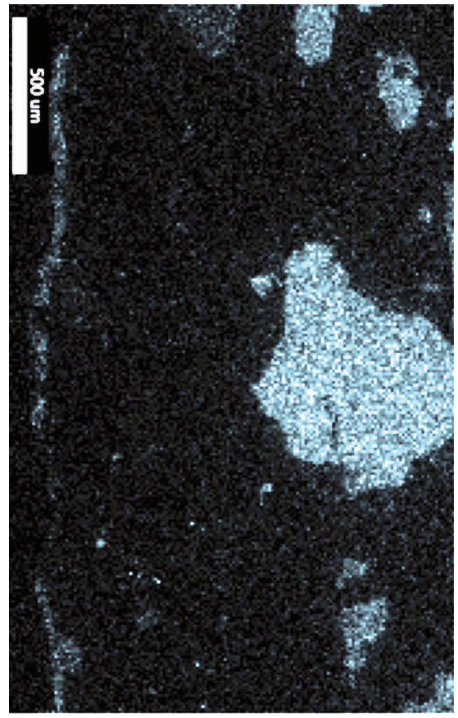
TUMA_03 EDS Oxygen



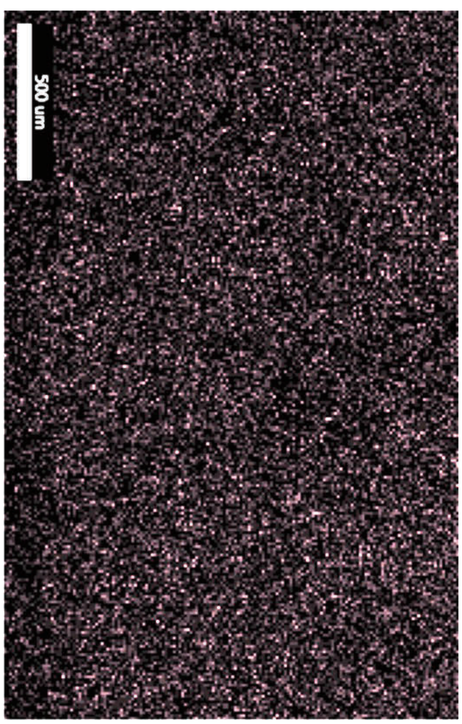
TUMA_03 EDS Magnesium



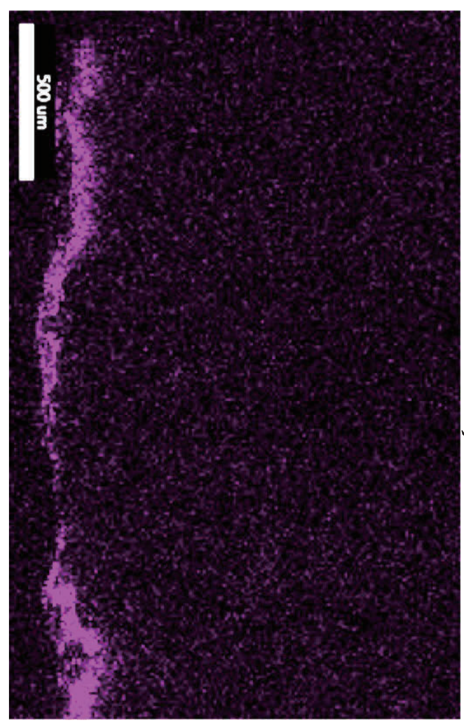
TUMA_03 EDS Silicon



TUMA_03 EDS Aluminum

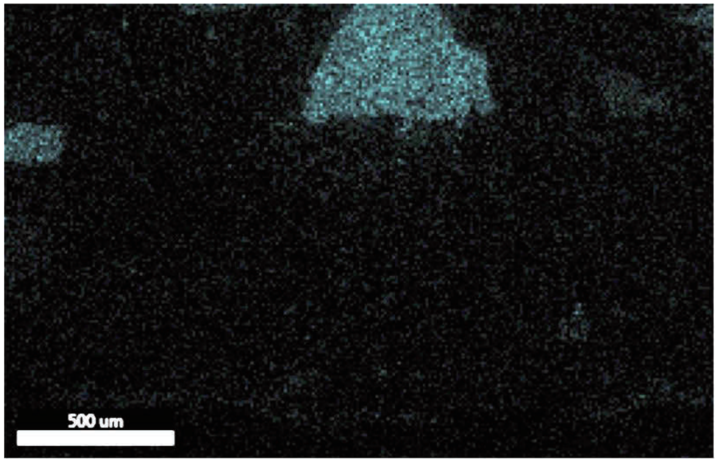


TUMA_03 EDS Chlorine

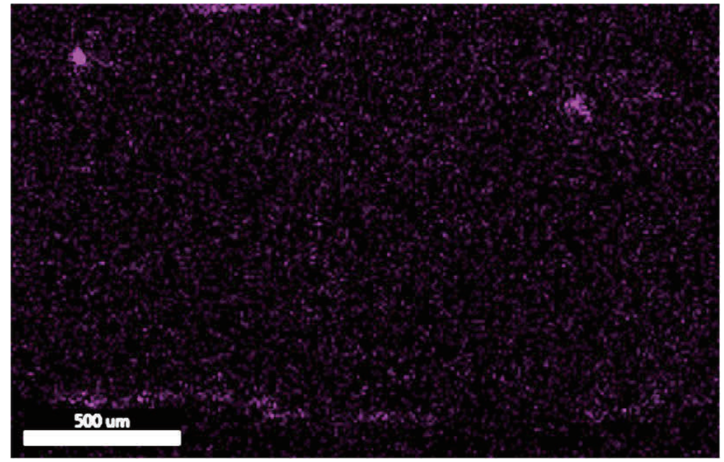


TUMA_03 EDS Molybedenum

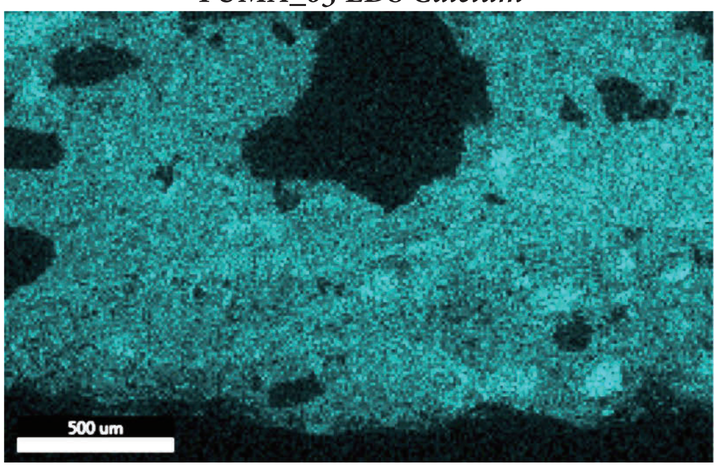
TUMA_03 EDS Potassium



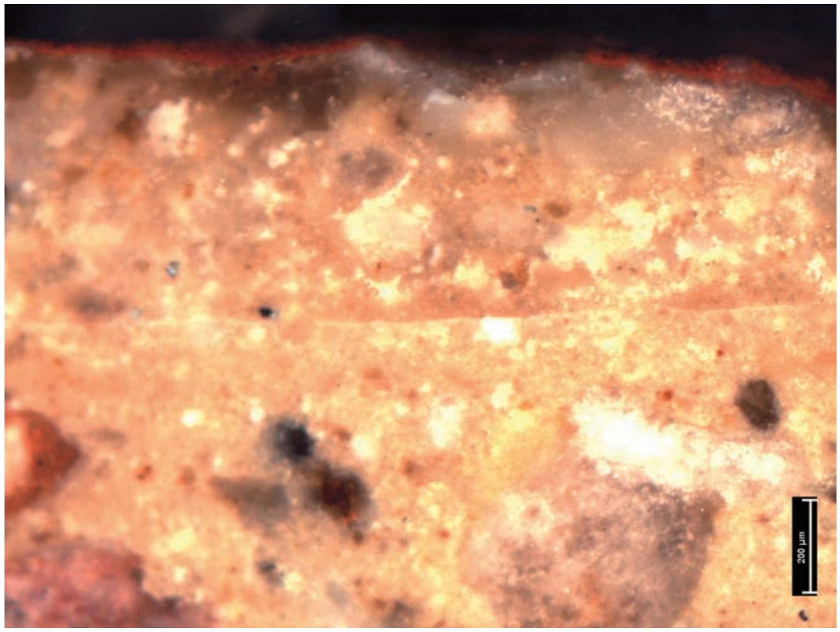
TUMA_03 EDS Iron

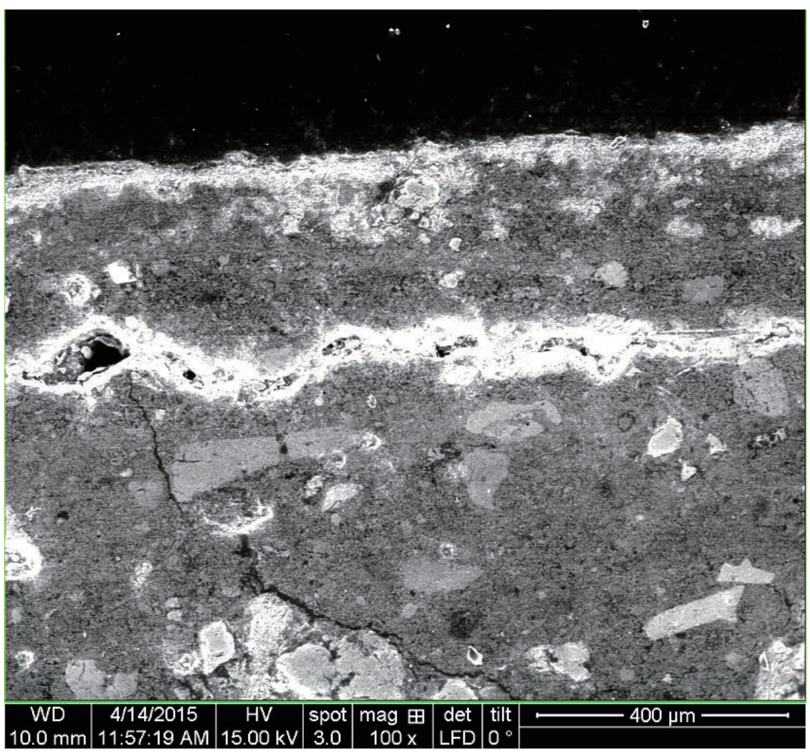


TUMA_03 EDS Calcium



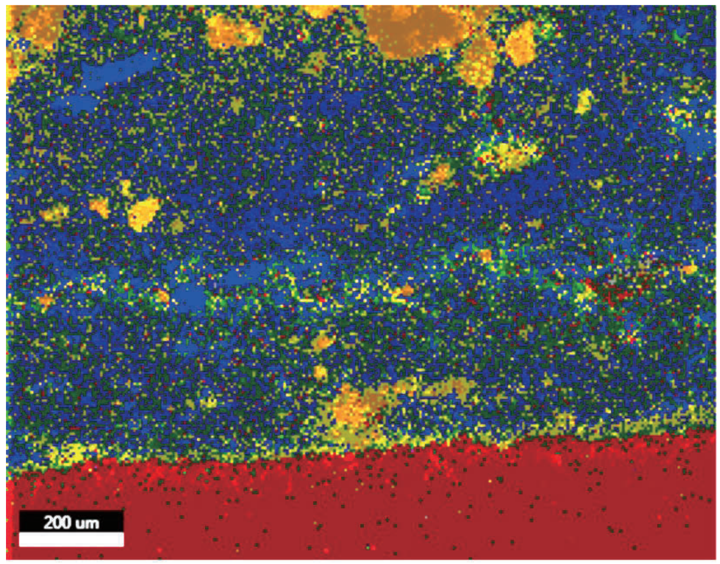
Singh Nanotechnology Center, University of Pennsylvania
TUMA_12 SEM-EDS Data

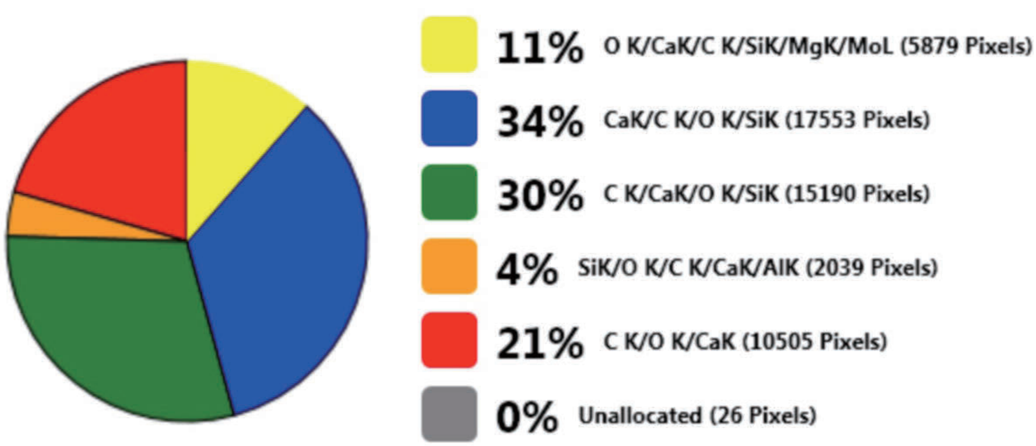

TUMA_12 in visible light at 40x

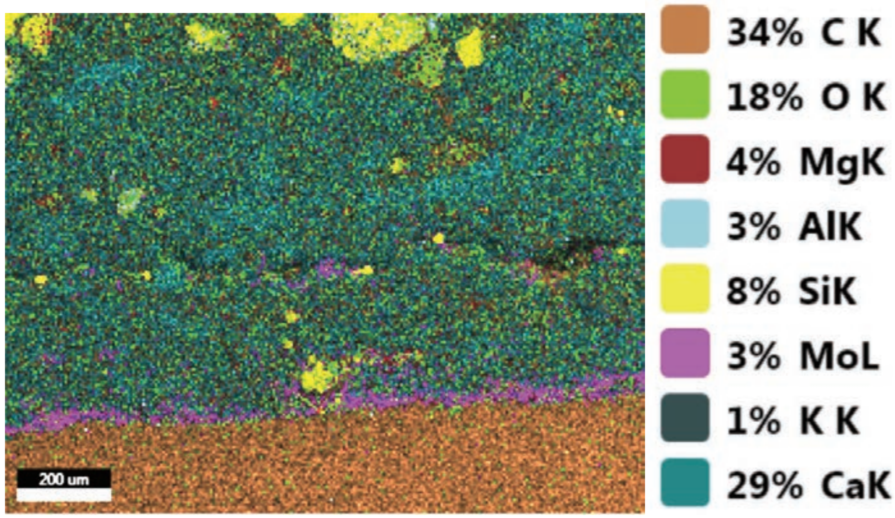


TUMA_12 backscattered electron image from SEM

TUMA_03 Elemental Mapping



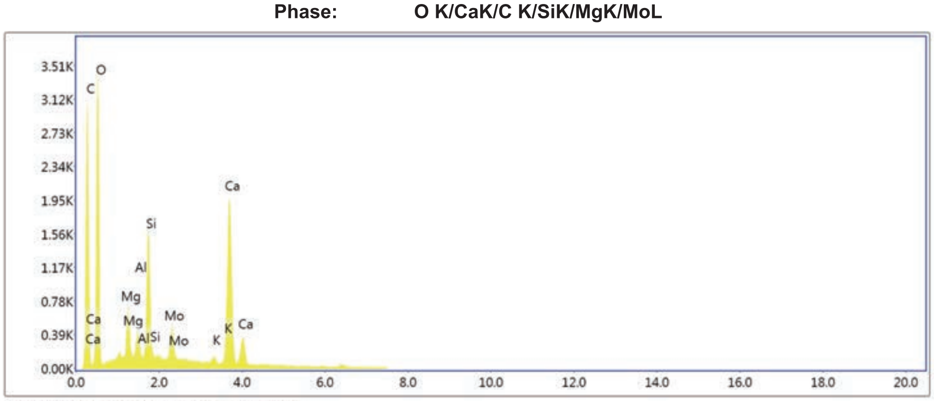




TUMA_12 EDS Spectra (1 of 6)

kV: 15 Mag: 200 Takeoff: 34.1 Live Time(s): 20 Amp Time(µs): 1.92 Resolution:(eV)135.:

Phase: O K/CaK/C K/SiK/MgK/MoL



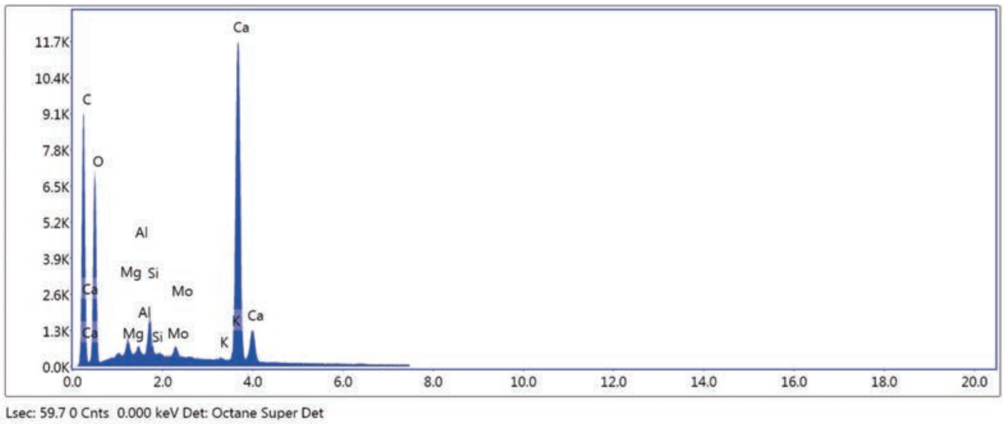
eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	32.99	45.81	2151.3	8.02	0.15	1.07	0.96	0.41	1.00
O K	40.62	42.35	2529.6	9.62	0.09	1.02	0.98	0.21	1.00
MgK	1.91	1.31	498.9	6.77	0.01	0.94	1.01	0.64	1.01
AlK	1.09	0.67	315.6	6.74	0.01	0.90	1.02	0.75	1.01
SiK	4.40	2.61	1377.3	3.95	0.03	0.92	1.03	0.84	1.01
MoL	2.71	0.47	363.8	9.10	0.02	0.69	1.22	1.07	1.03
K K	0.52	0.22	100	13.71	0.00	0.85	1.05	0.99	1.07
CaK	15.76	6.56	2376.9	2.34	0.14	0.86	1.05	1.00	1.02

TUMA_12 EDS Spectra (2 of 6)

kV: 15 Mag: 200 Takeoff: 34.1 Live Time(s): 59.7 Amp Time(μs): 1.92 Resolution:(eV)135.3

Phase: CaK/C K/O K/SiK



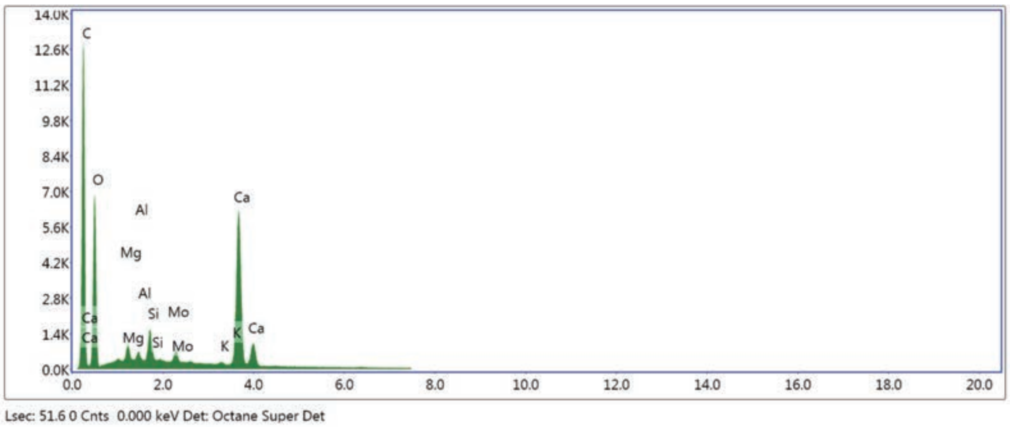
eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	28.41	42.55	2168.1	6.64	0.16	1.09	0.95	0.51	1.00
O K	37.02	41.62	1760.3	9.87	0.07	1.04	0.97	0.17	1.00
MgK	0.68	0.50	160.7	8.03	0.00	0.95	1.01	0.61	1.01
AlK	0.30	0.20	80.6	10.71	0.00	0.91	1.01	0.74	1.01
SiK	1.48	0.95	439	4.53	0.01	0.93	1.02	0.84	1.02
MoL	0.88	0.17	116.8	16.53	0.01	0.70	1.21	1.09	1.06
K K	0.14	0.06	27.6	23.47	0.00	0.86	1.05	1.00	1.16
CaK	31.10	13.96	4477.1	1.93	0.28	0.88	1.05	1.01	1.01

TUMA_12 EDS Spectra (3 of 6)

kV: 15 Mag: 200 Takeoff: 34.1 Live Time(s): 51.6 Amp Time(μs): 1.92 Resolution:(eV)135.3

Phase: C K/CaK/O K/SiK



eZAF Smart Quant Results

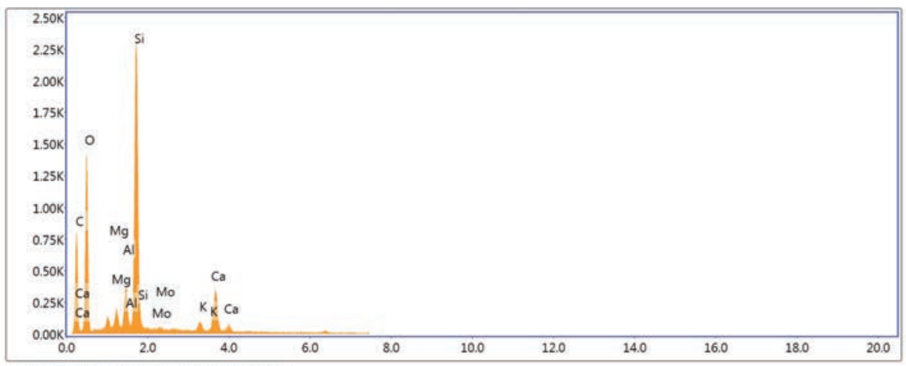
Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	40.47	54.12	3381.7	6.24	0.23	1.06	0.97	0.53	1.00
O K	36.09	36.23	1972	9.68	0.07	1.01	0.99	0.19	1.00
MgK	0.85	0.56	221.7	7.09	0.01	0.93	1.02	0.64	1.01
AlK	0.43	0.26	125.9	8.11	0.00	0.89	1.02	0.77	1.01
SiK	1.49	0.85	473.2	4.27	0.01	0.91	1.03	0.86	1.01
MoL	1.27	0.21	175.2	8.73	0.01	0.68	1.22	1.10	1.04
K K	0.29	0.12	58.5	15.09	0.00	0.84	1.05	1.00	1.12
CaK	19.10	7.65	2885.5	2.07	0.17	0.85	1.06	1.01	1.02

TUMA_12 EDS Spectra (4 of 6)

EDAX TEAM

kV: 15 Mag: 200 Takeoff: 34.1 Live Time(s): 6.9 Amp Time(μs): 1.92 Resolution:(eV)135.3

Phase: **SiK/O K/C K/CaK/AlK**



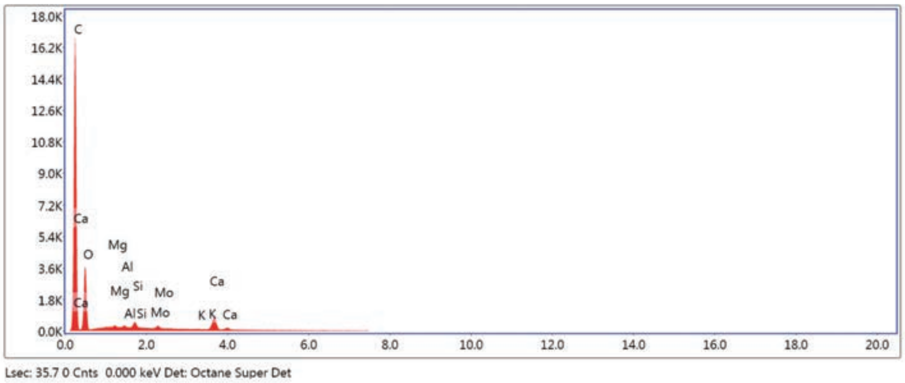
eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	34.78	46.94	1578.2	10.42	0.10	1.06	0.97	0.27	1.00
O K	37.94	38.44	2972.4	9.56	0.09	1.01	0.99	0.25	1.00
MgK	0.68	0.45	203.5	14.80	0.00	0.93	1.02	0.69	1.01
AlK	2.07	1.24	687.6	6.61	0.02	0.89	1.03	0.80	1.02
SiK	17.39	10.03	6011	3.27	0.14	0.91	1.03	0.87	1.01
MoL	0.01	0.00	1.3	73.26	0.00	0.68	1.22	1.01	1.02
K K	0.76	0.32	150.9	16.95	0.01	0.84	1.06	0.98	1.04
CaK	6.37	2.58	1024.3	5.18	0.05	0.85	1.06	0.99	1.02

TUMA_12 EDS Spectra (5 of 6)

kV: 15 Mag: 200 Takeoff: 34.1 Live Time(s): 35.7 Amp Time(µs): 1.92 Resolution:(eV)135.3

Phase: C K/O K/CaK



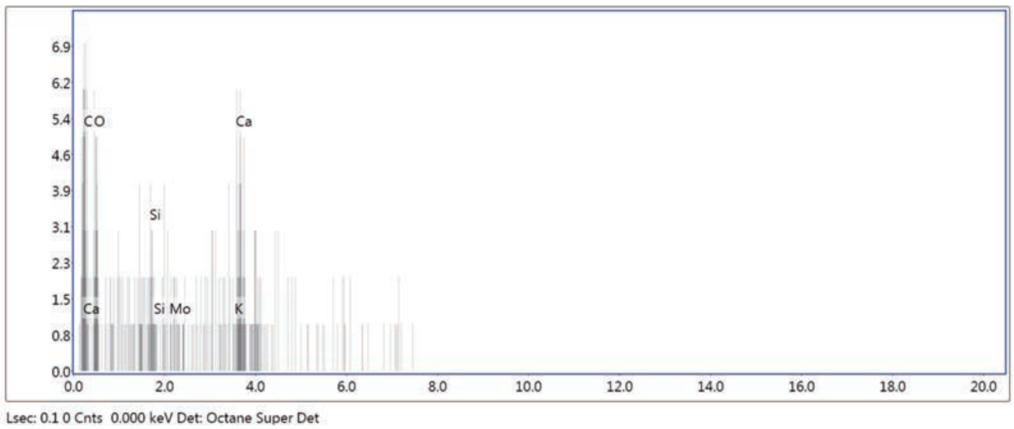
eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	65.02	73.26	6351.1	4.79	0.45	1.03	0.99	0.67	1.00
O K	29.16	24.67	1549.1	9.73	0.06	0.97	1.01	0.20	1.00
MgK	0.40	0.22	105.3	9.51	0.00	0.89	1.03	0.70	1.00
AlK	0.32	0.16	91.2	9.22	0.00	0.86	1.04	0.82	1.01
SiK	0.70	0.34	215.7	5.15	0.01	0.88	1.04	0.90	1.01
MoL	0.72	0.10	93.6	15.25	0.01	0.65	1.23	1.13	1.04
K K	0.20	0.07	35.3	22.19	0.00	0.81	1.07	1.02	1.06
CaK	3.48	1.17	496.9	3.48	0.03	0.82	1.07	1.02	1.03

TUMA_12 EDS Spectra (6 of 6)

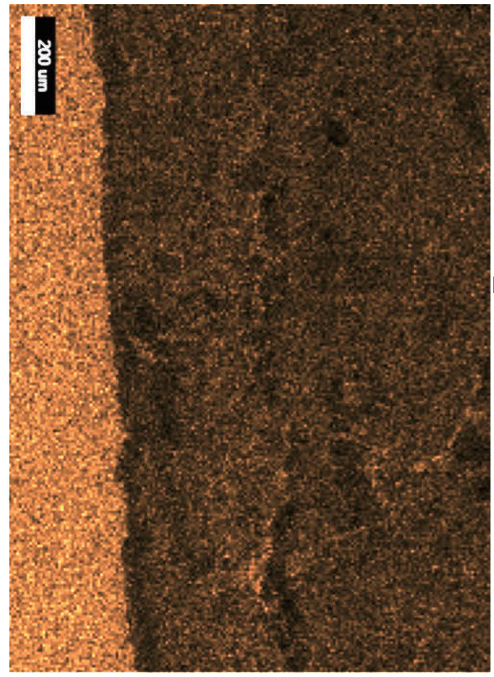
kV: 15 Mag: 200 Takeoff: 34.1 Live Time(s): 0.1 Amp Time(μs): 1.92 Resolution:(eV)135.3

Phase: Unallocated

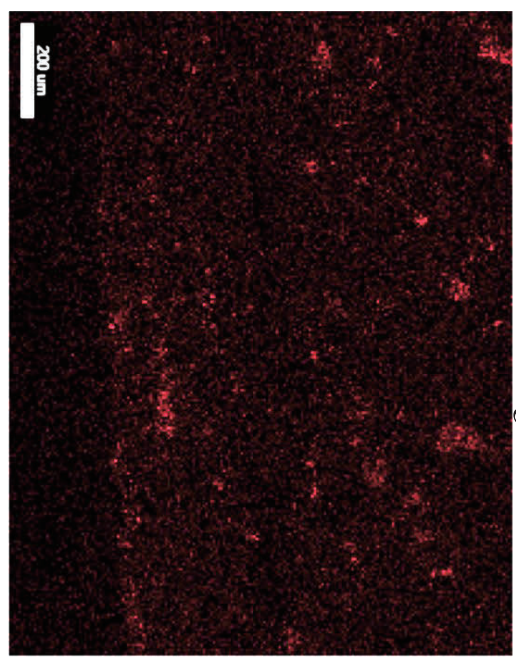


eZAF Smart Quant Results

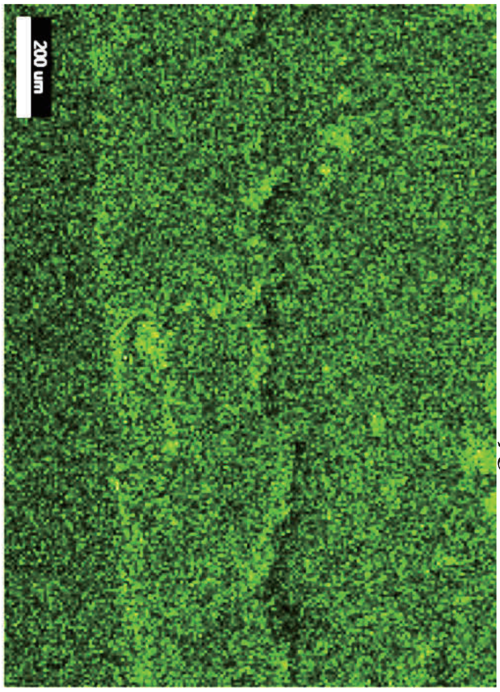
Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	34.34	48.98	789.7	99.99	0.16	1.08	0.96	0.43	1.00
O K	34.79	37.25	643.2	29.04	0.07	1.03	0.98	0.19	1.00
MgK	1.37	0.96	120.5	88.64	0.01	0.95	1.01	0.64	1.01
AlK	1.93	1.22	189.5	80.07	0.01	0.91	1.02	0.76	1.01
SiK	3.16	1.93	333.4	72.93	0.02	0.93	1.02	0.84	1.01
MoL	3.28	0.59	149.5	67.31	0.03	0.69	1.21	1.08	1.03
K K	3.33	1.46	214.9	73.70	0.03	0.86	1.05	0.99	1.07
CaK	17.81	7.61	897.4	27.35	0.16	0.87	1.05	0.99	1.01



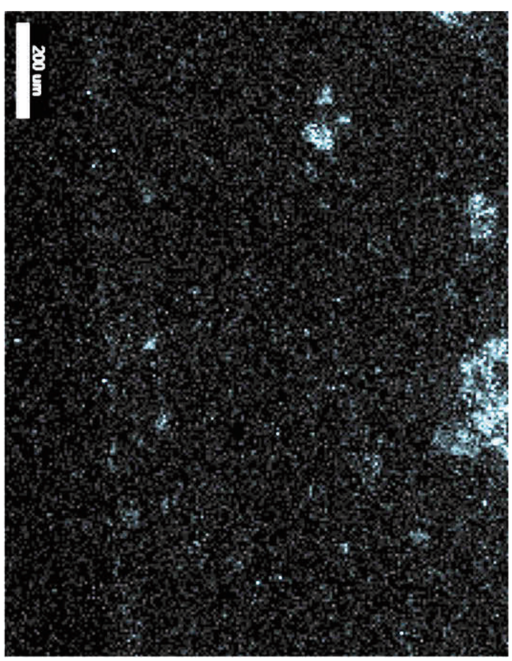
TUMA_12 EDS Carbon



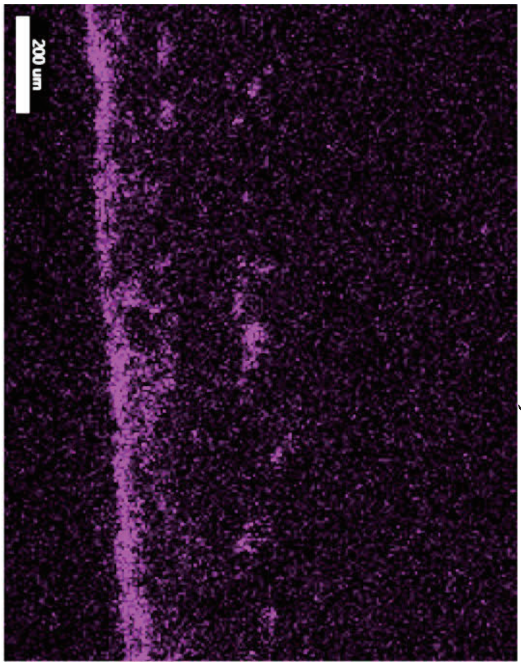
TUMA_12 EDS Magnesium



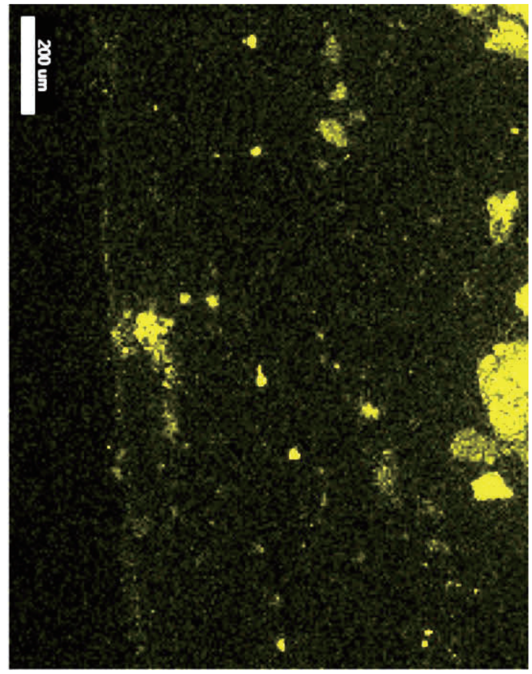
TUMA_12 EDS Oxygen



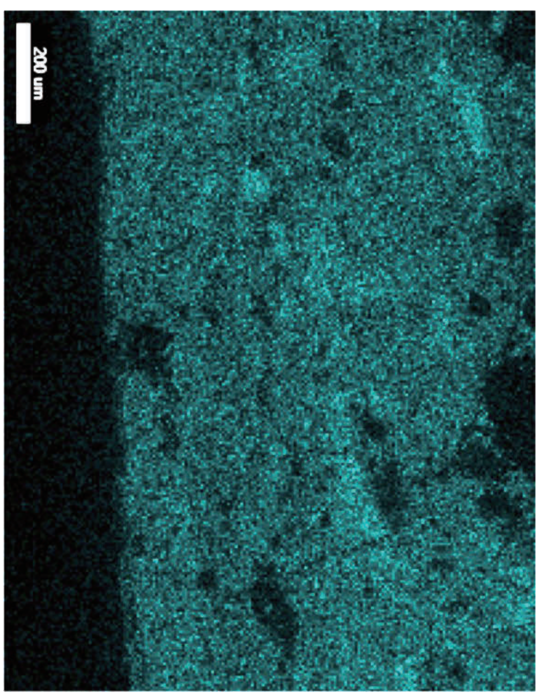
TUMA_12 EDS Aluminum



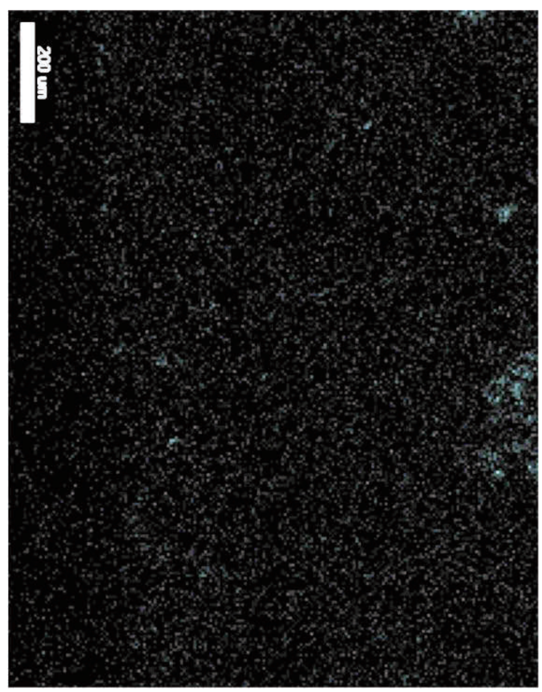
TUMA_12 EDS Molybdenum



TUMA_12 EDS Silicon

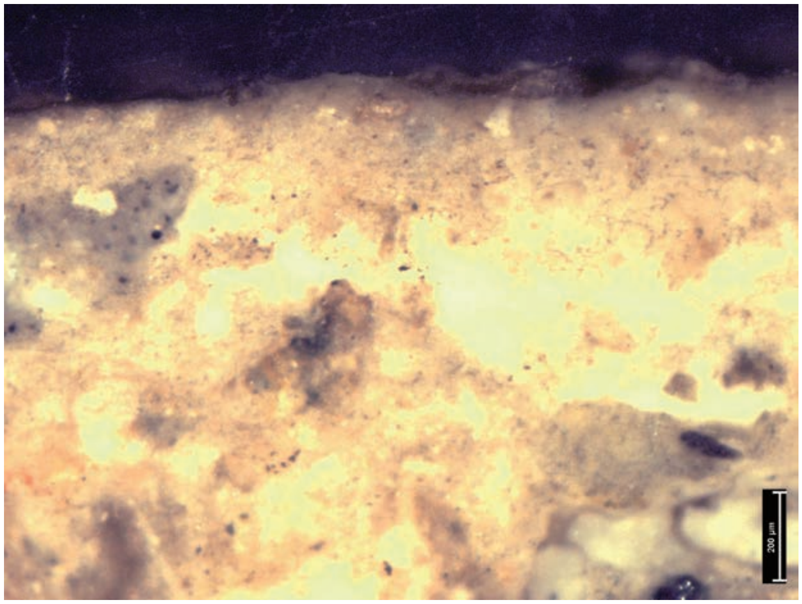


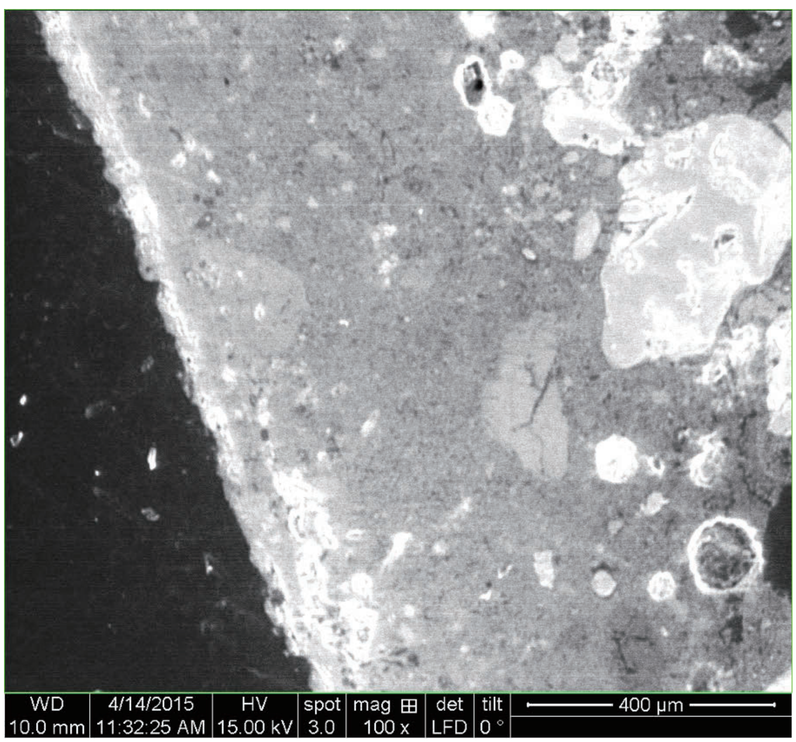
TUMA_12 EDS Silicon



TUMA_12 EDS Potassium

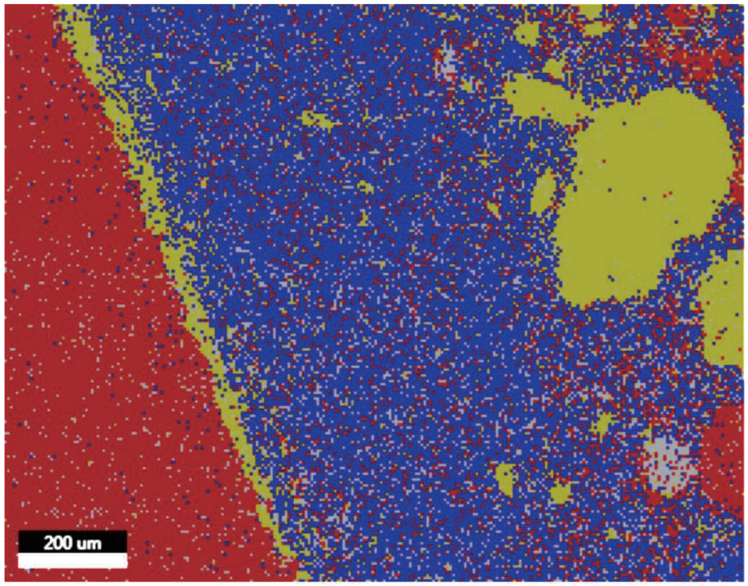
Singh Nanotechnology Center, University of Pennsylvania
TUMA_14 SEM-EDS Data

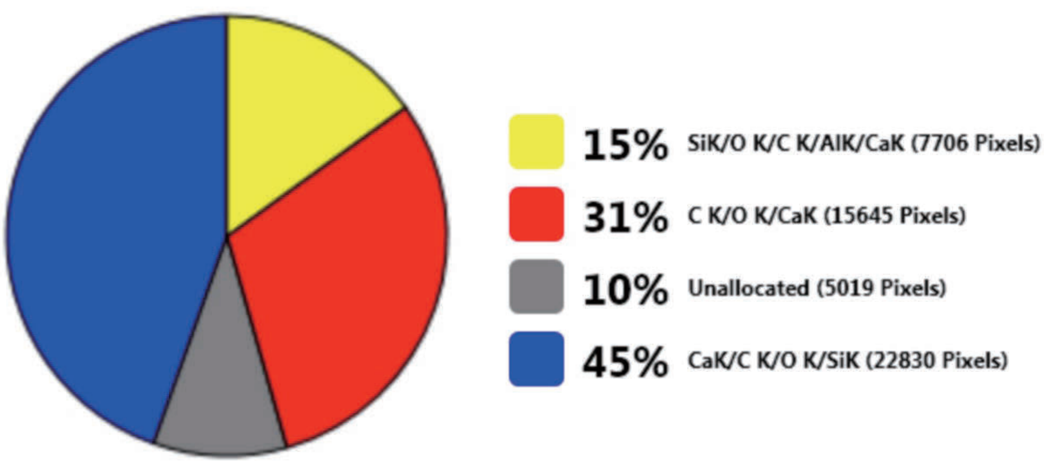

TUMA14_ in visible light at 40x



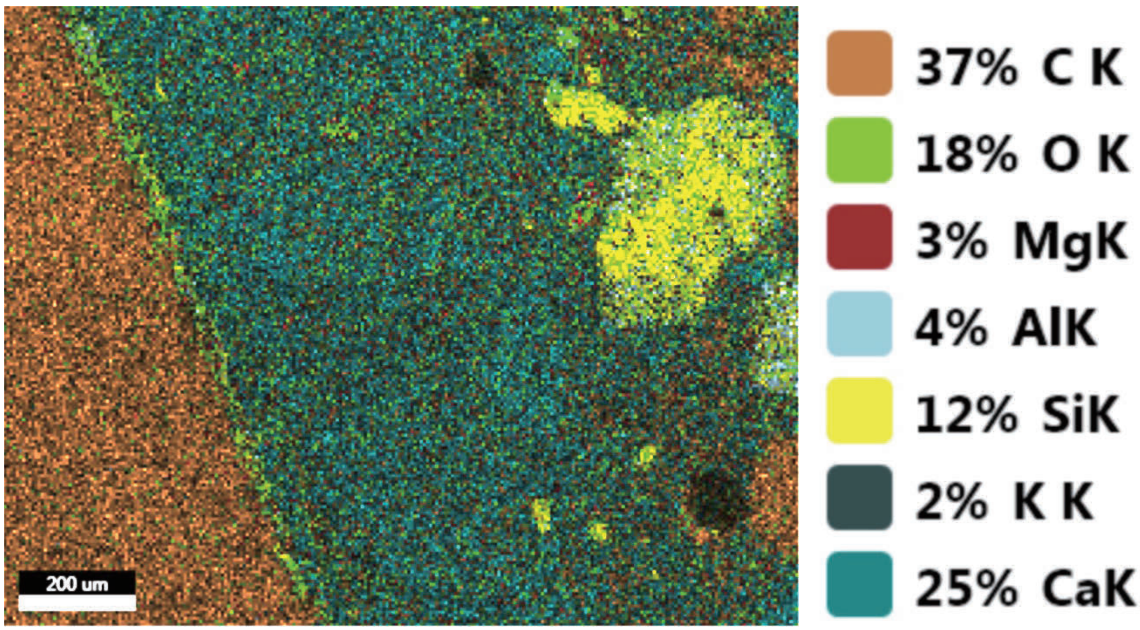
TUMA_14 backscattered electron image from SEM, note finish layer rotation

TUMA_14 Elemental Mapping





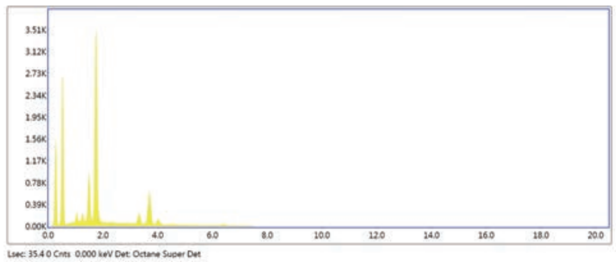
TUMA_14 Elemental Mapping



TUMA_14 EDS Data

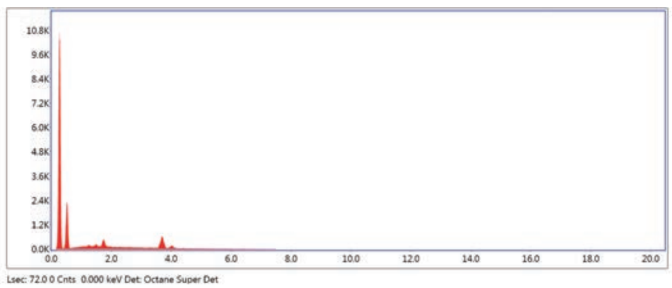
kV: 15 Mag: 200 Takeoff: 34 Live Time(s): 35.4 Amp Time(μs): 1.92 Resolution:(eV)135.3

Phase: SiK/O K/C K/AlK/CaK



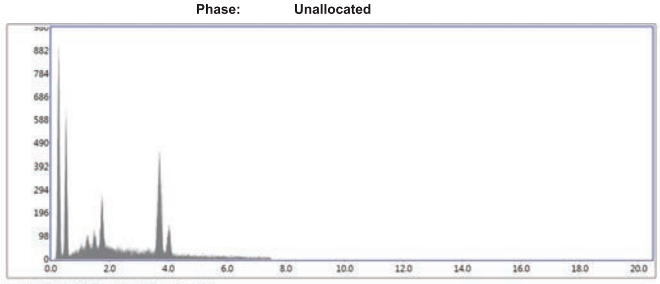
kV: 15 Mag: 200 Takeoff: 34 Live Time(s): 72 Amp Time(μs): 1.92 Resolution:(eV)135.3

Phase: C K/O K/CaK



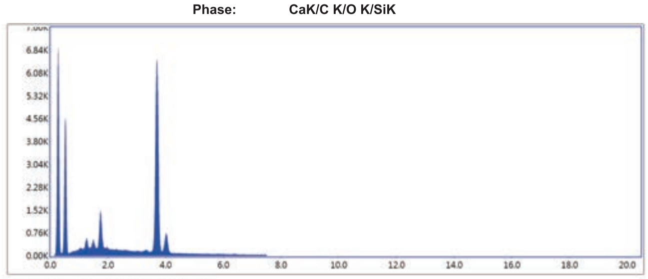
kV: 15 Mag: 200 Takeoff: 34 Live Time(s): 23.1 Amp Time(μs): 1.92 Resolution:(eV)135.3

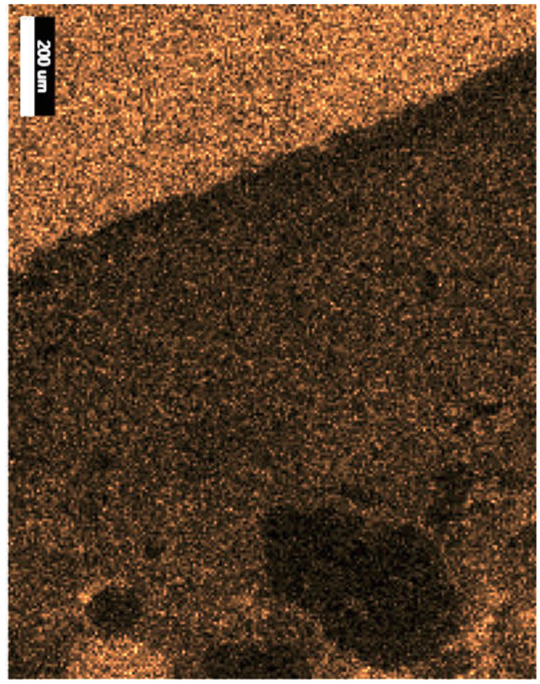
Phase: Unallocated



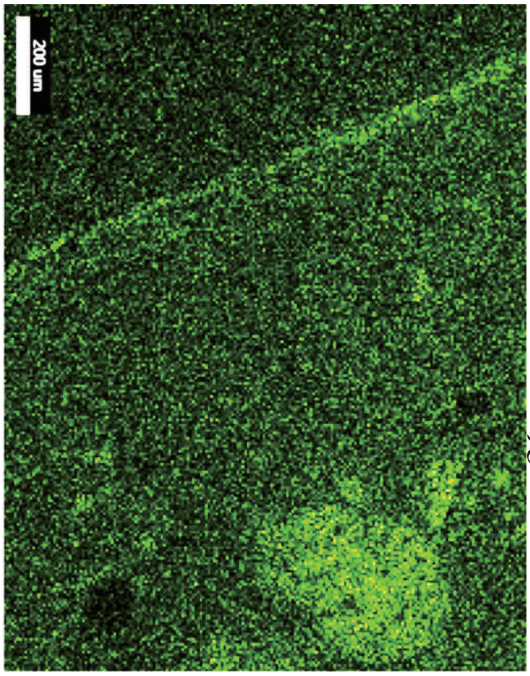
kV: 15 Mag: 200 Takeoff: 34 Live Time(s): 105 Amp Time(μs): 1.92 Resolution:(eV)135.3

Phase: CaK/C K/O K/SiK

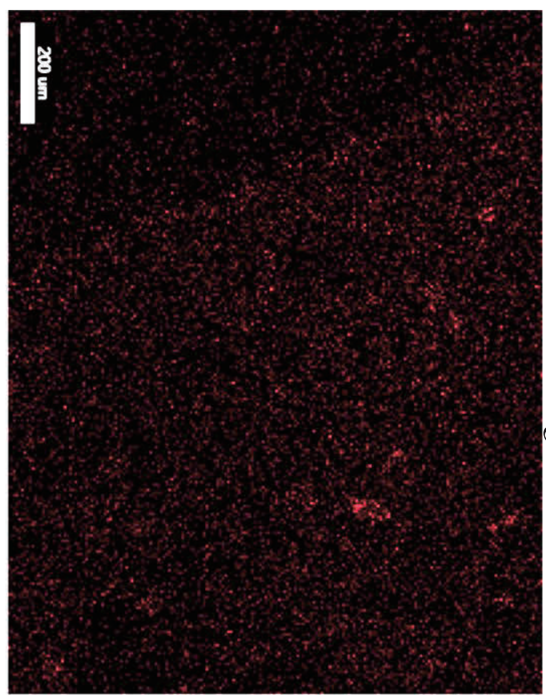




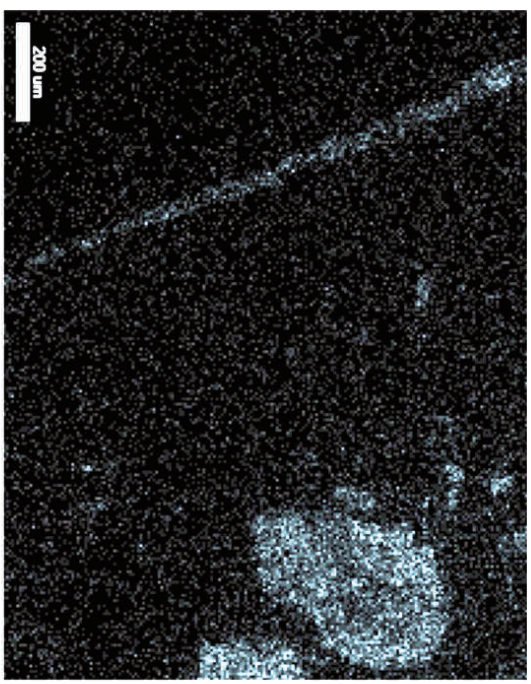
TUMA_14 EDS Carbon



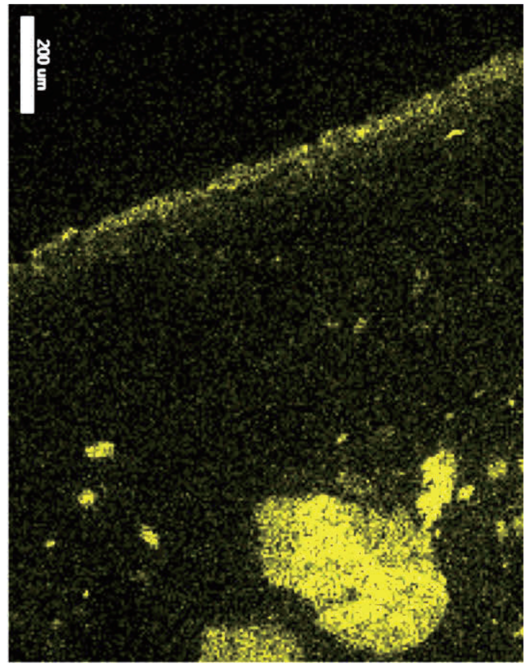
TUMA_14 EDS Oxygen



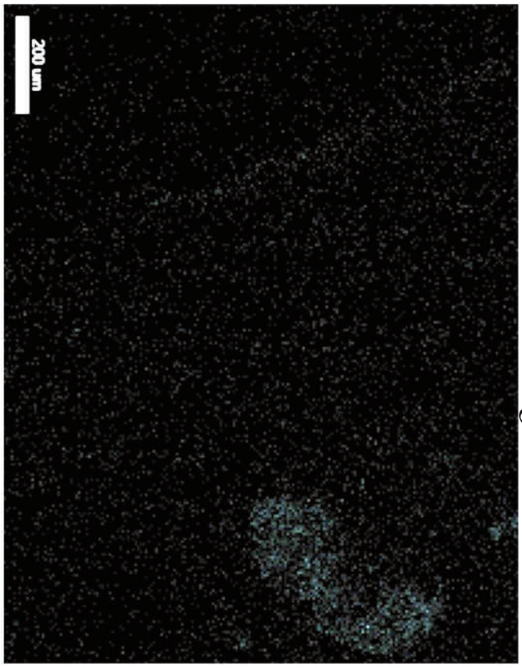
TUMA_14 EDS Magnesium



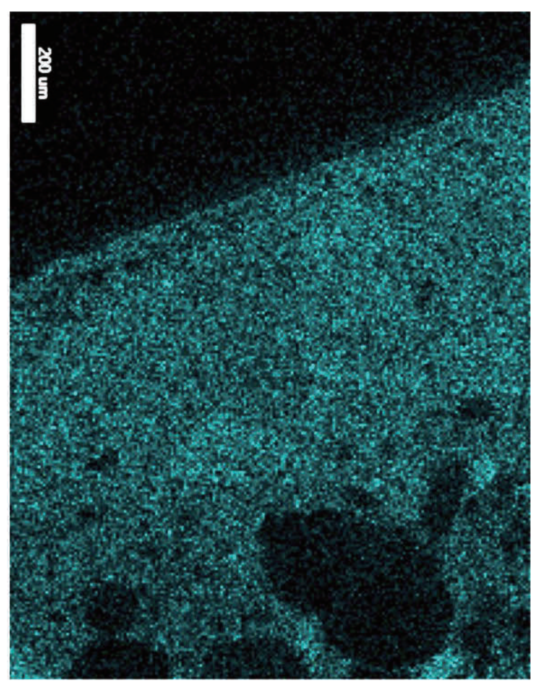
TUMA_14 EDS Aluminum



TUMA_14 EDS Silicon

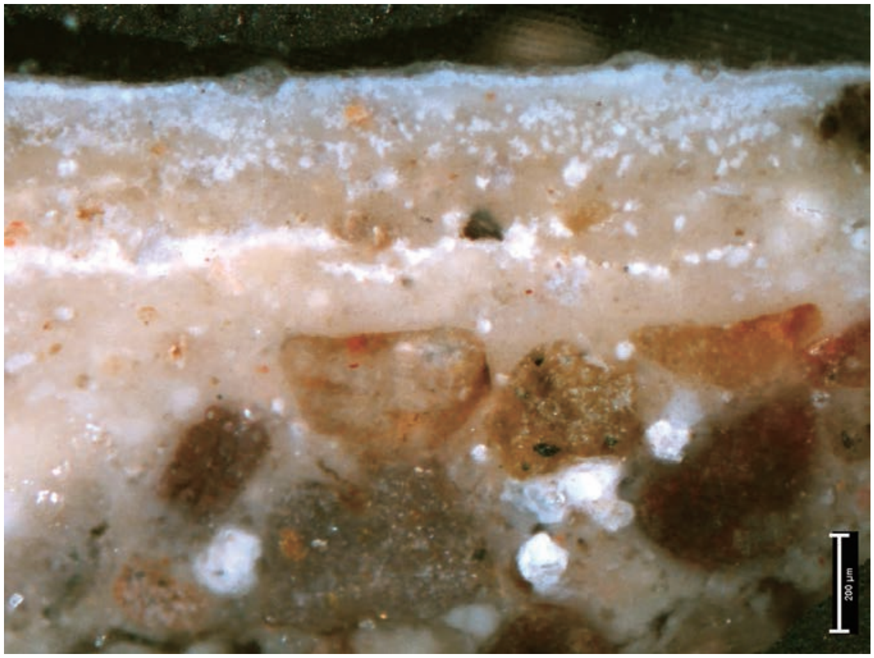


TUMA_14 EDS Magnesium

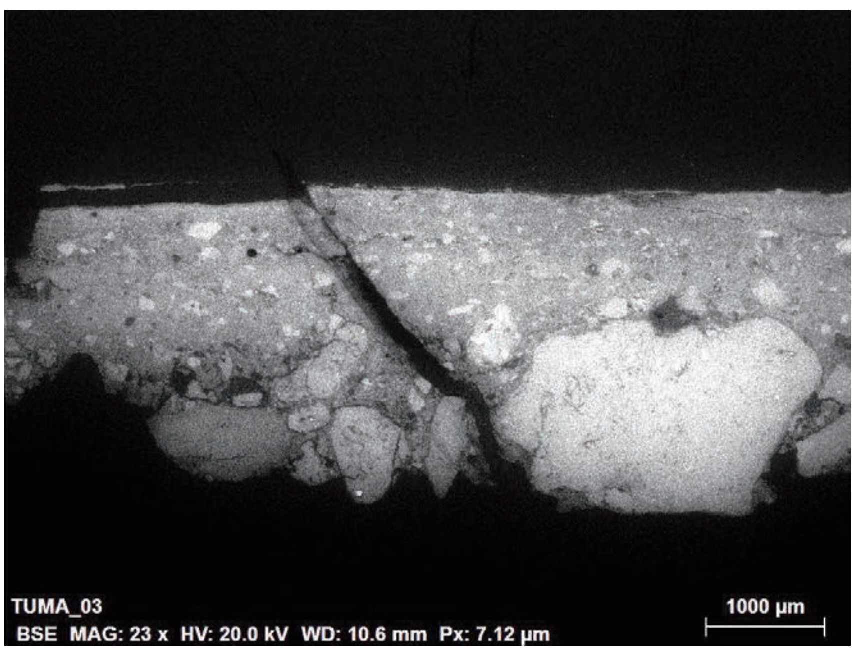


TUMA_14 EDS Calcium

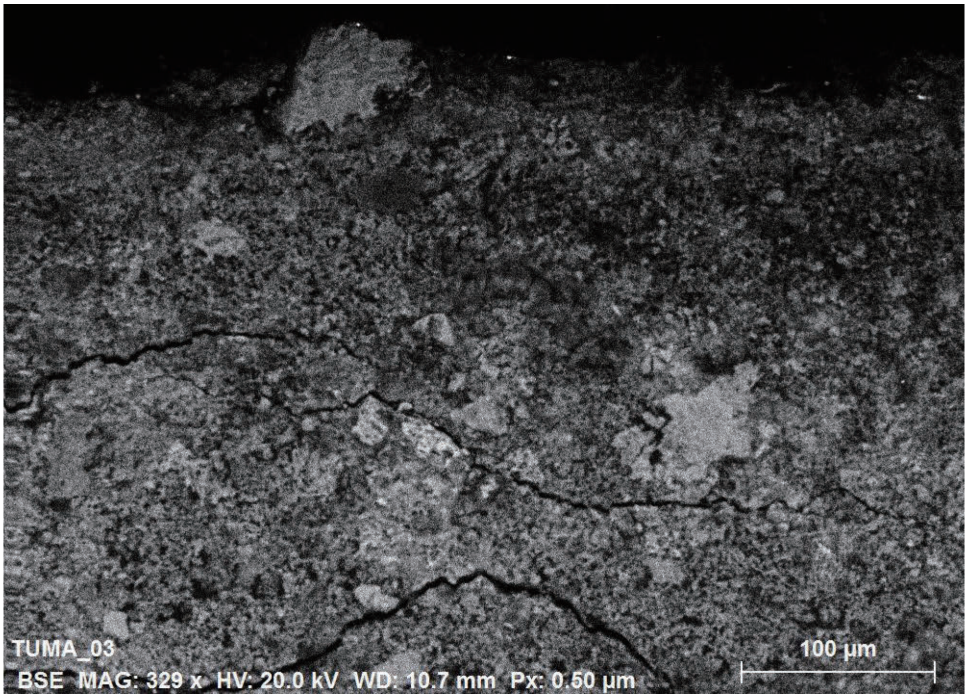
Scientific Research & Analysis Laboratory, Winterthur Museum
TUMA_03 SEM-EDS Data



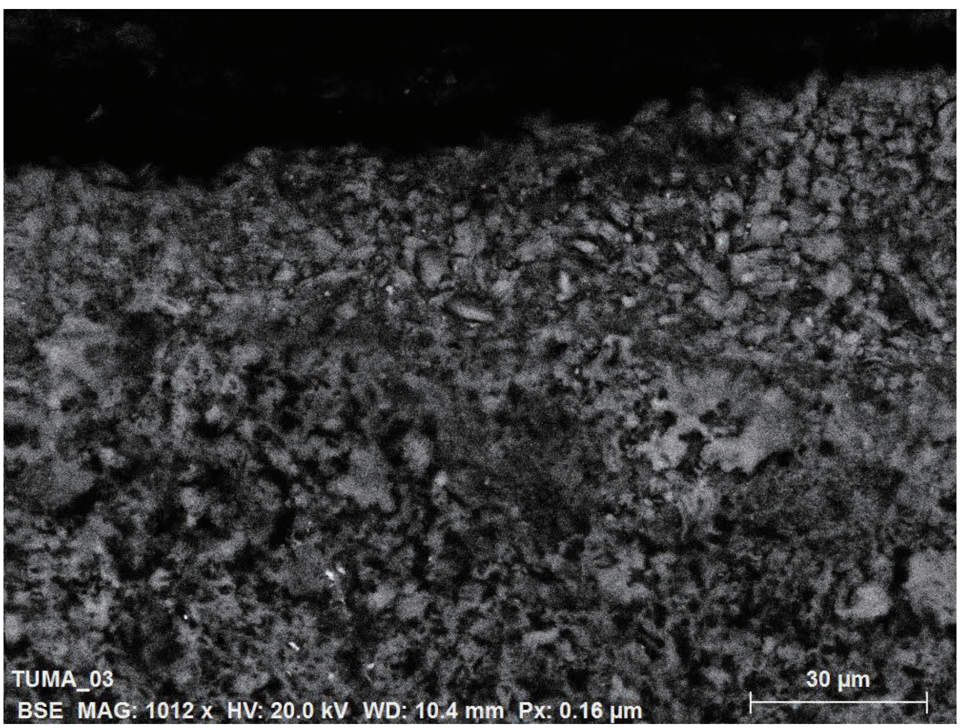
TUMA03 in visible light at 40x



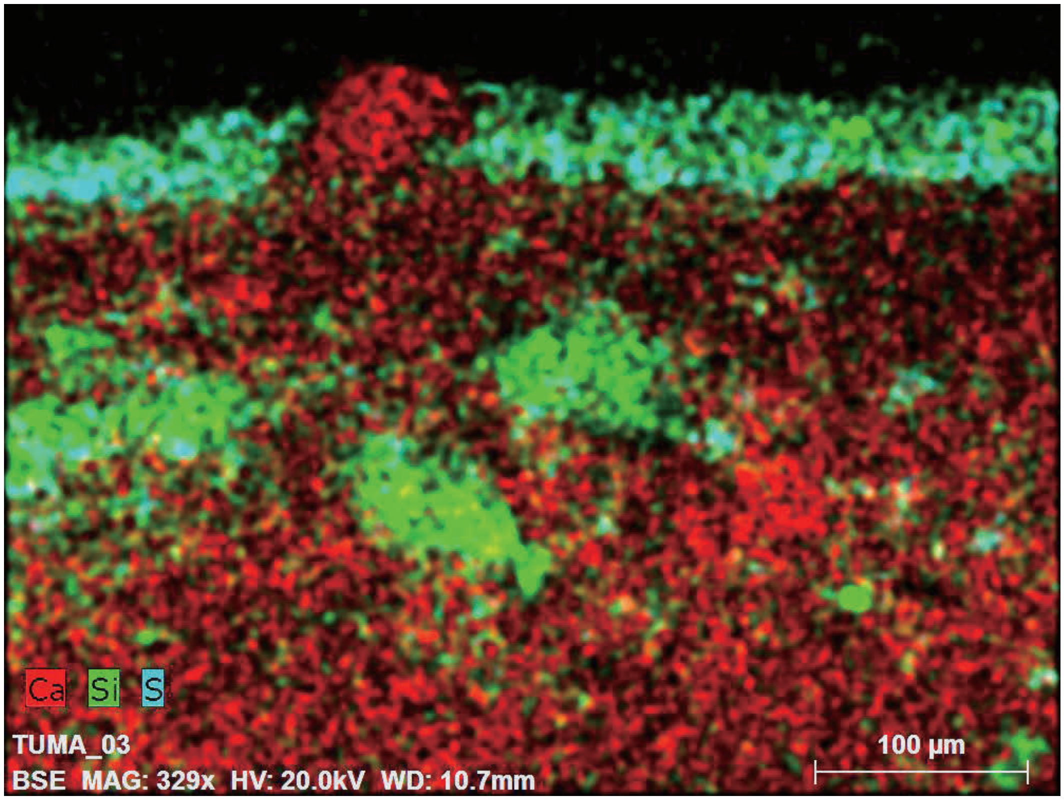
TUMA_03 backscattered electron image from SEM



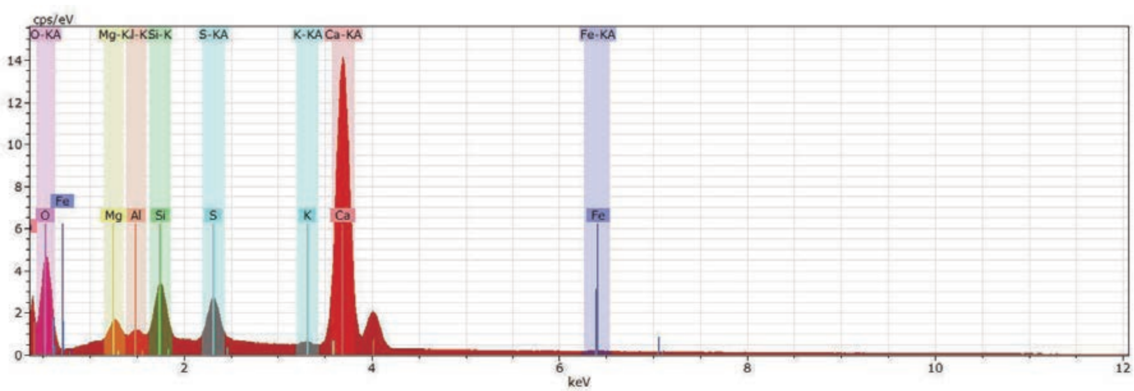
TUMA_03 backscattered electron image at 329x



TUMA_03 backscattered electron image at 1012x

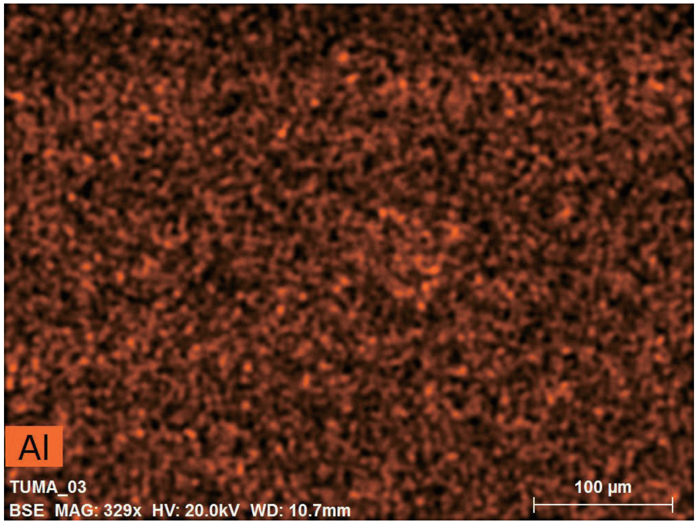


TUMA_03 most abundant elements at 329x

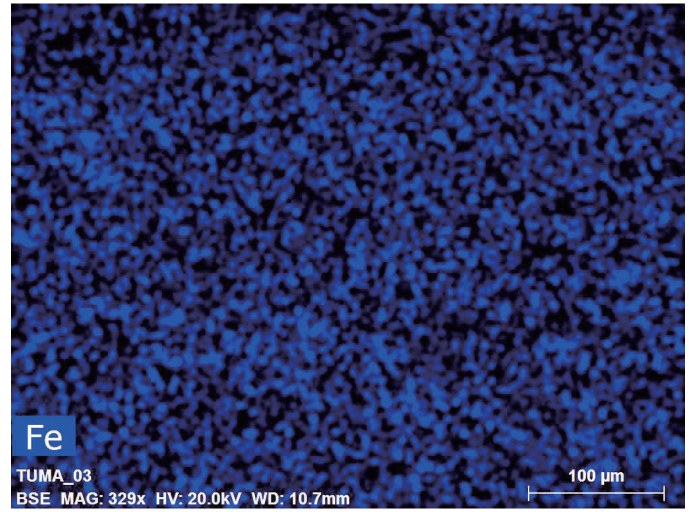


TUMA_03 elemental mapping

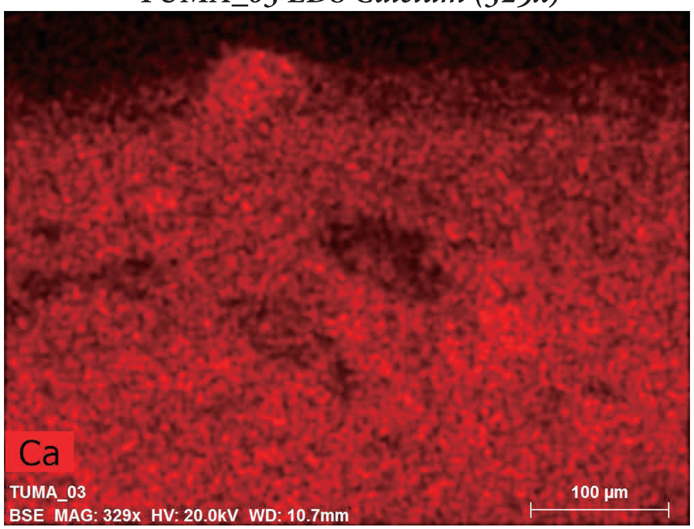
TUMA_03 EDS Aluminum (329x)



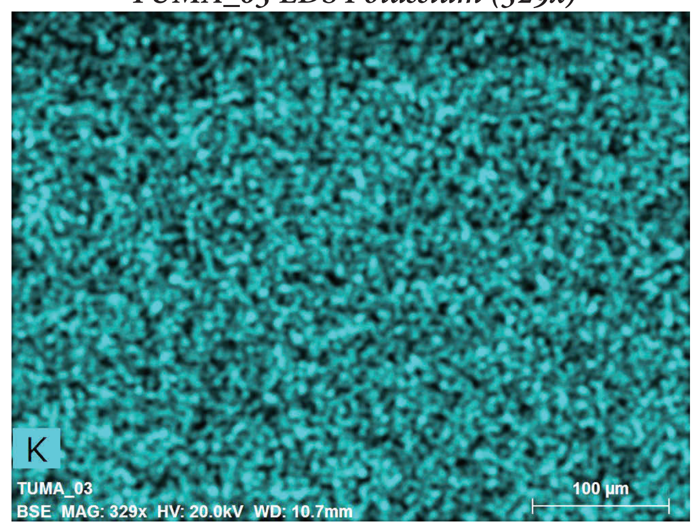
TUMA_03 EDS Iron (329x)



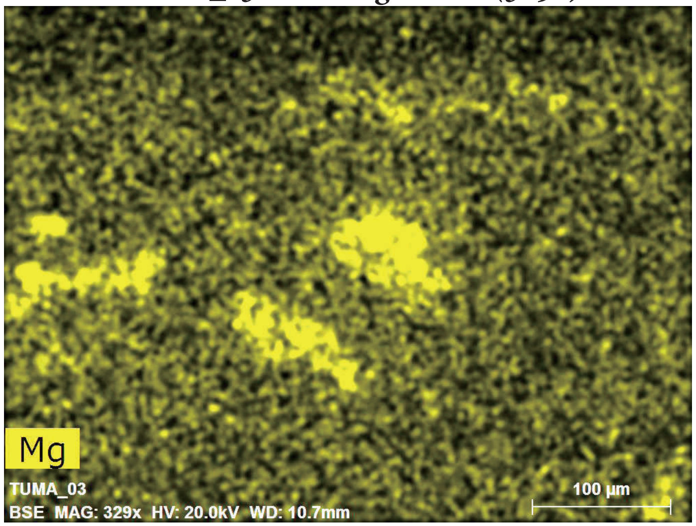
TUMA_03 EDS Calcium (329x)



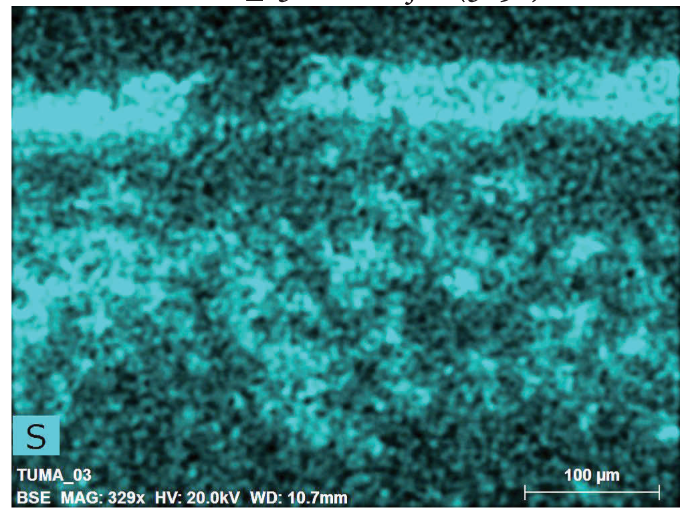
TUMA_03 EDS Potassium (329x)



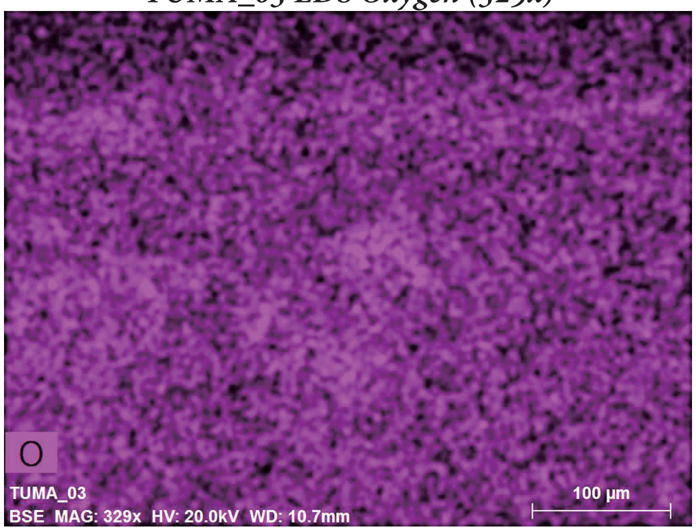
TUMA_03 EDS Magnesium (329x)



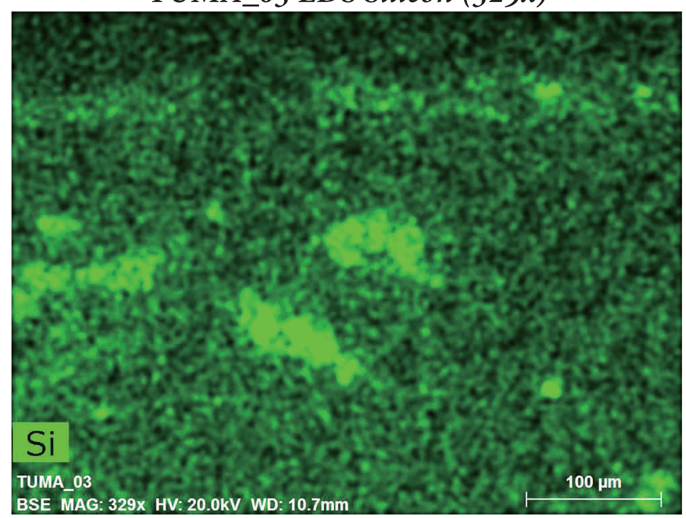
TUMA_03 EDS Sulfur (329x)

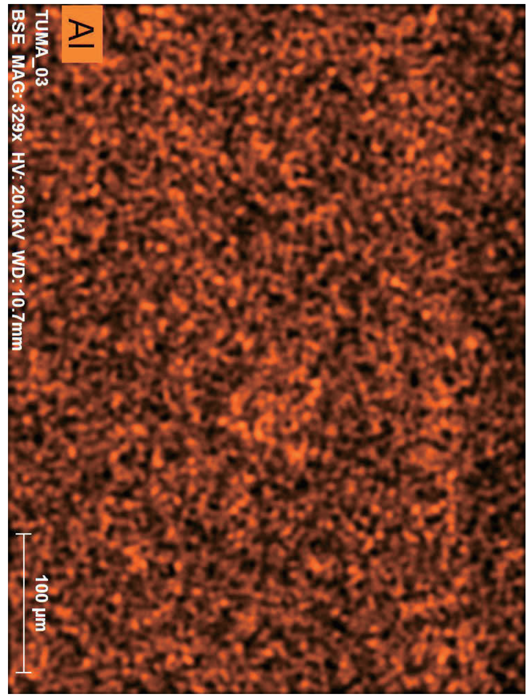


TUMA_03 EDS Oxygen (329x)

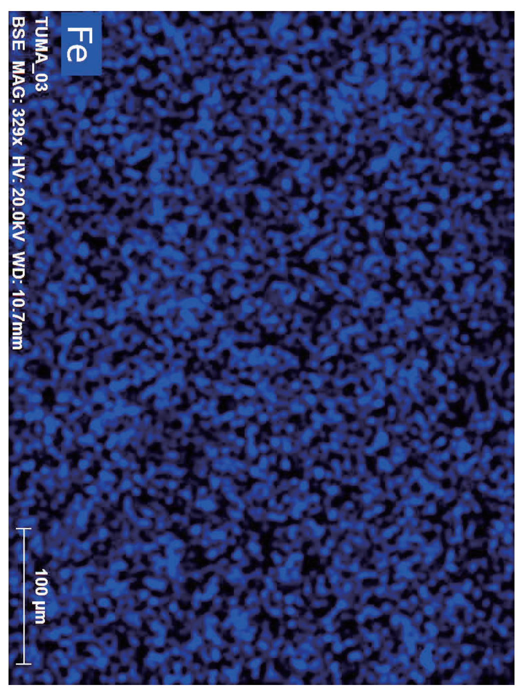


TUMA_03 EDS Silicon (329x)

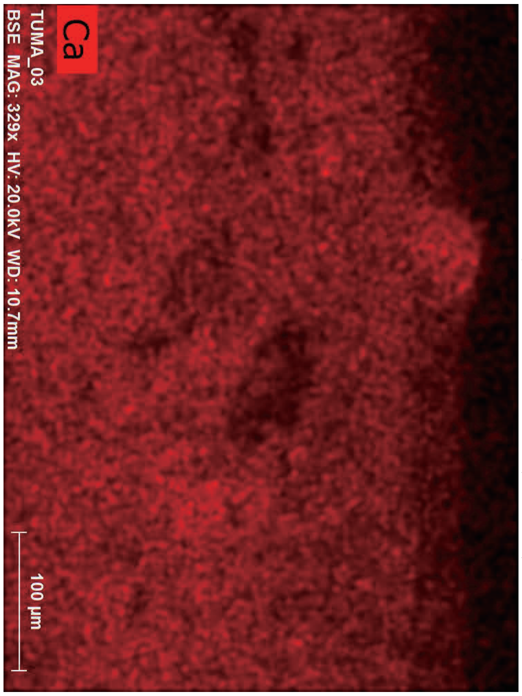




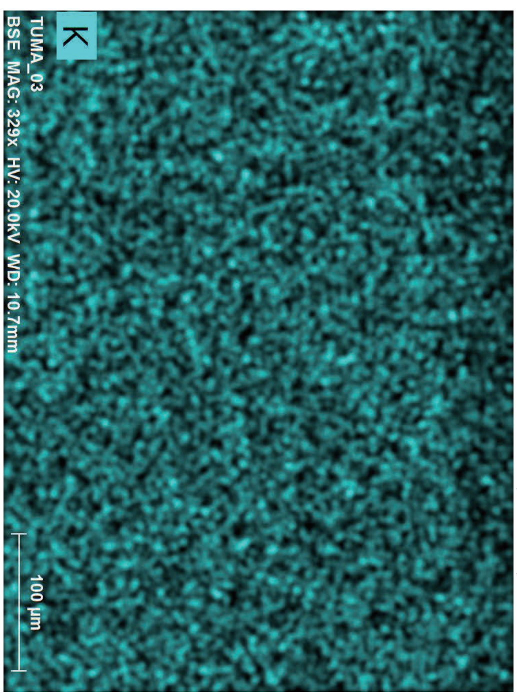
TUMA_03 EDS Aluminum (1012x)



TUMA_03 EDS Iron (1012x)

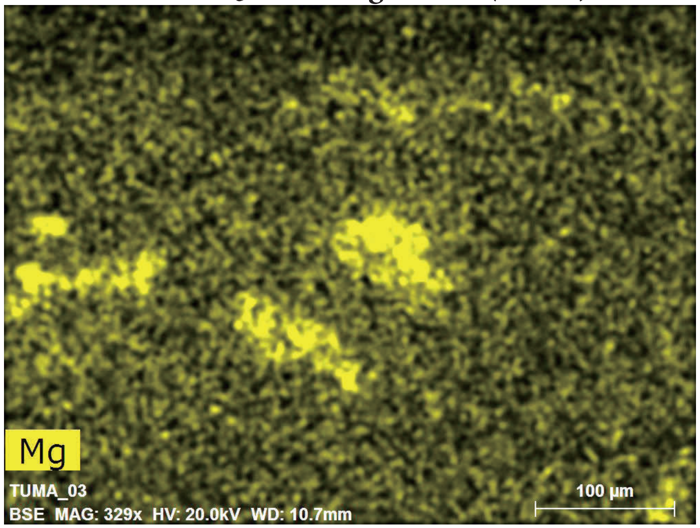


TUMA_03 EDS Calcium (1012x)

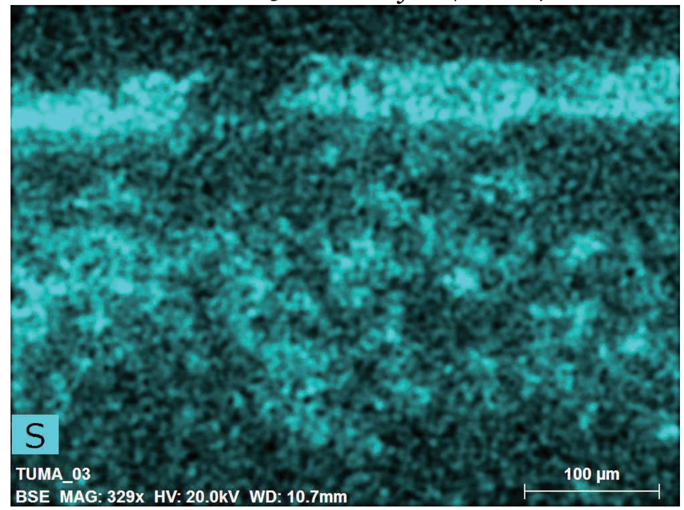


TUMA_03 EDS Potassium (1012x)

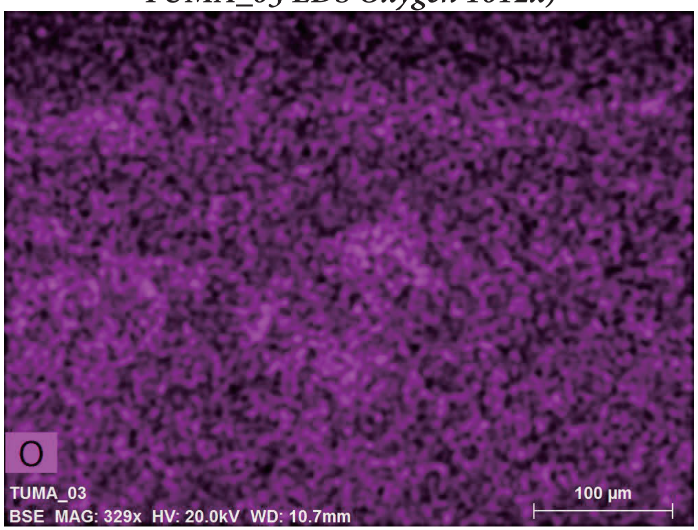
TUMA_03 EDS Magnesium (1012x)



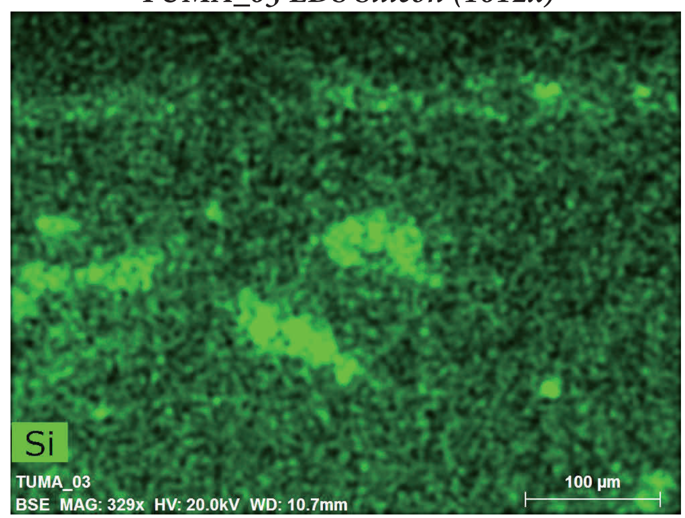
TUMA_03 EDS Sulfur (1012x)



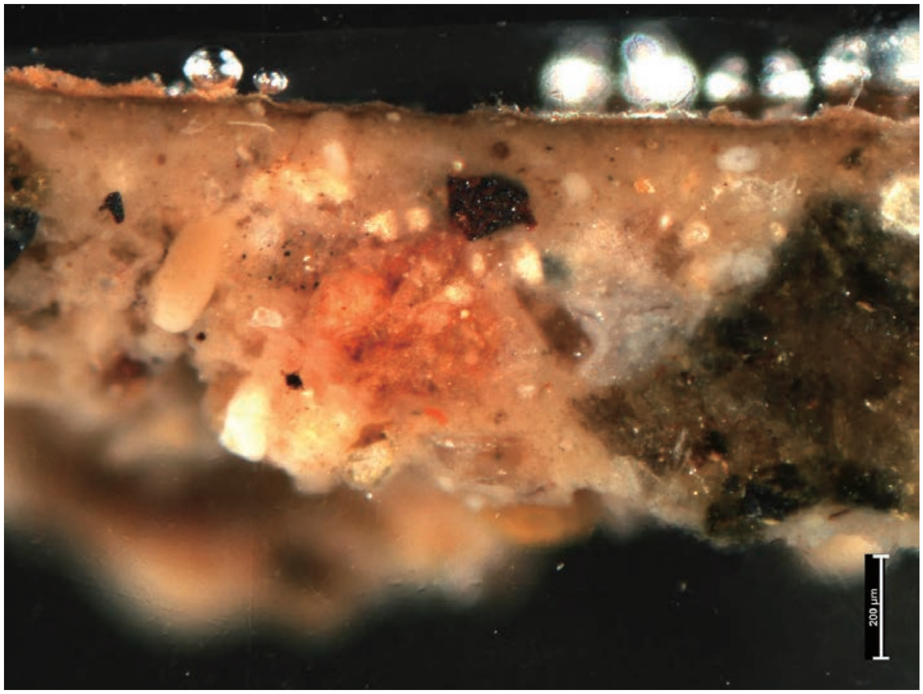
TUMA_03 EDS Oxygen 1012x)



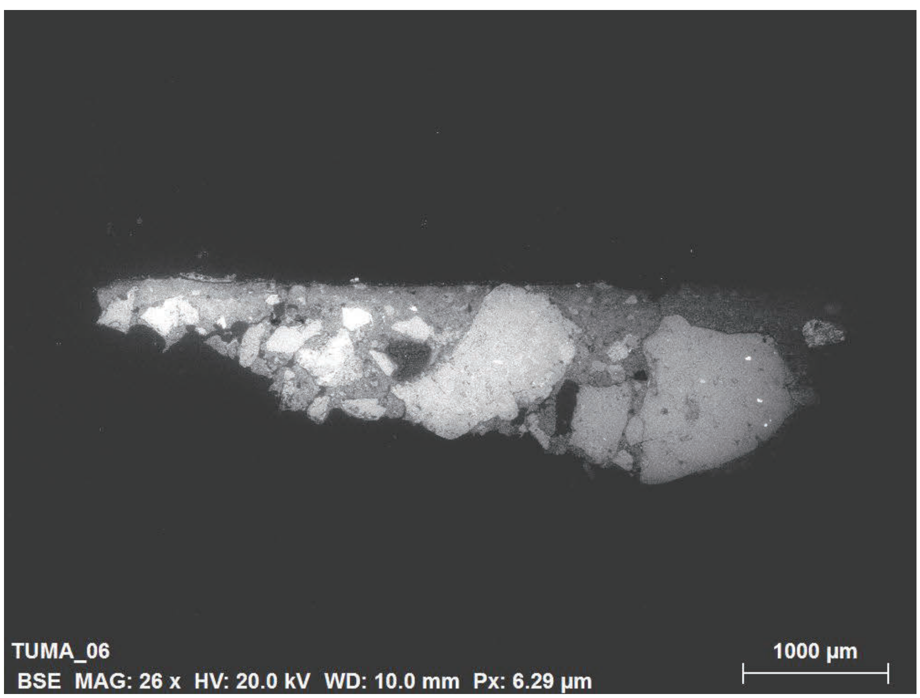
TUMA_03 EDS Silicon (1012x)



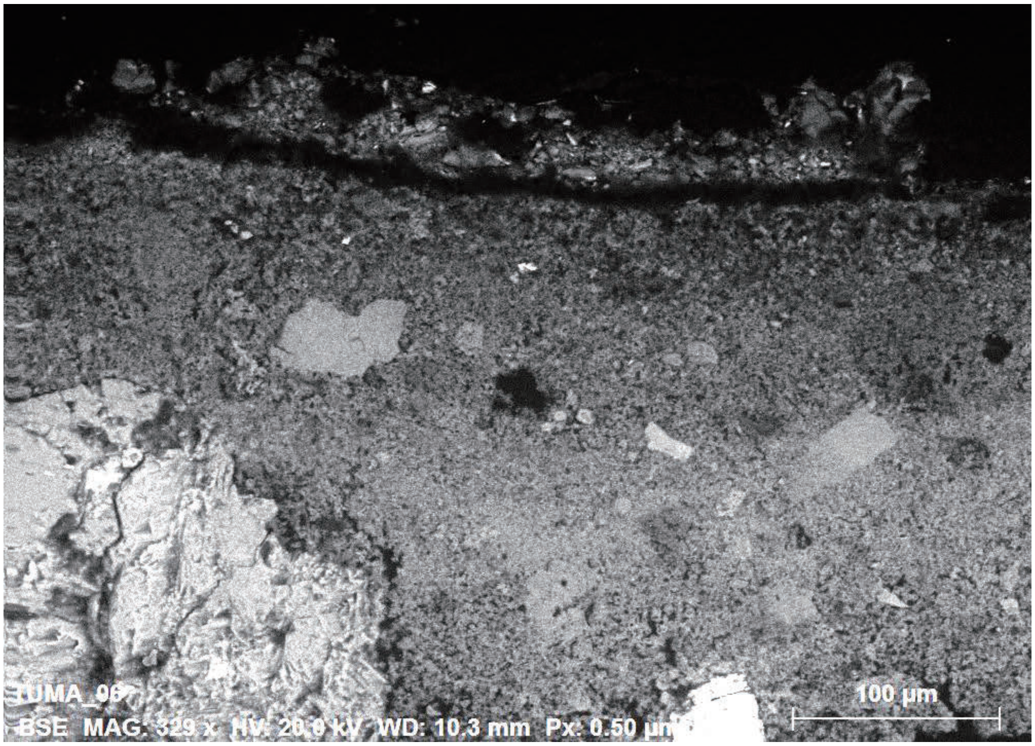
Scientific Research & Analysis Laboratory, Winterthur Museum
TUMA_06 SEM-EDS Data



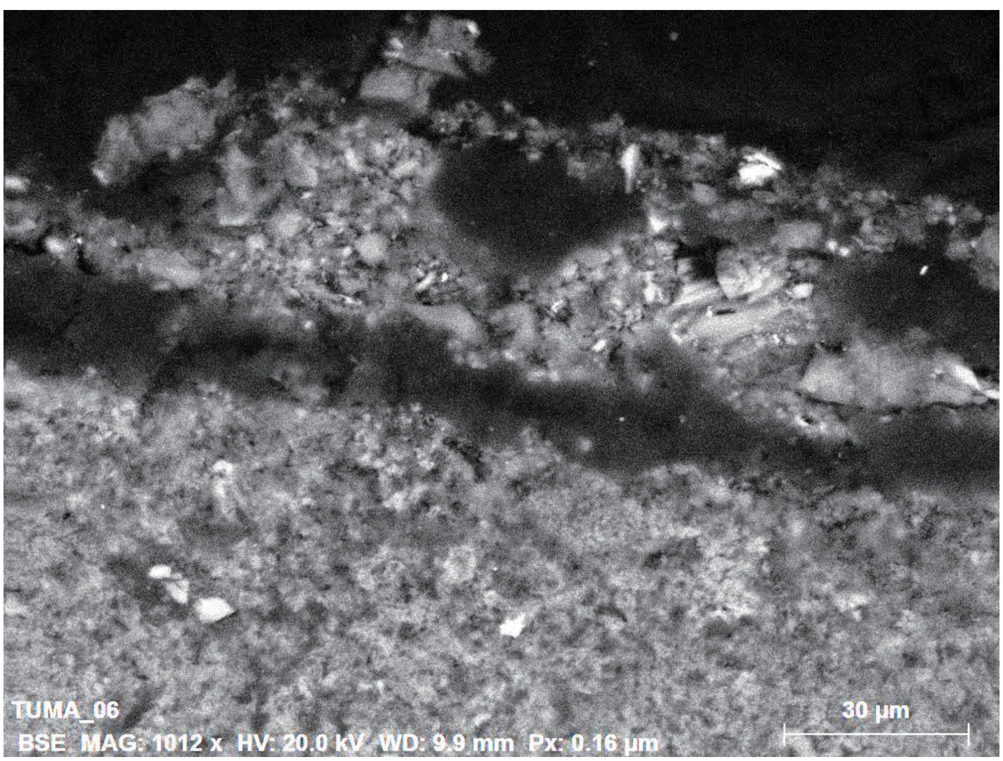
TUMA03 in visible light at 40x



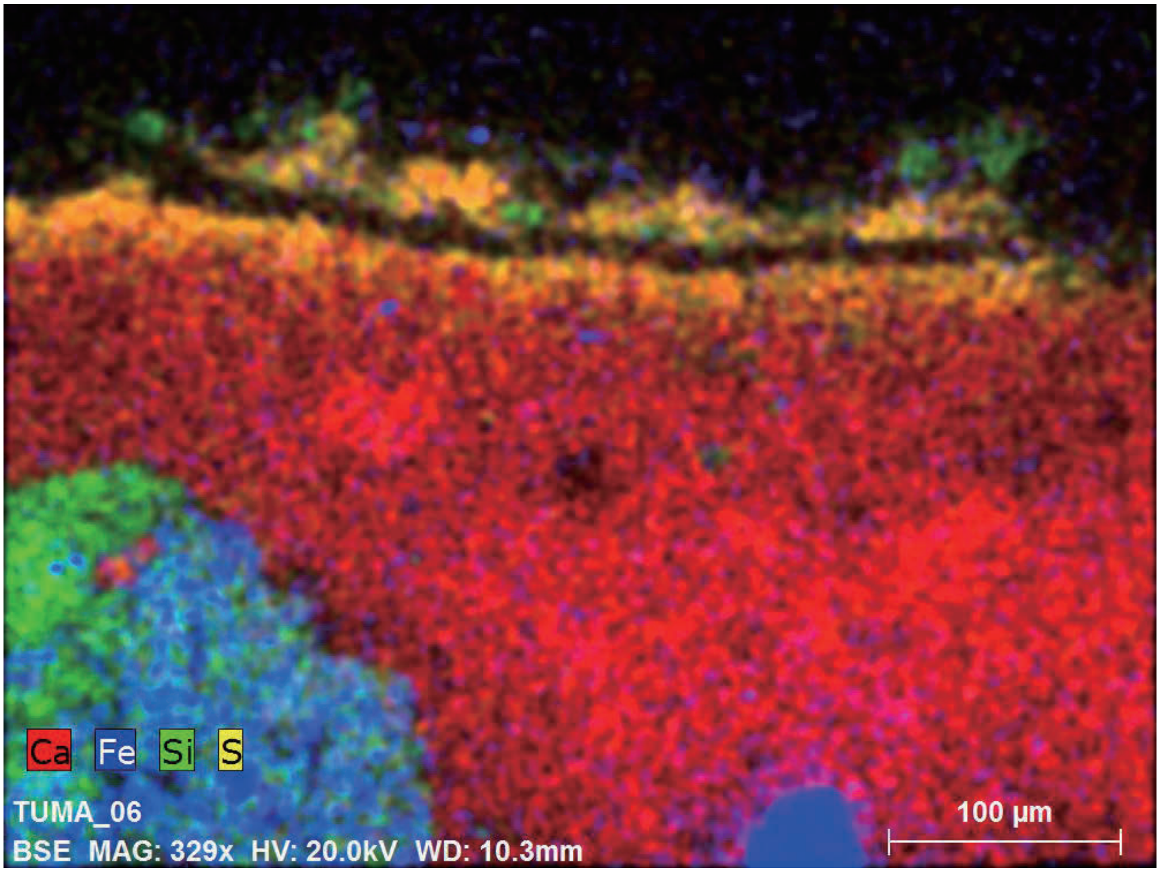
TUMA_06 backscattered electron image from SEM



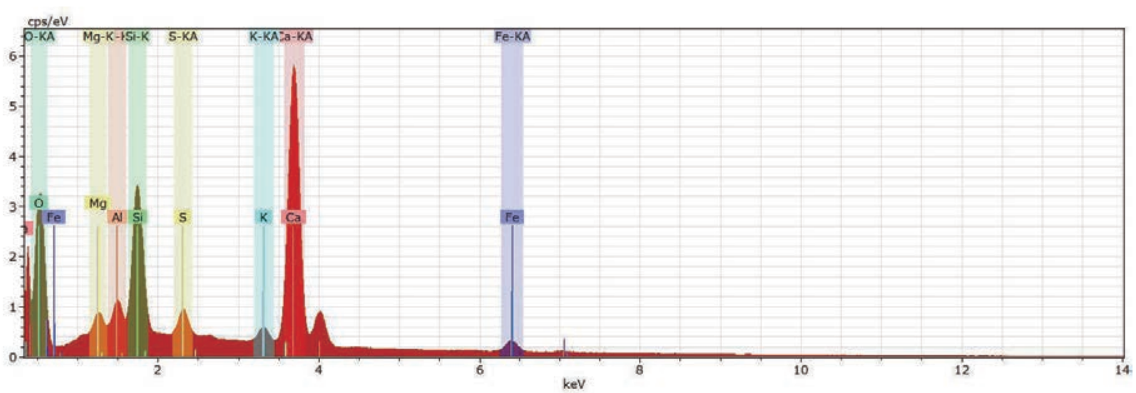
TUMA_06 backscattered electron image at 329x



TUMA_06 backscattered electron image at 1012x

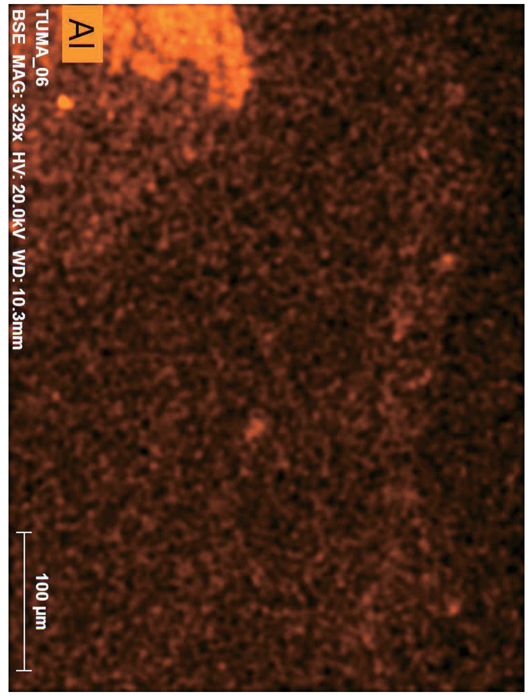


TUMA_06 most abundant elements at 329x

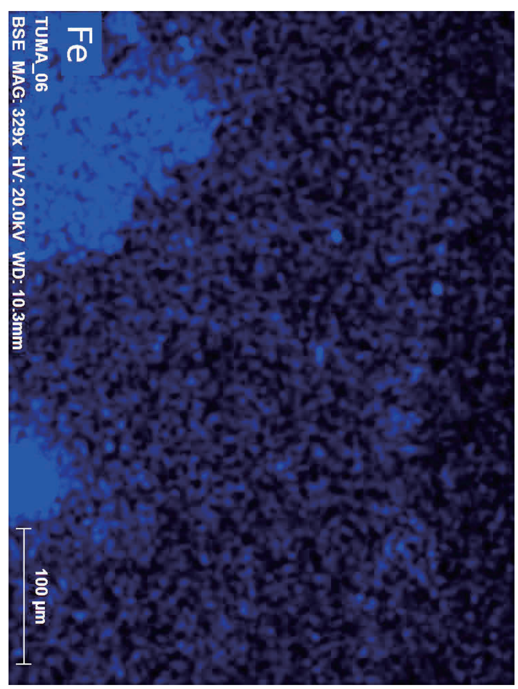


TUMA_06 elemental mapping

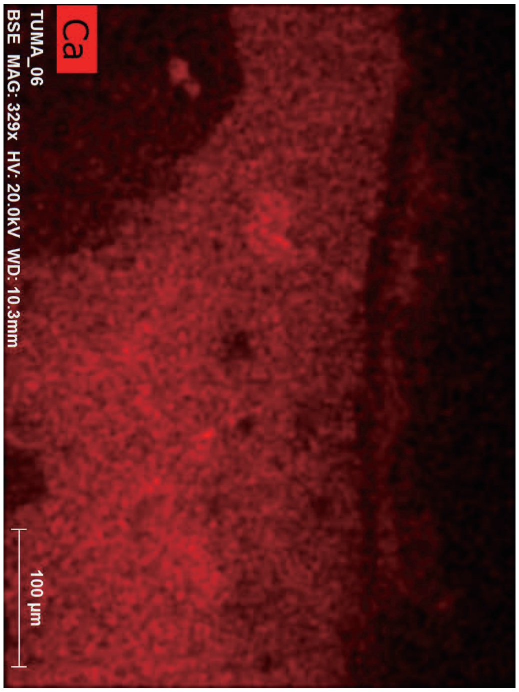
TUMA_06 EDS Aluminum (329x)



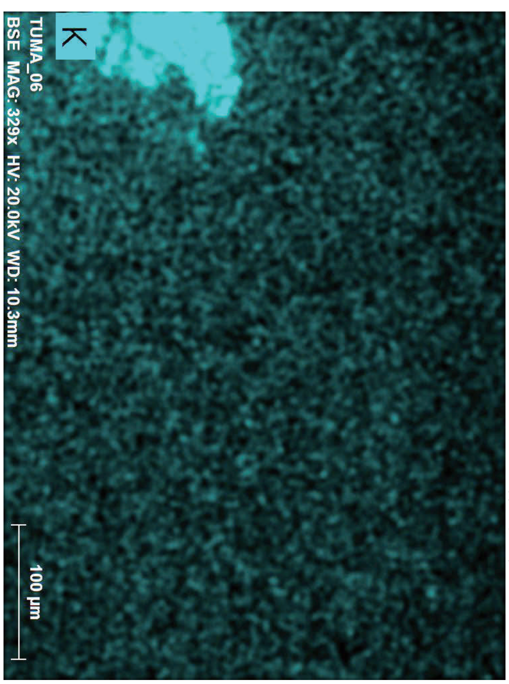
TUMA_06 EDS Iron (329x)



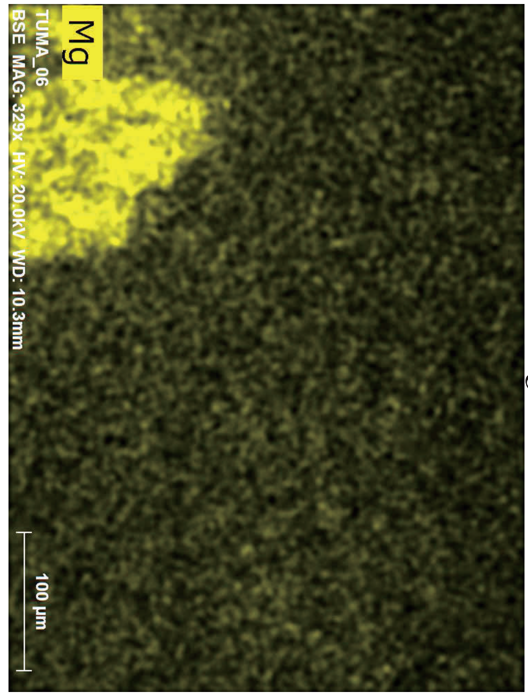
TUMA_06 EDS Calcium (329x)



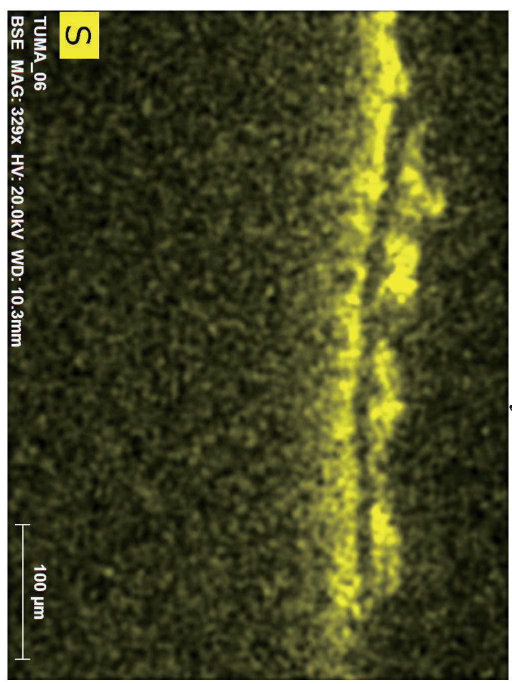
TUMA_06 EDS Potassium (329x)



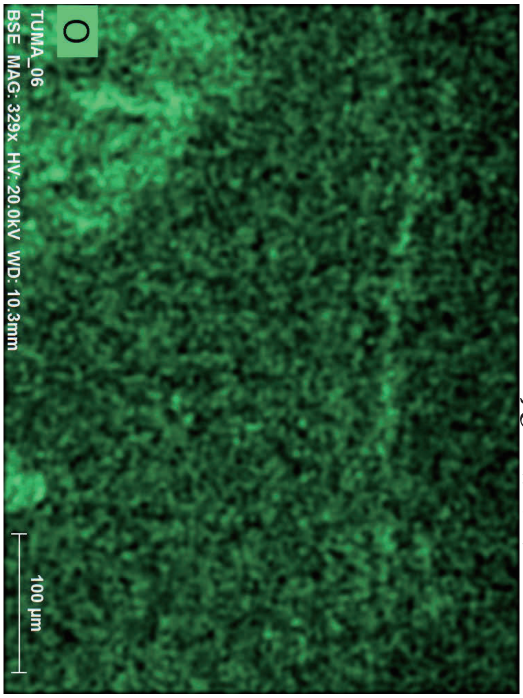
TUMA_06 EDS Magnesium (329x)



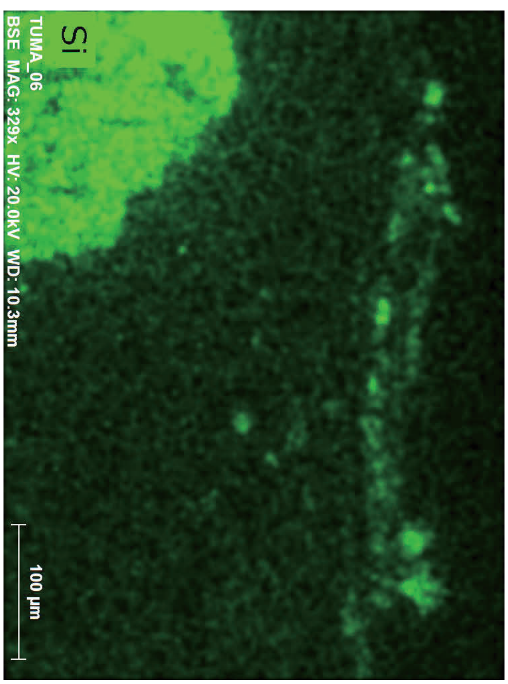
TUMA_03 EDS Sulfur (329x)

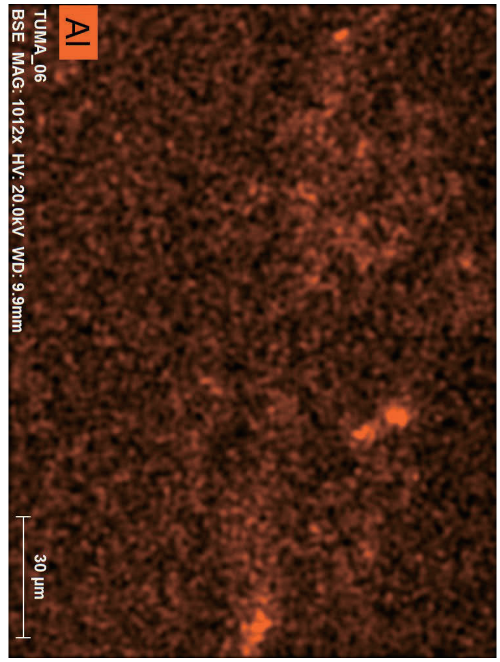


TUMA_06 EDS Oxygen (329x)

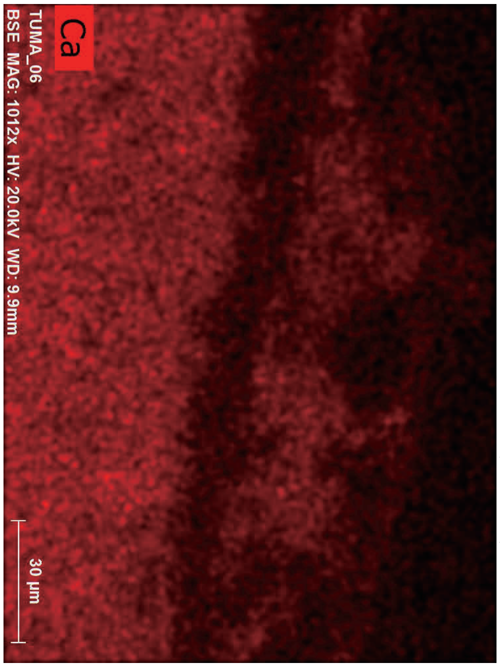


TUMA_03 EDS Silicon (329x)

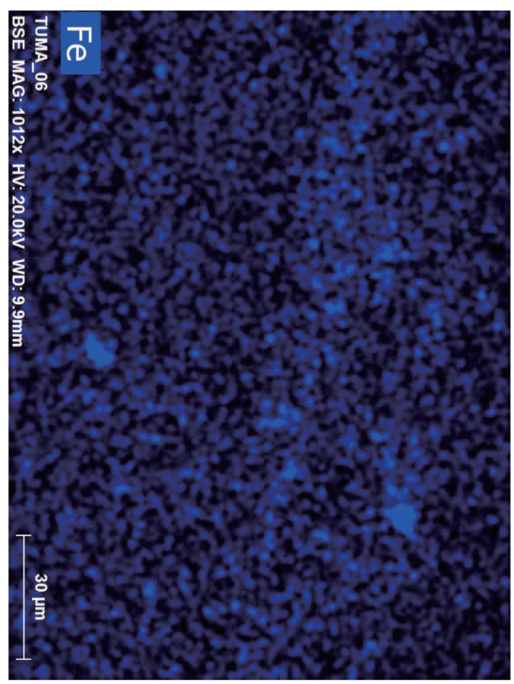




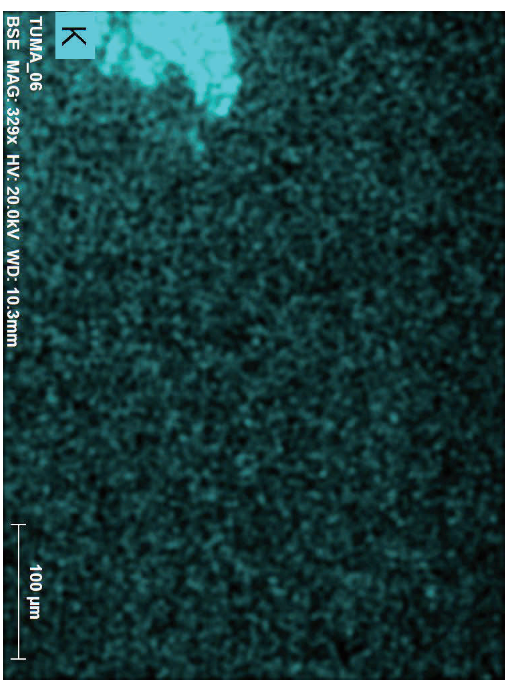
TUMA_06 EDS Aluminum (1012x)



TUMA_06 EDS Calcium (1012x)

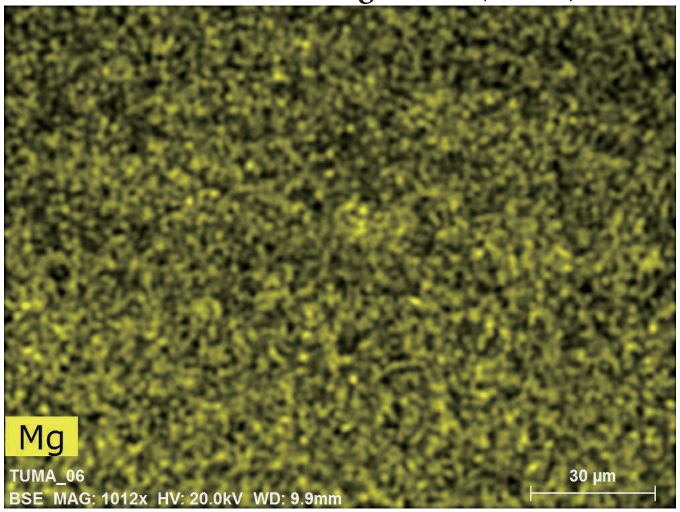


TUMA_06 EDS Iron (1012x)

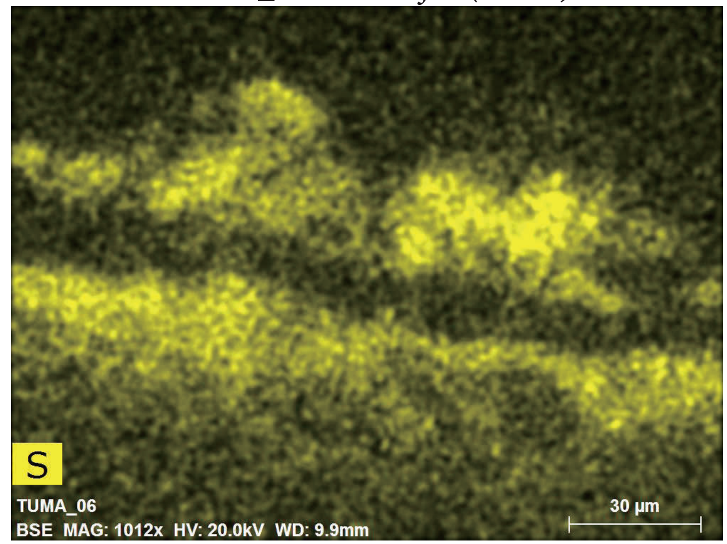


TUMA_06 EDS Potassium (1012x)

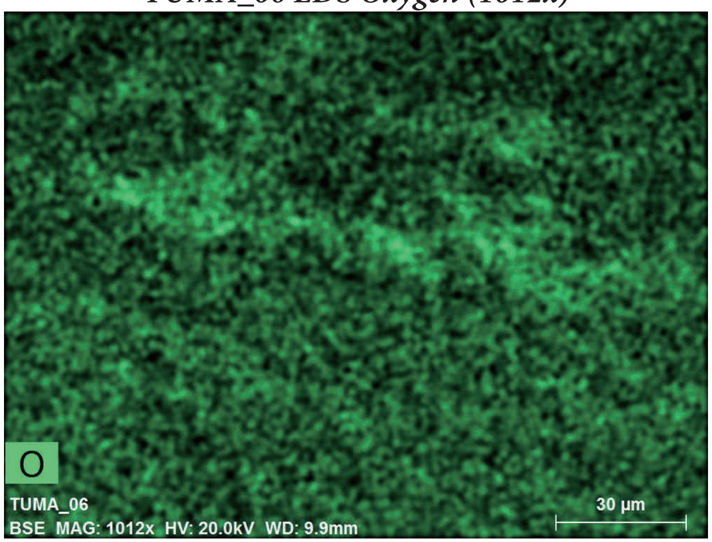
TUMA_06 EDS Magnesium (1012x)



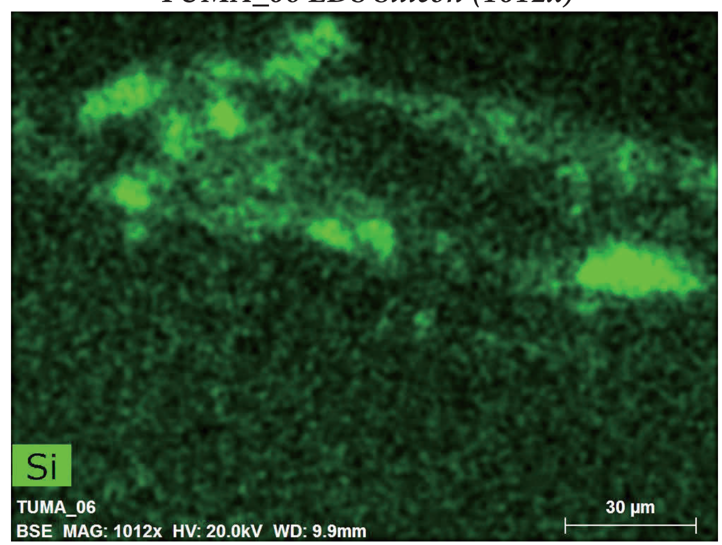
TUMA_06 EDS Sulfur (1012x)



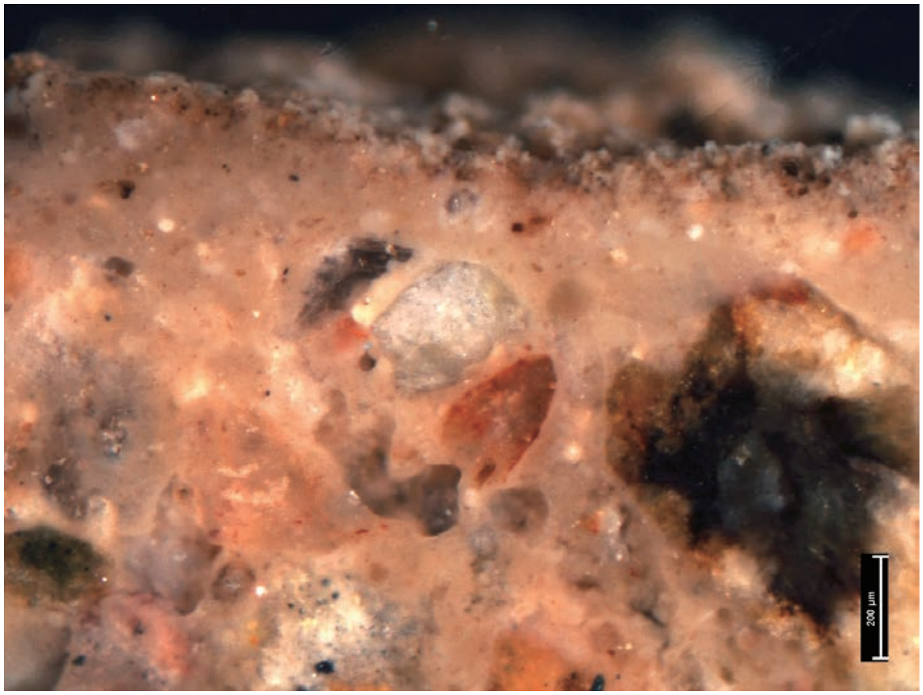
TUMA_06 EDS Oxygen (1012x)



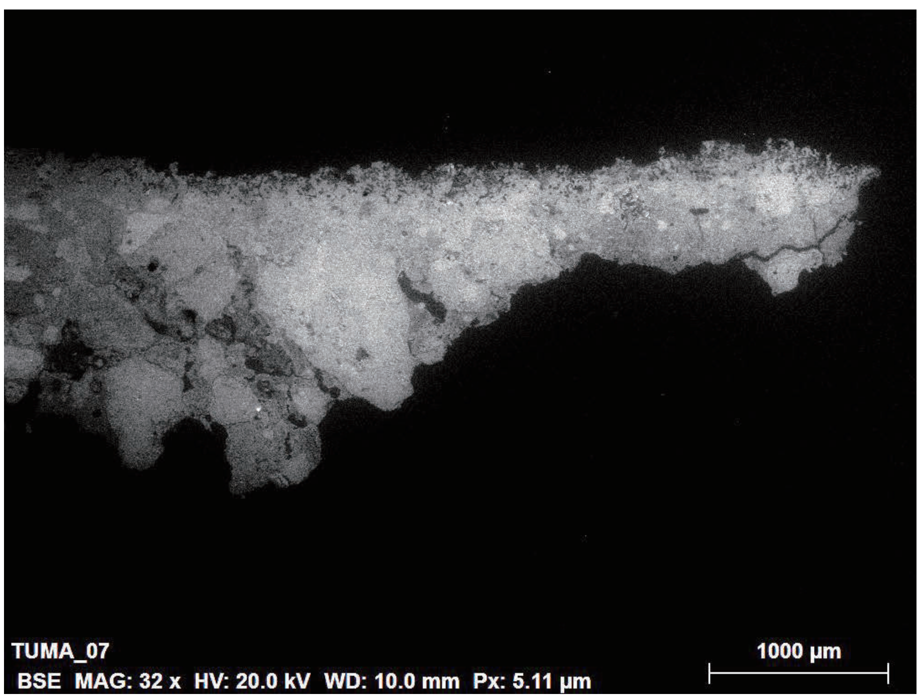
TUMA_06 EDS Silicon (1012x)



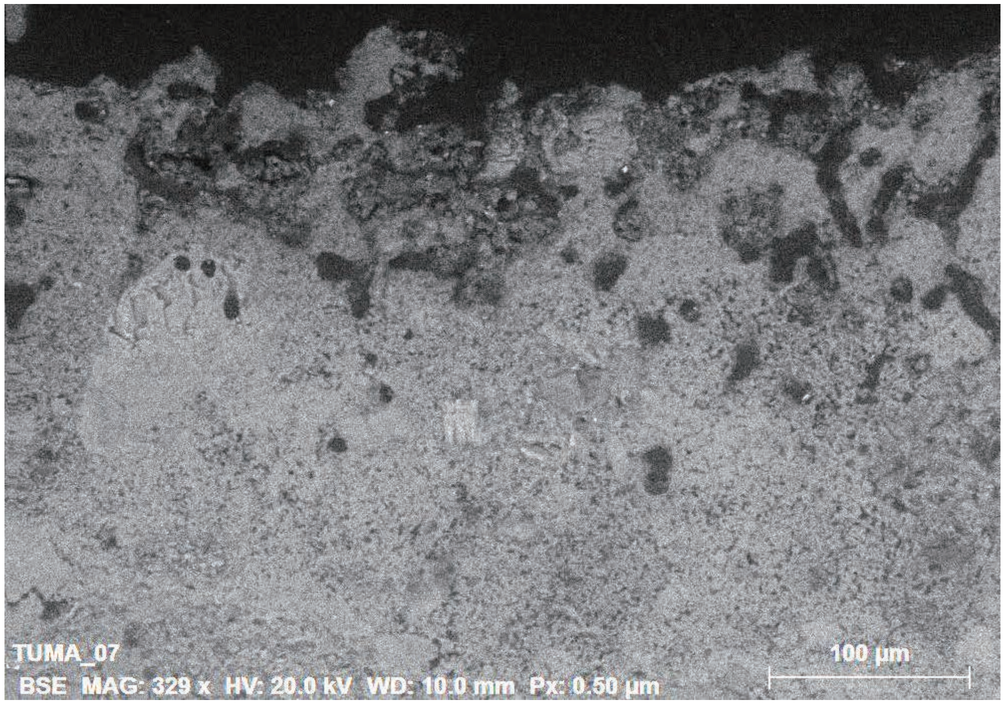
Scientific Research & Analysis Laboratory, Winterthur Museum
TUMA_07 SEM-EDS Data



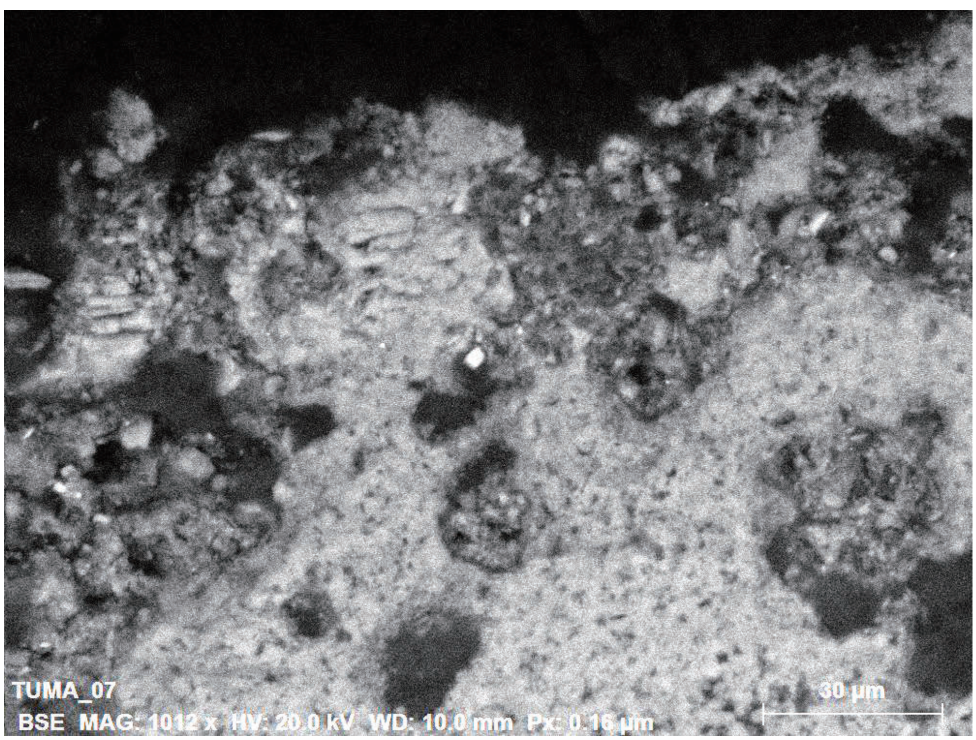
TUMA07 in visible light at 40x



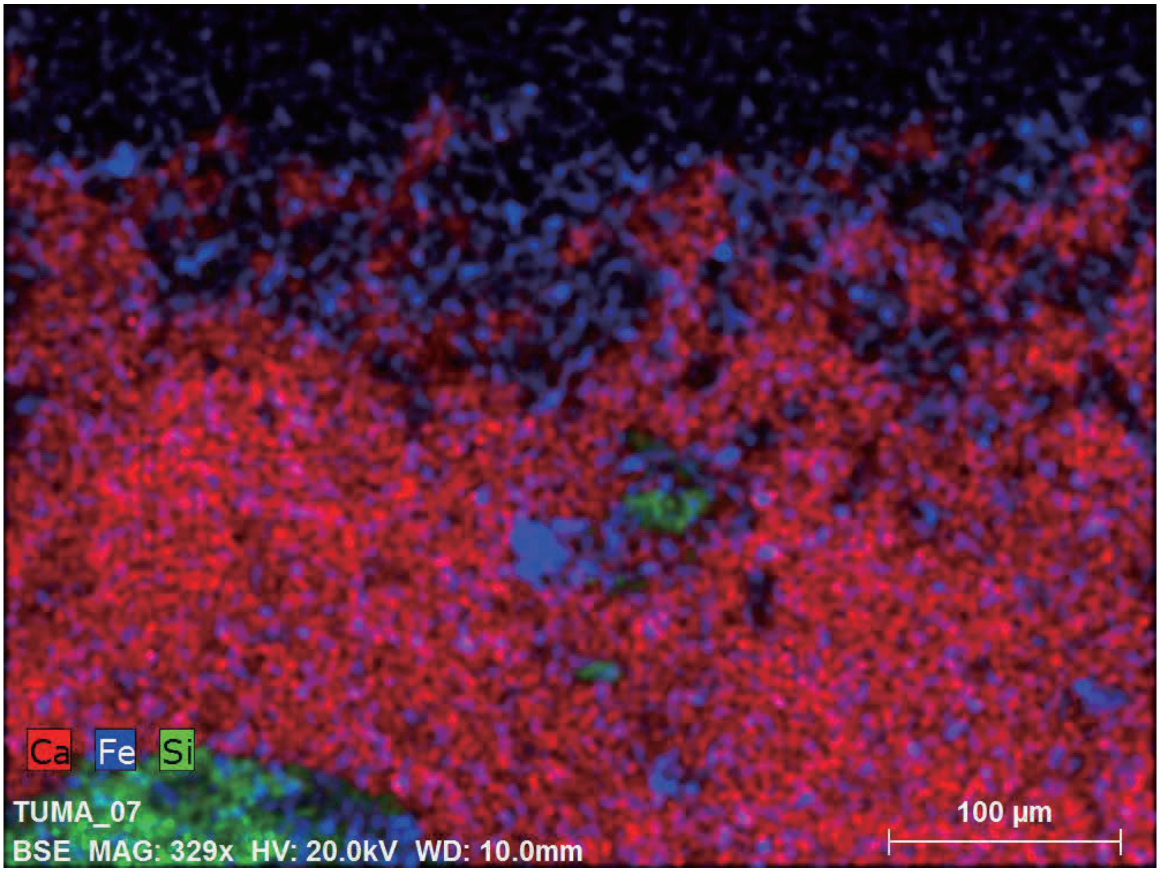
TUMA_07 backscattered electron image from SEM



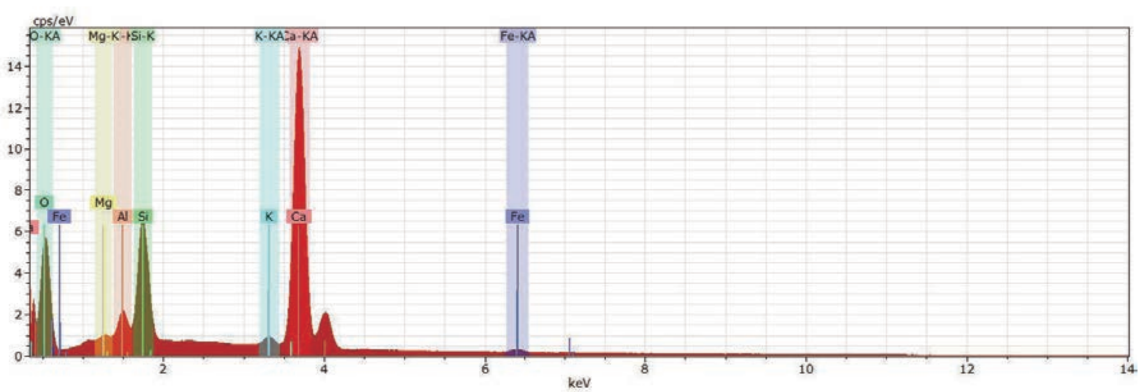
TUMA_07 backscattered electron image at 329x



TUMA_07 backscattered electron image at 1012x

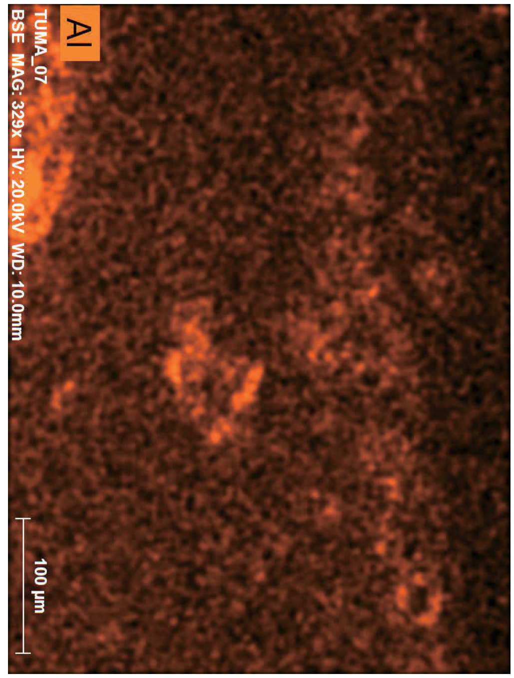


TUMA_07 most abundant elements at 329x

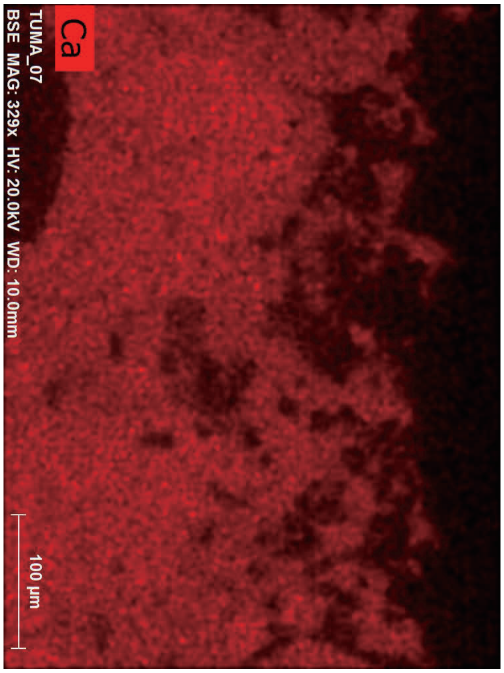


TUMA_07 elemental mapping

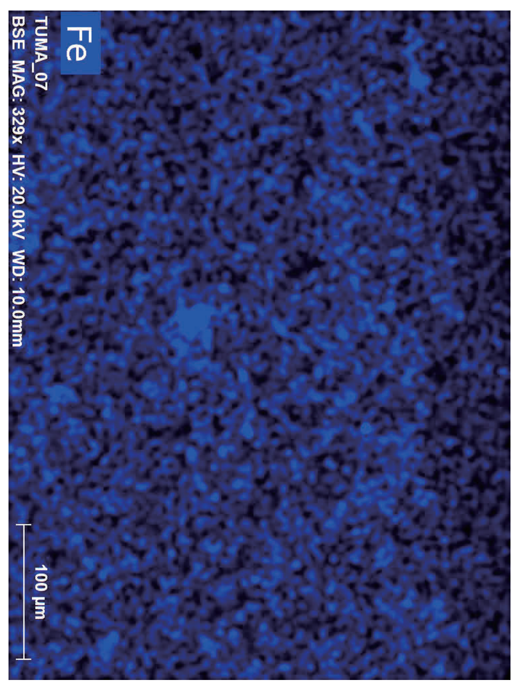
TUMA_07 EDS Aluminum (329x)



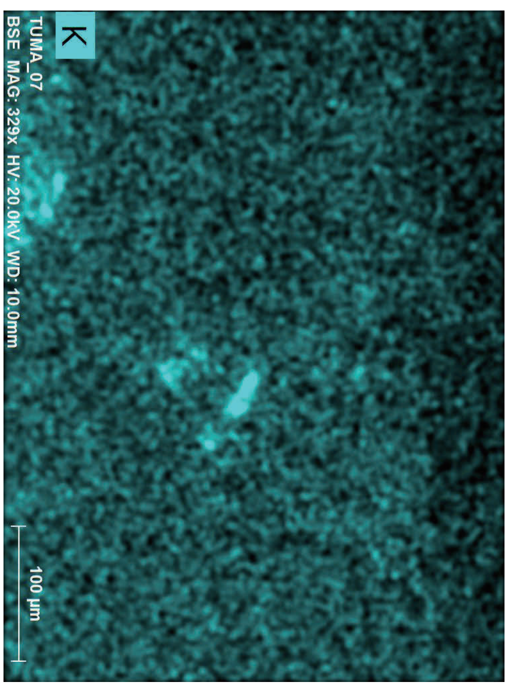
TUMA_07 EDS Calcium (329x)



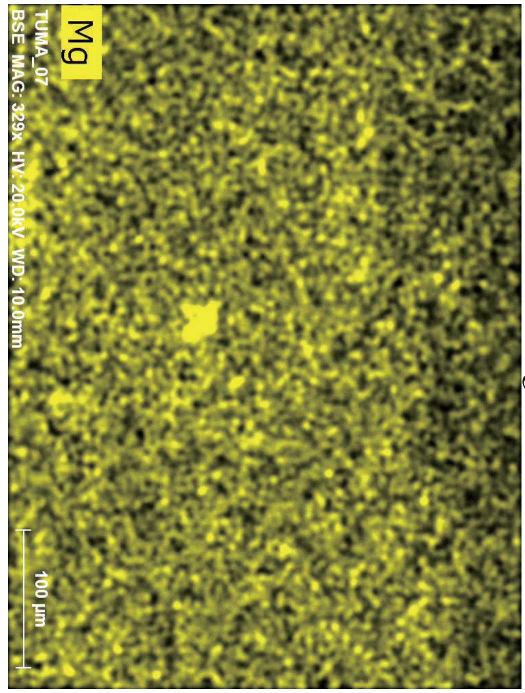
TUMA_07 EDS Iron (329x)



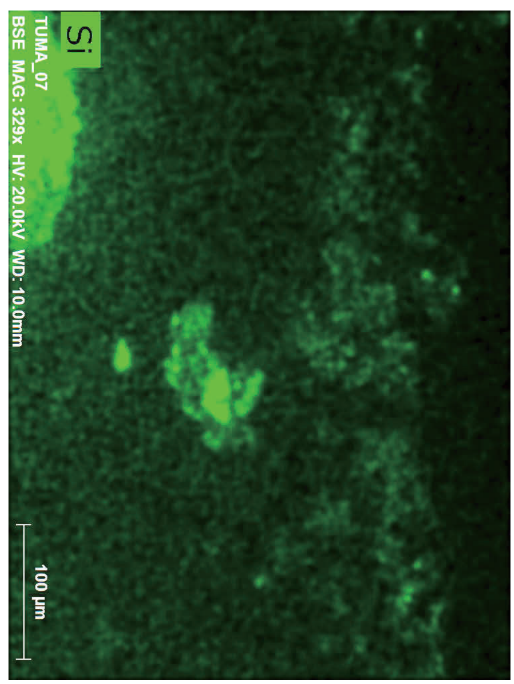
TUMA_07 EDS Potassium (329x)



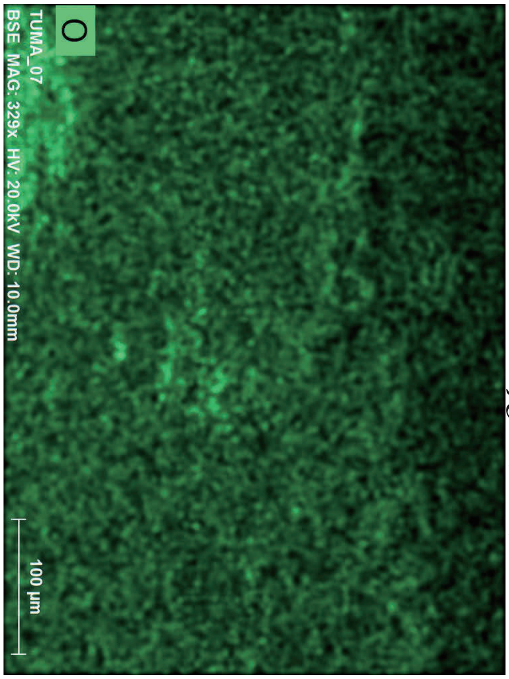
TUMA_07 EDS Magnesium (329x)



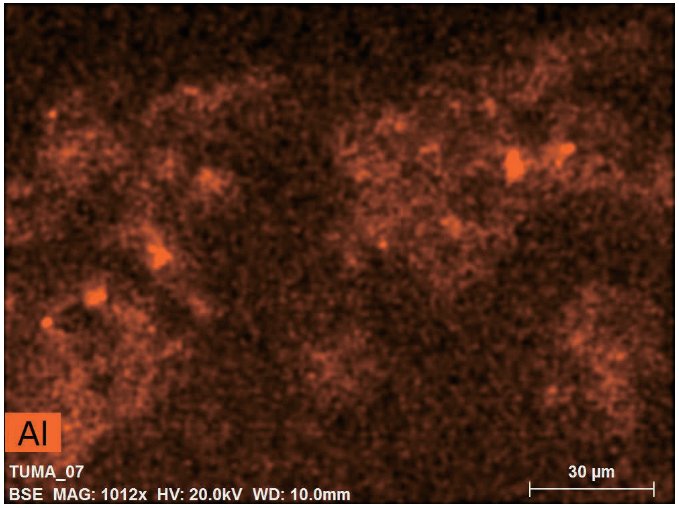
TUMA_07 EDS Silicon (329x)



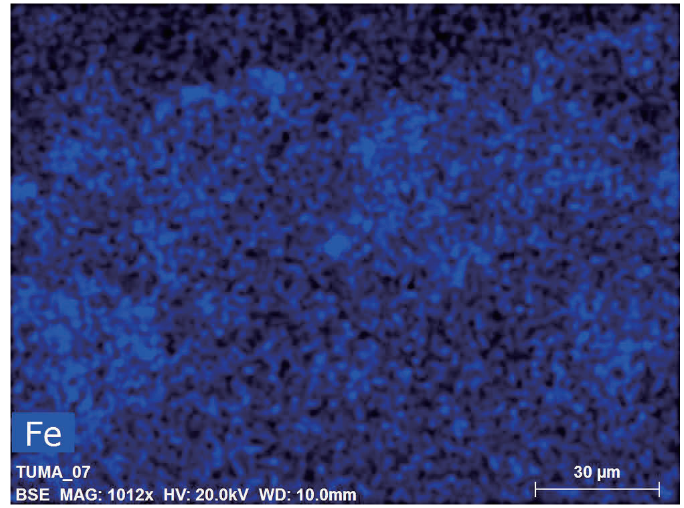
TUMA_07 EDS Oxygen (329x)



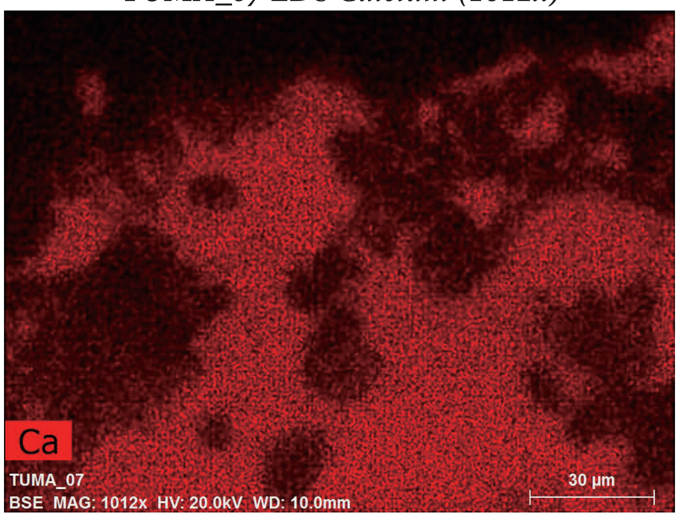
TUMA_07 EDS Aluminum (1012x)



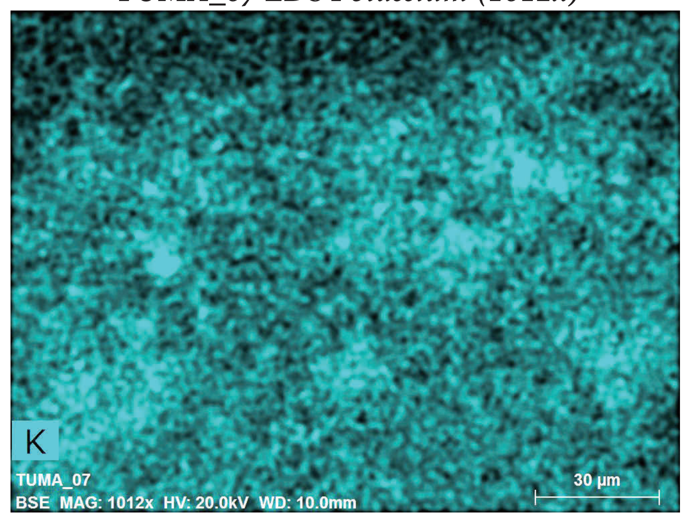
TUMA_07 EDS Iron (1012x)



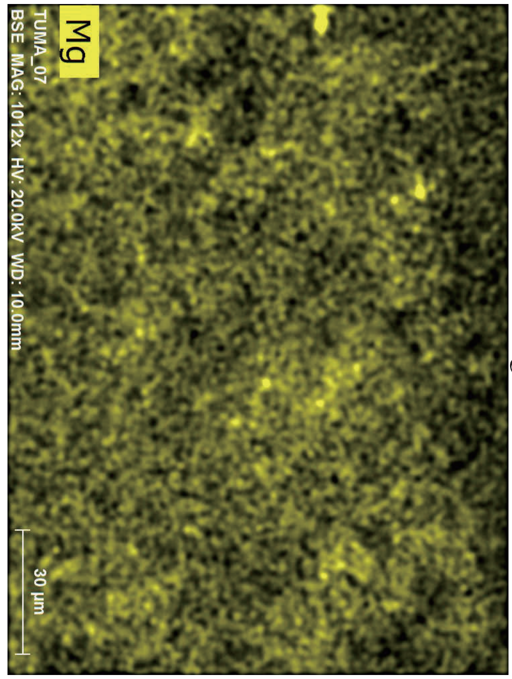
TUMA_07 EDS Calcium (1012x)



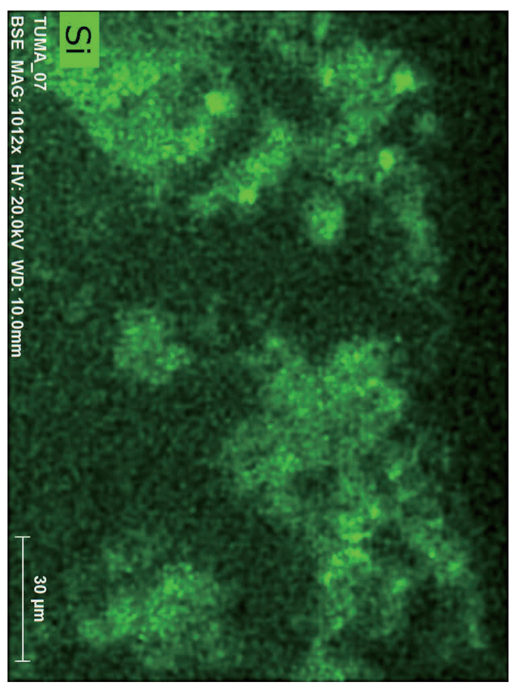
TUMA_07 EDS Potassium (1012x)



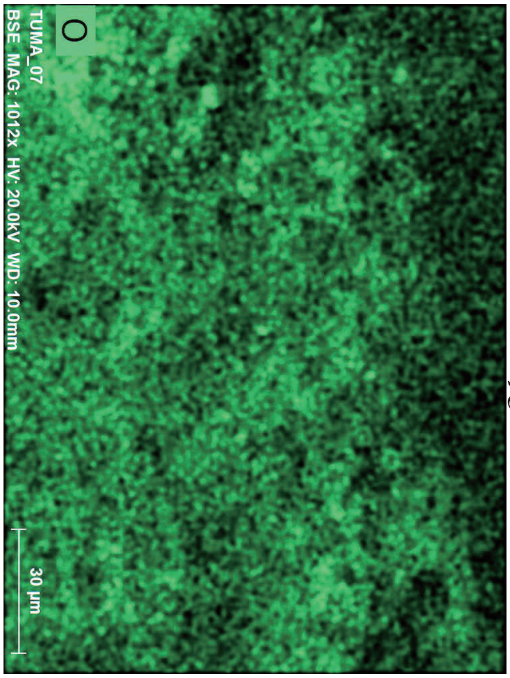
TUMA_07 EDS Magnesium (1012x)



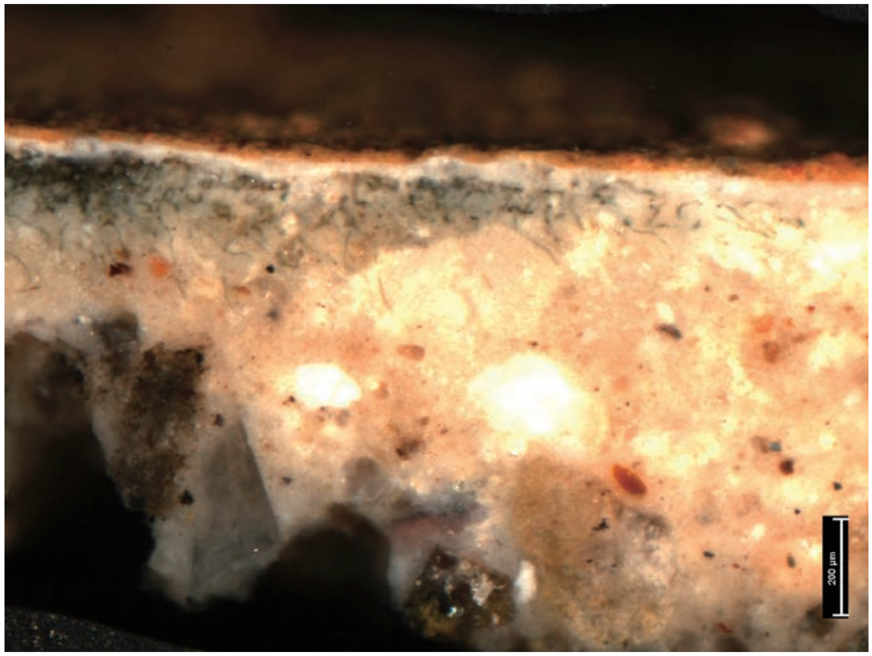
TUMA_07 EDS Silicon (1012x)



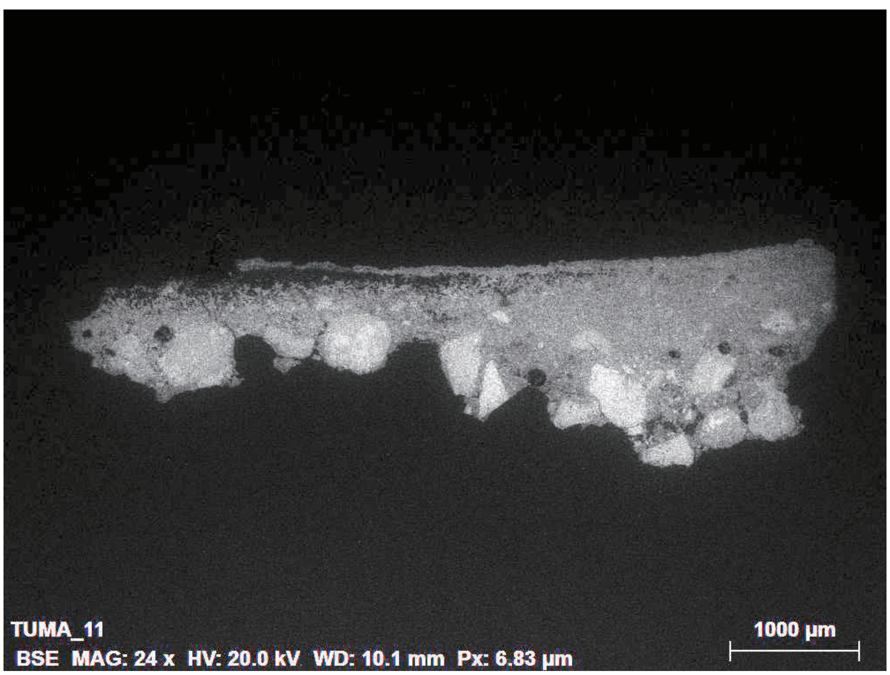
TUMA_07 EDS Oxygen (1012x)



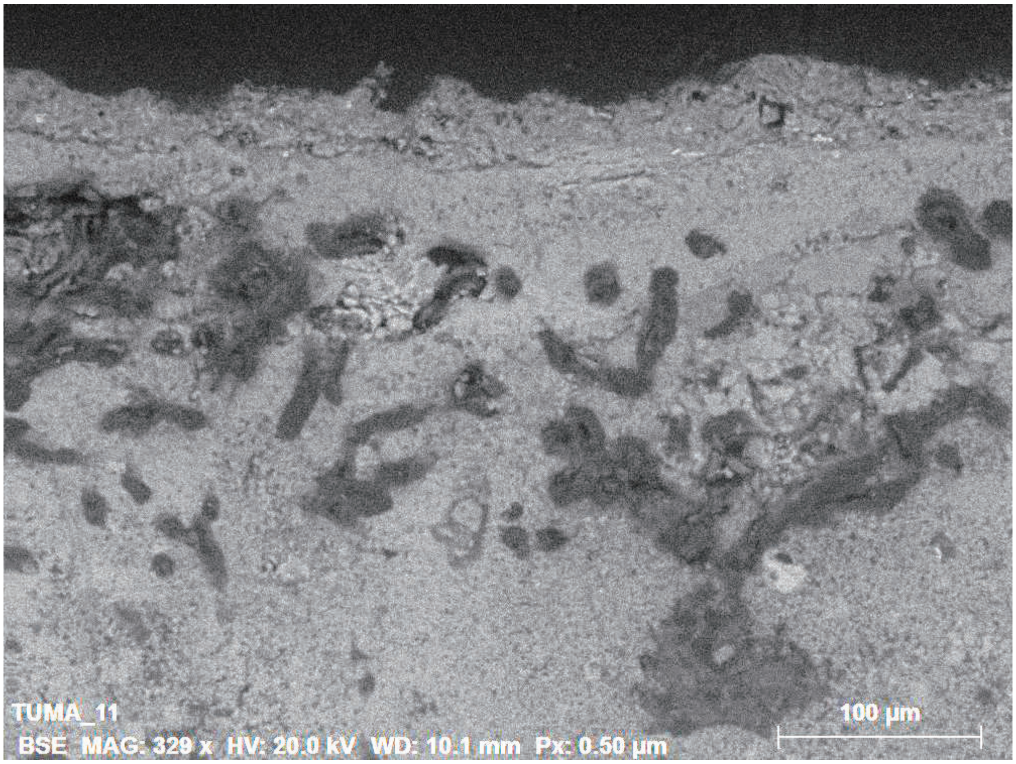
Scientific Research & Analysis Laboratory, Winterthur Museum
TUMA_11 SEM-EDS Data



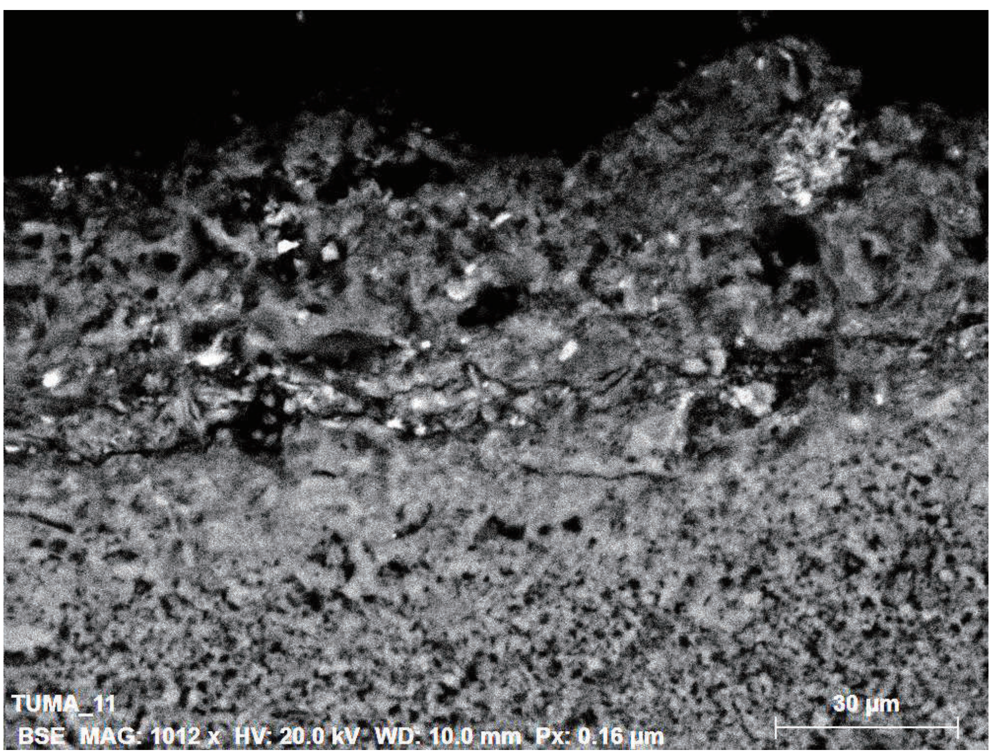
TUMA_11 in visible light at 40x



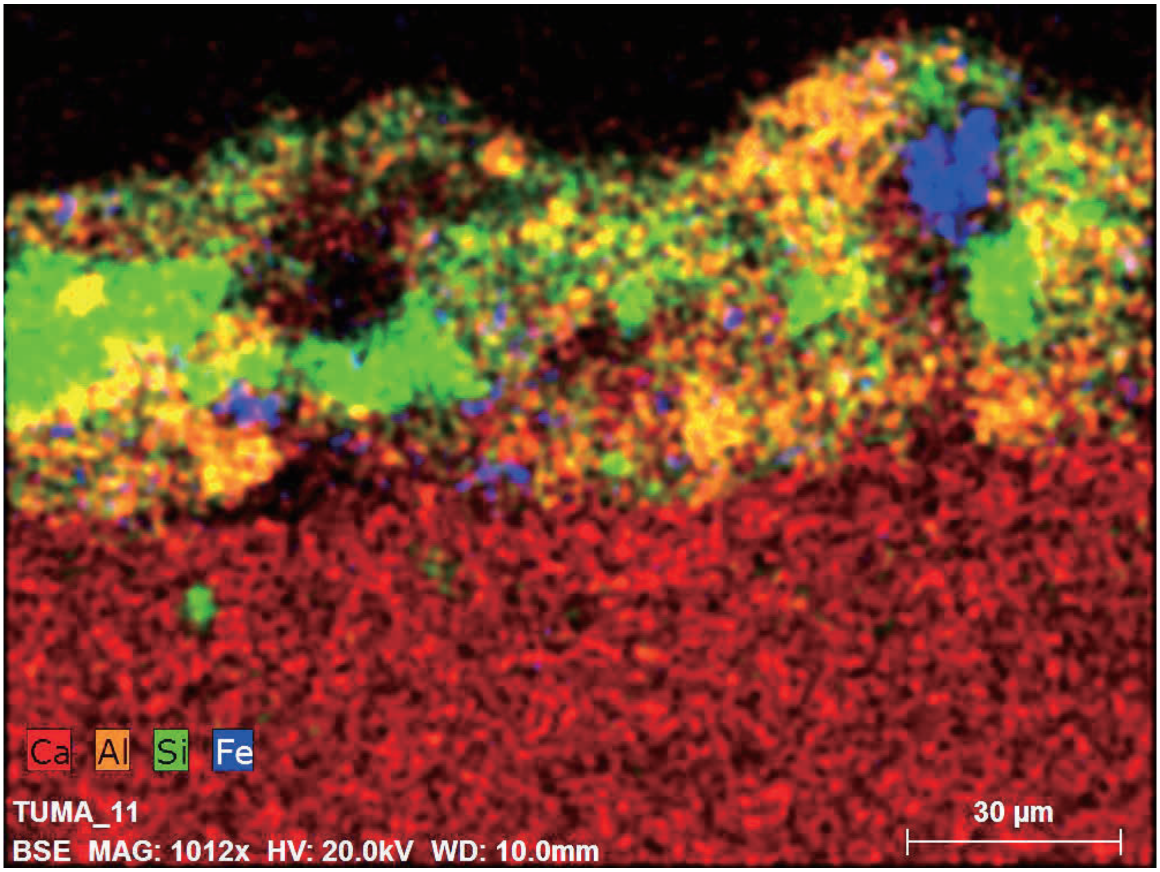
TUMA_11 backscattered electron image from SEM



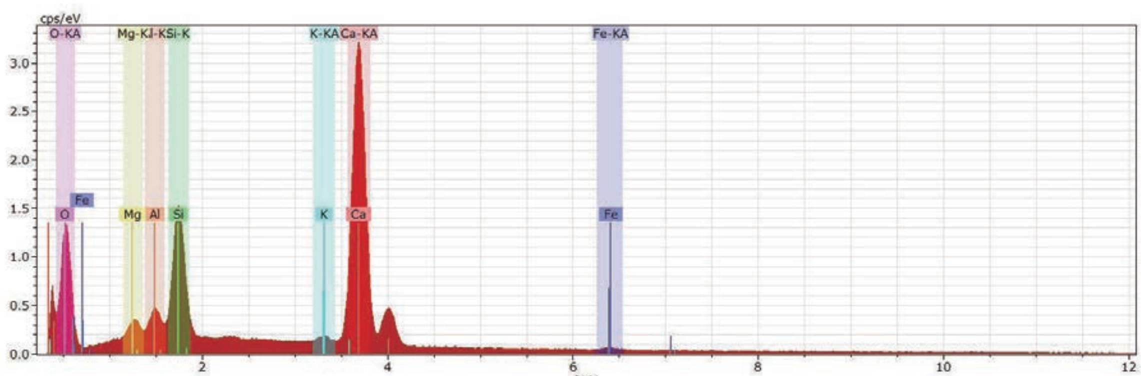
TUMA_11 backscattered electron image at 329x



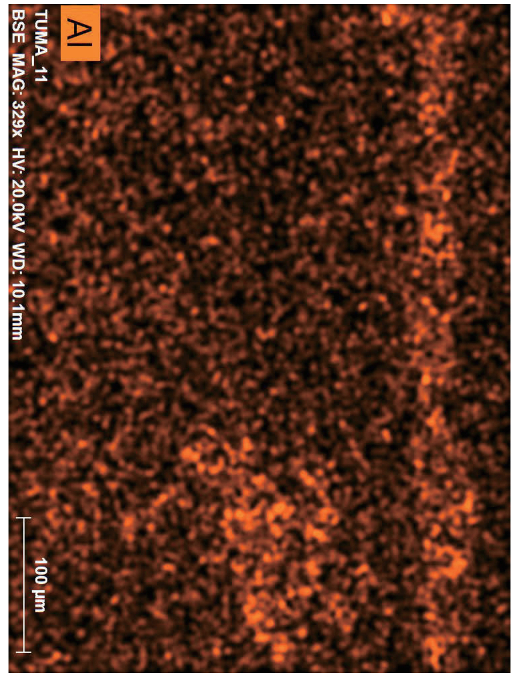
TUMA_11 backscattered electron image at 1012x



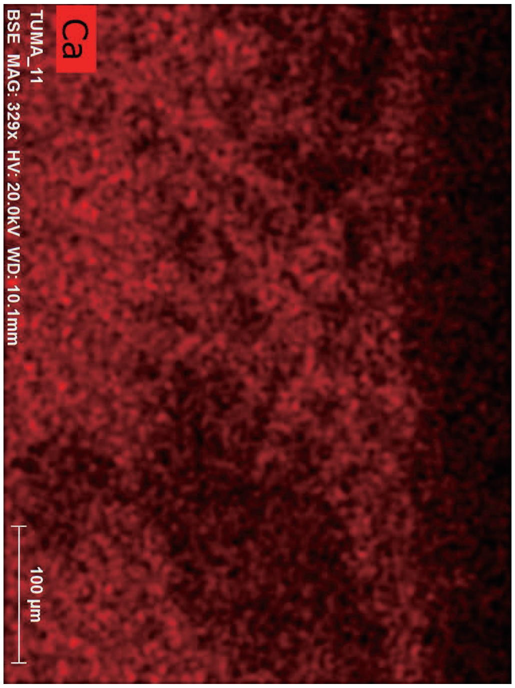
TUMA_11 most abundant elements at 1012x



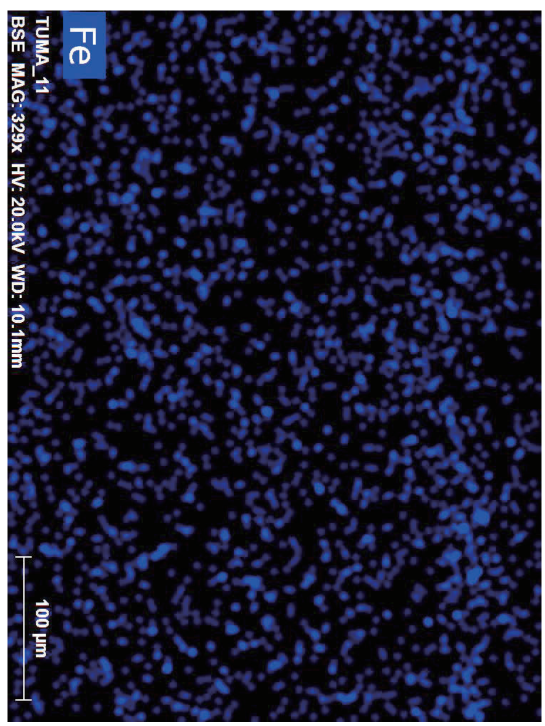
TUMA_11 elemental mapping



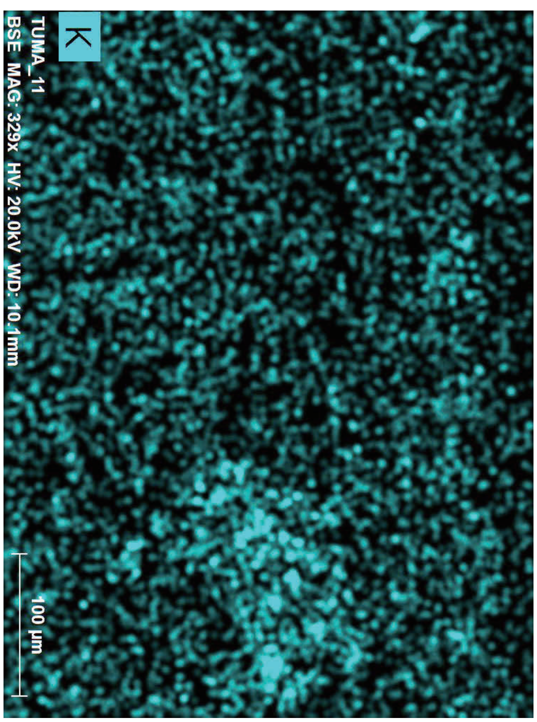
TUMA_11 EDS Aluminum (329x)



TUMA_11 EDS Calcium (1012x)

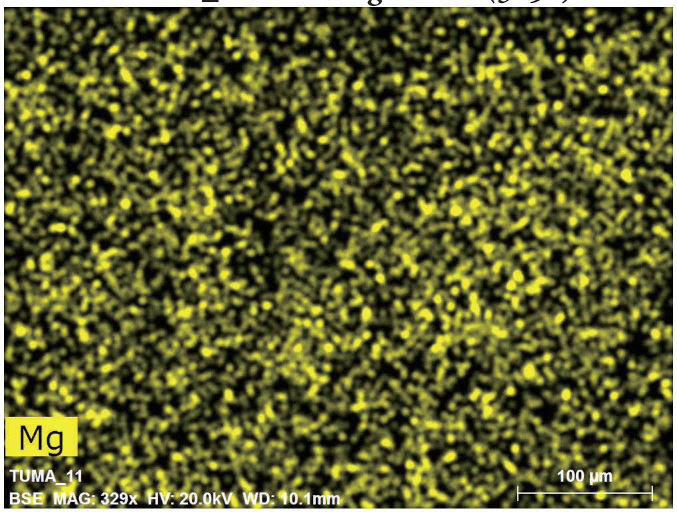


TUMA_11 EDS Iron (329x)

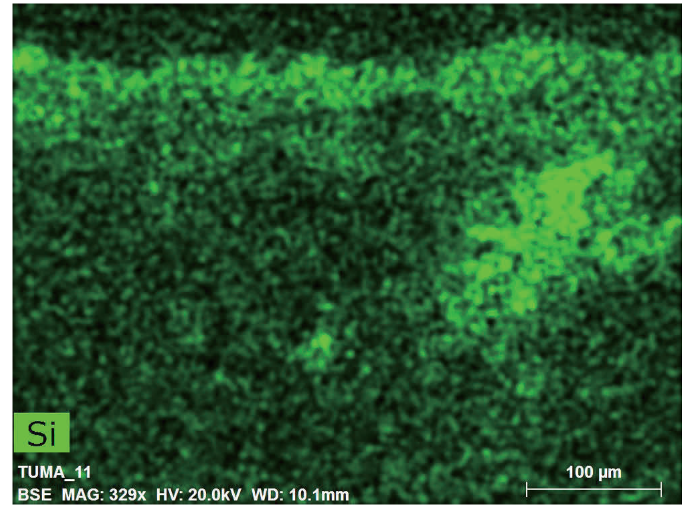


TUMA_11 EDS Potassium (329x)

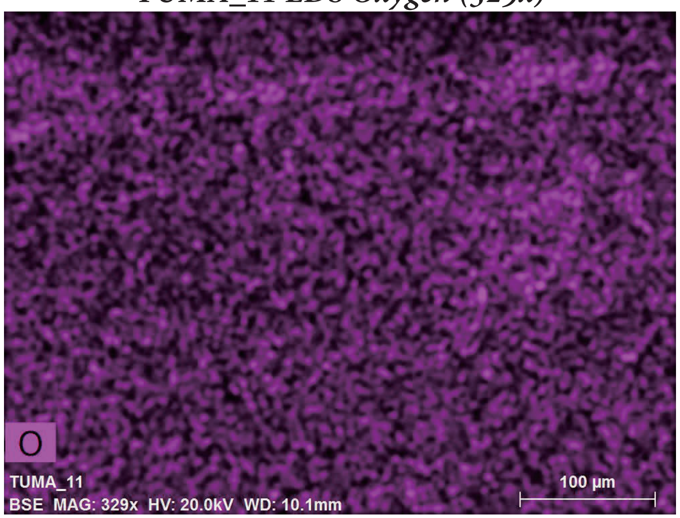
TUMA_11 EDS Magnesium (329x)



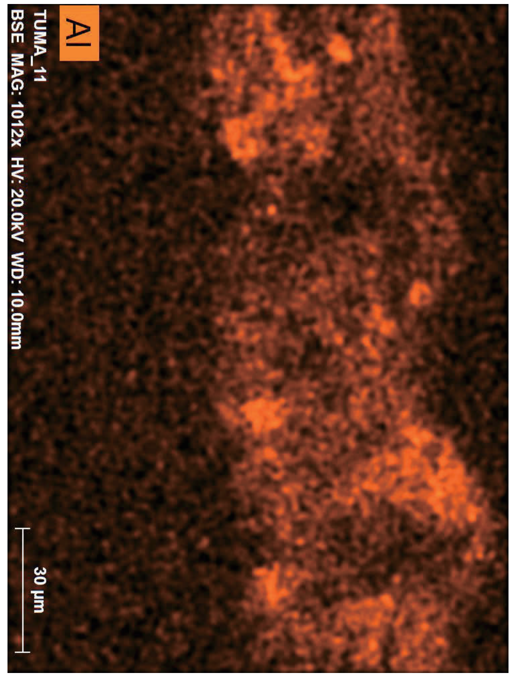
TUMA_11 EDS Silicon (329x)



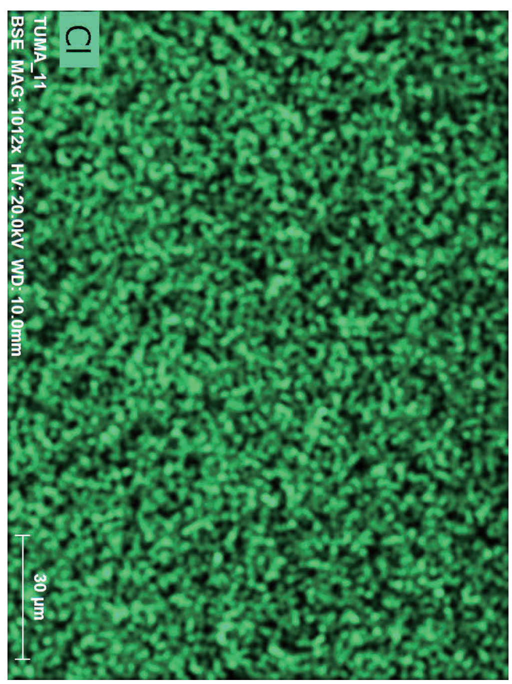
TUMA_11 EDS Oxygen (329x)



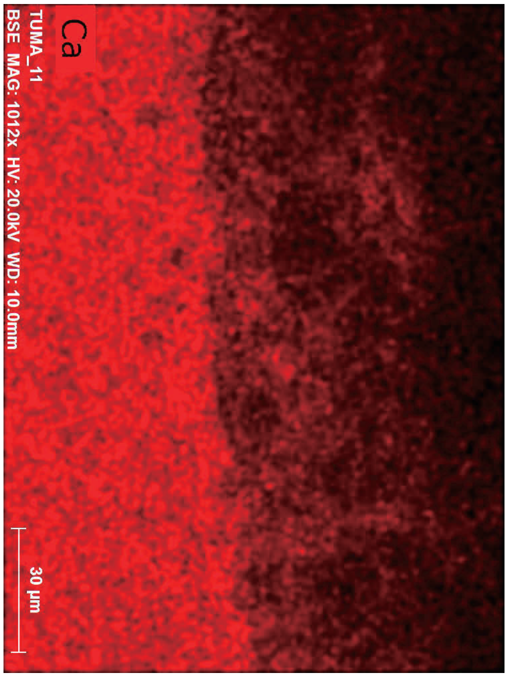
TUMA_11 EDS Aluminum (1012x)



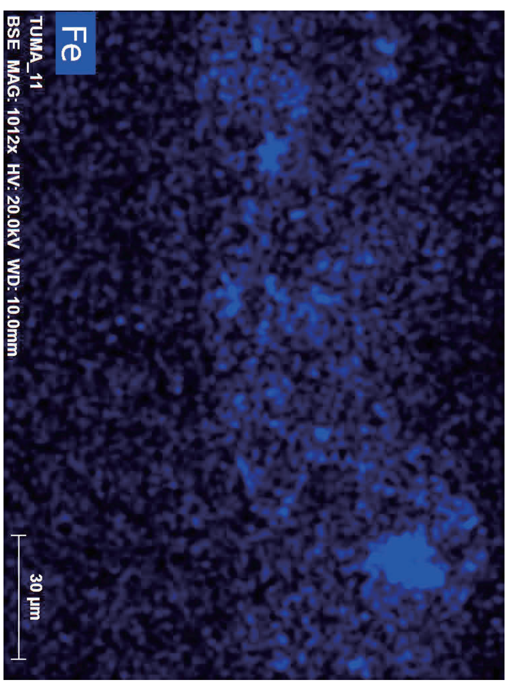
TUMA_11 EDS Chlorine (1012x)



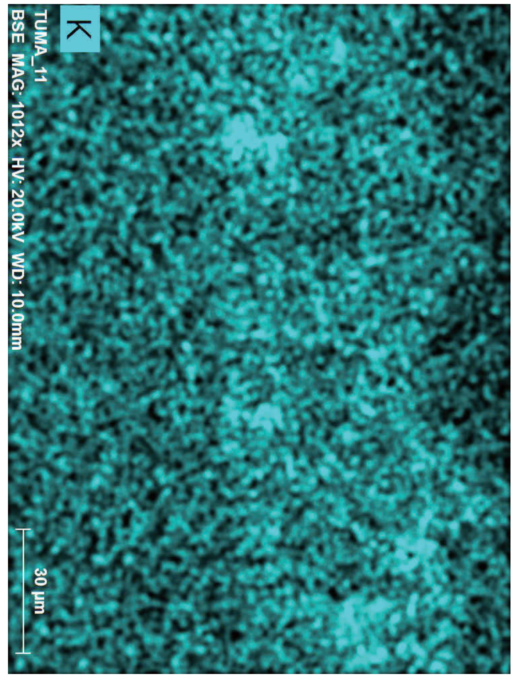
TUMA_11 EDS Calcium (1012x)



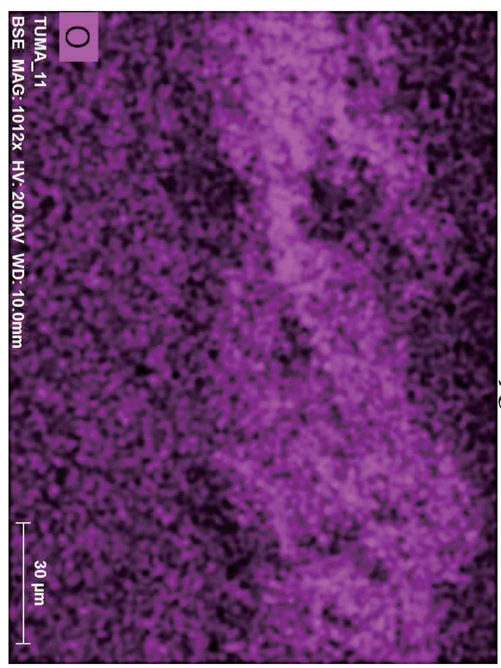
TUMA_11 EDS Iron (1012x)



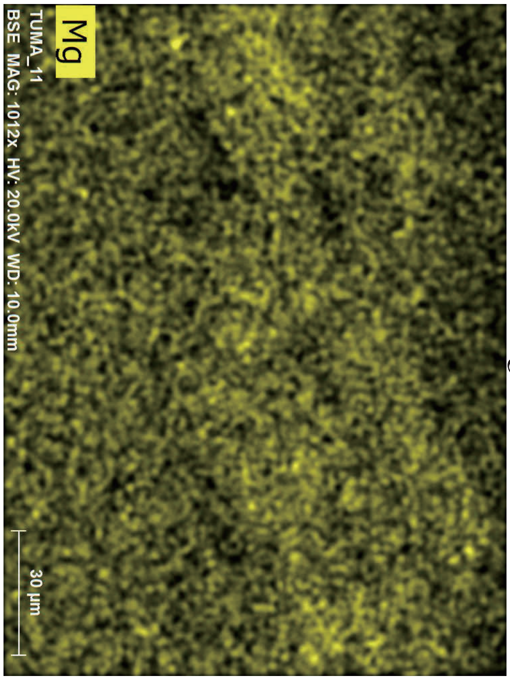
TUMA_11 EDS Potassium (1012x)



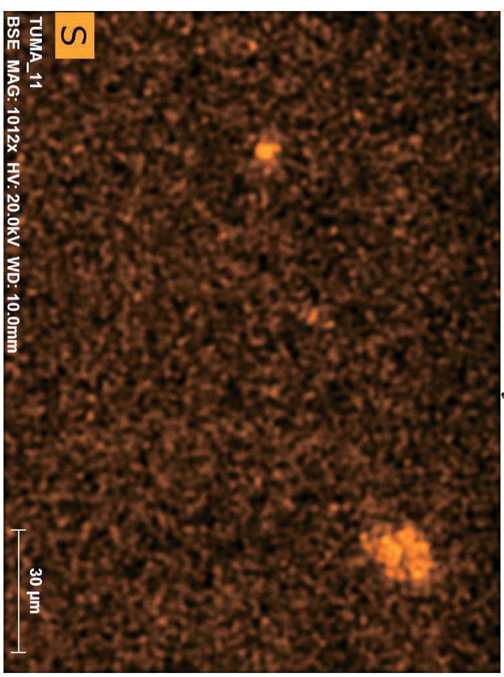
TUMA_11 EDS Oxygen (1012x)

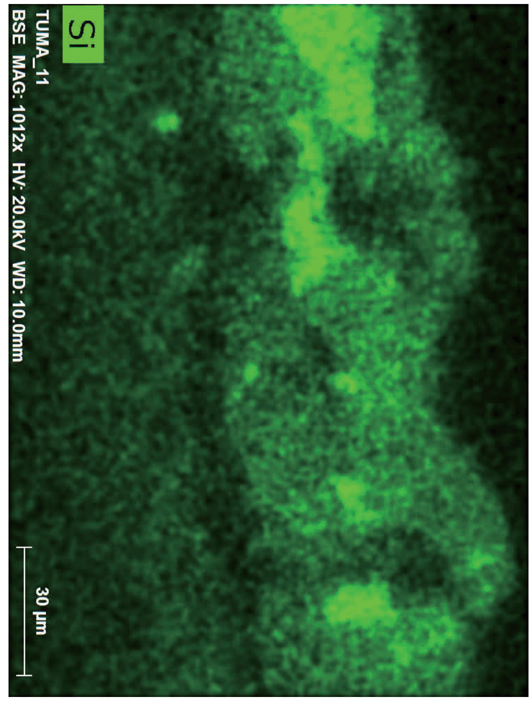


TUMA_11 EDS Magnesium (1012x)



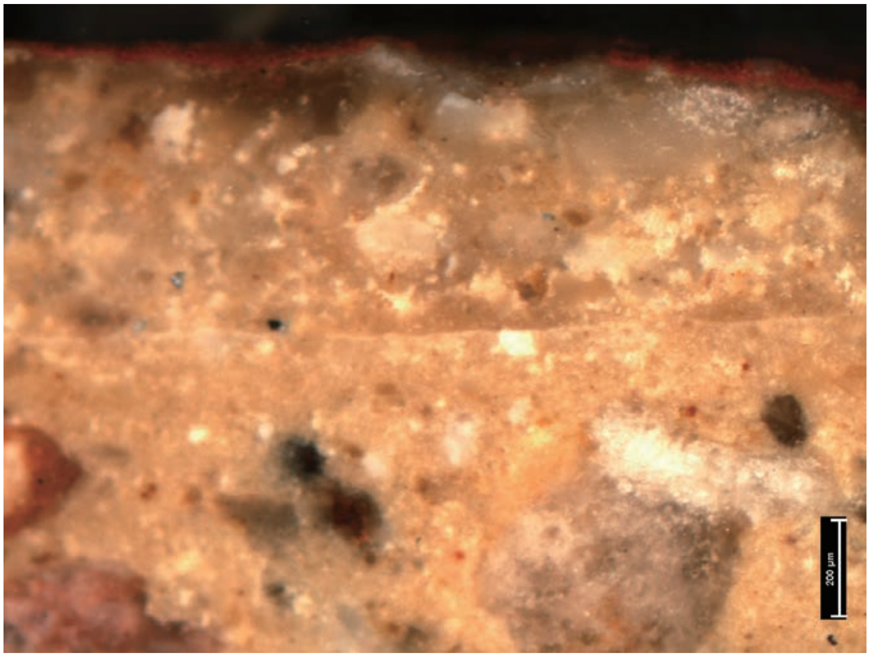
TUMA_11 EDS Sulfur (1012x)



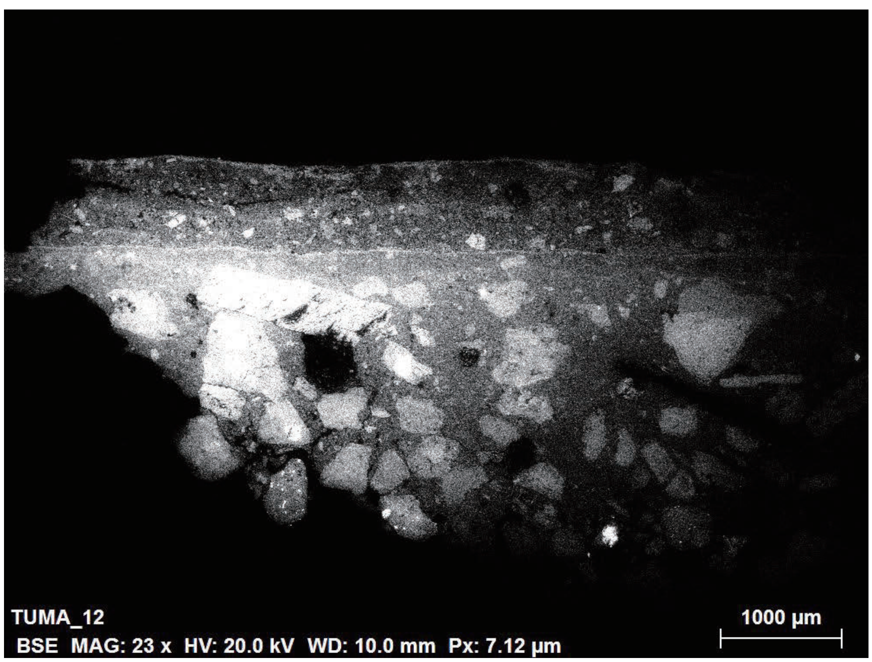


TUMA_11 EDS Silicon (1012x)

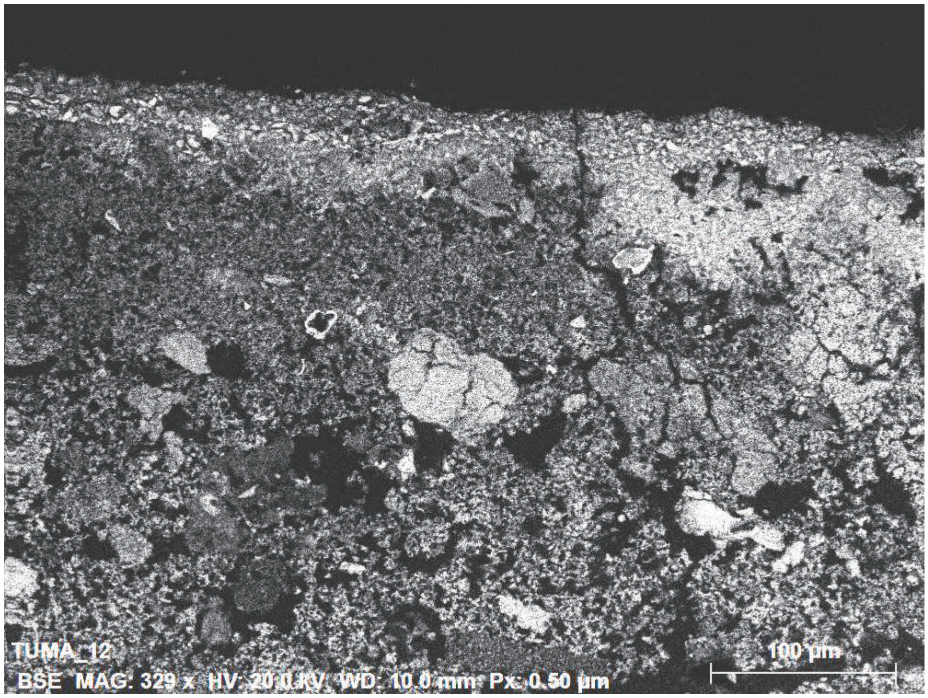
Scientific Research & Analysis Laboratory, Winterthur Museum
TUMA_12 SEM-EDS Data



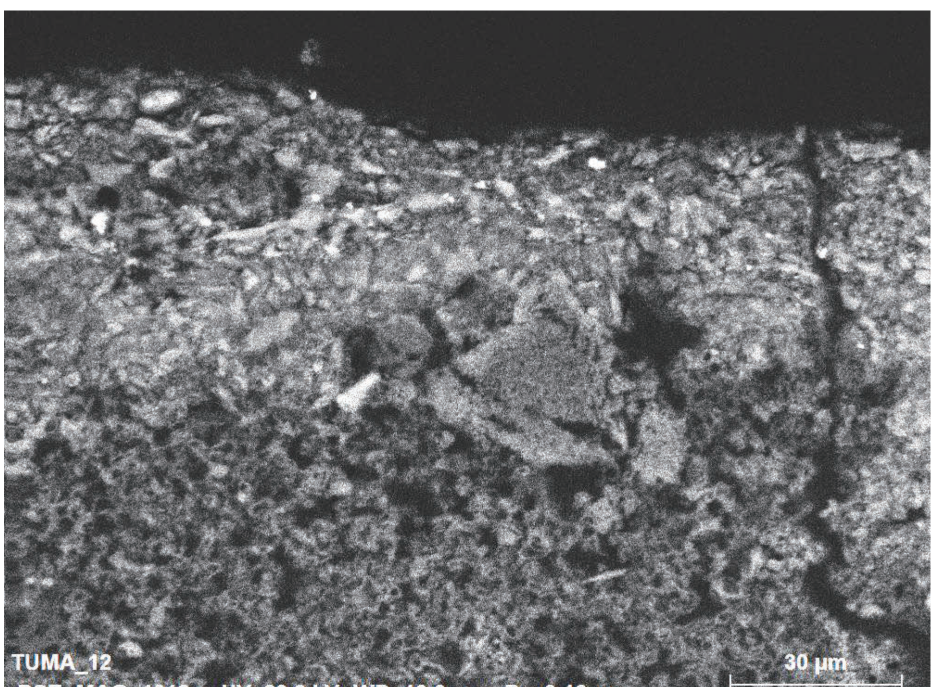
TUMA_12 in visible light at 40x



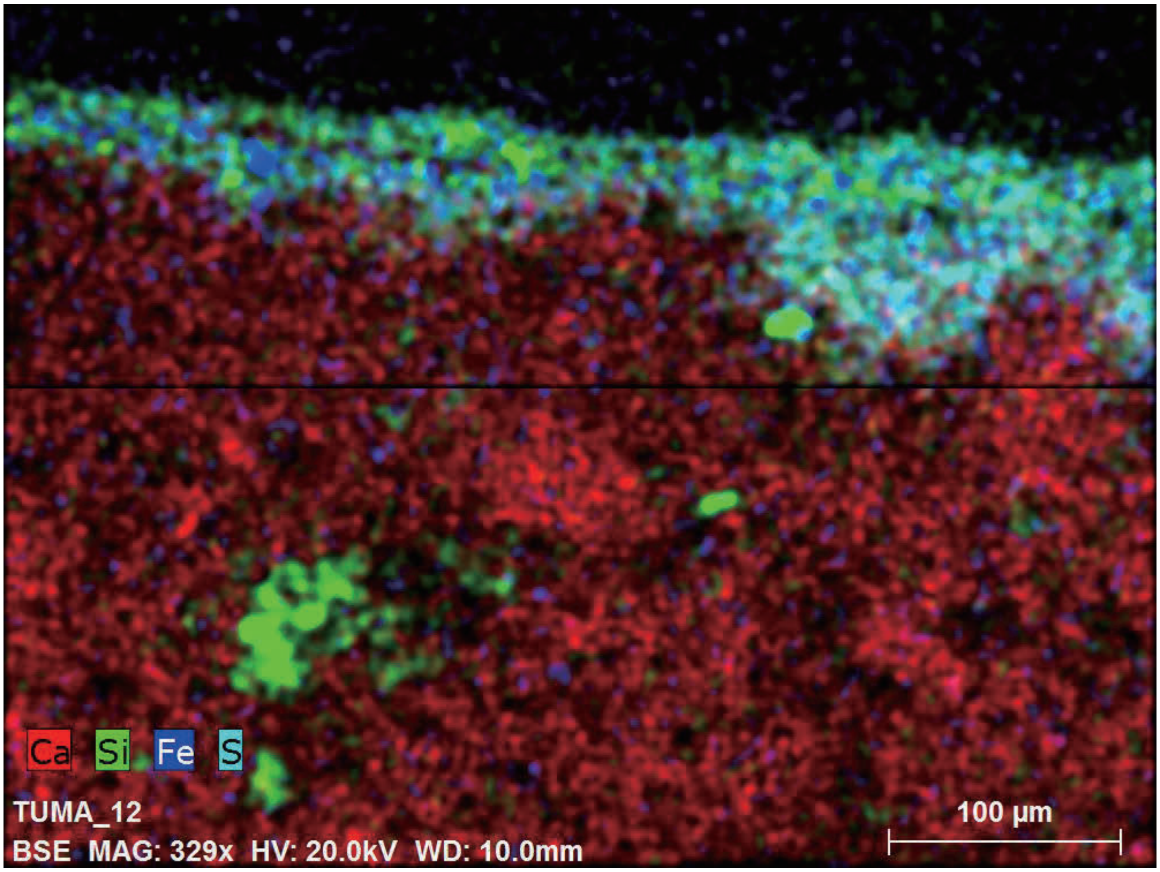
TUMA_12 backscattered electron image from SEM



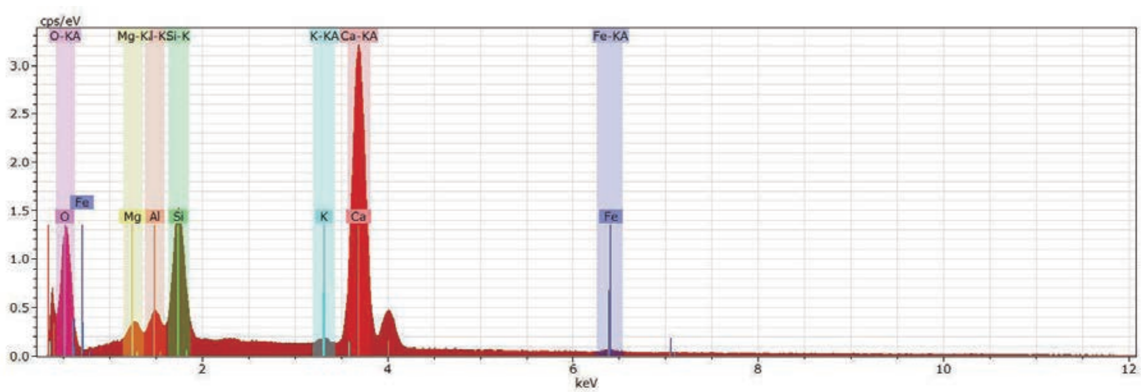
TUMA_12 backscattered electron image at 329x



TUMA_12 backscattered electron image at 1012x

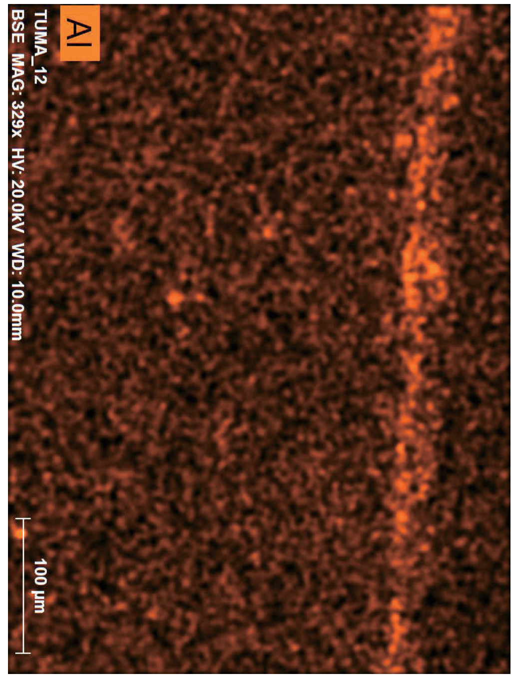


TUMA_12 most abundant elements at 1012x

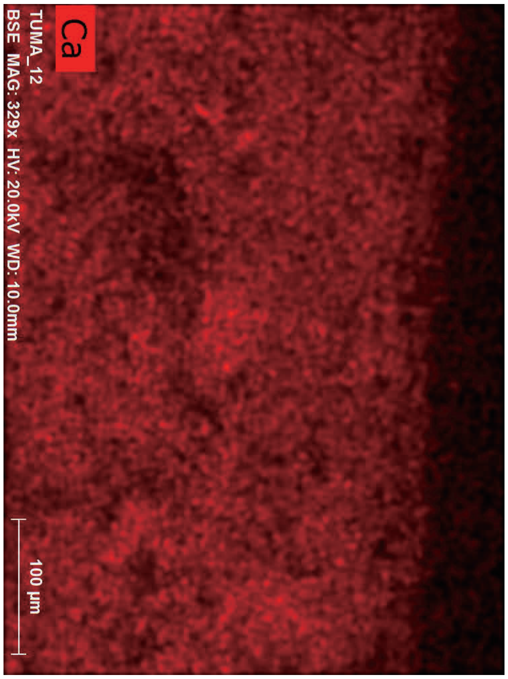


TUMA_12 elemental mapping

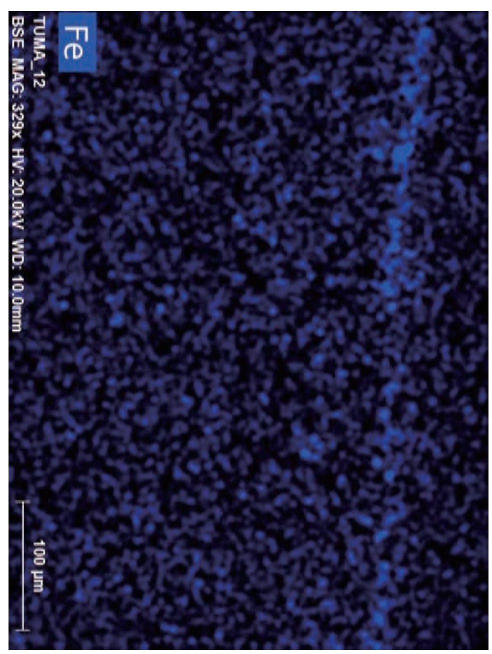
TUMA_12 EDS Aluminum (329x)



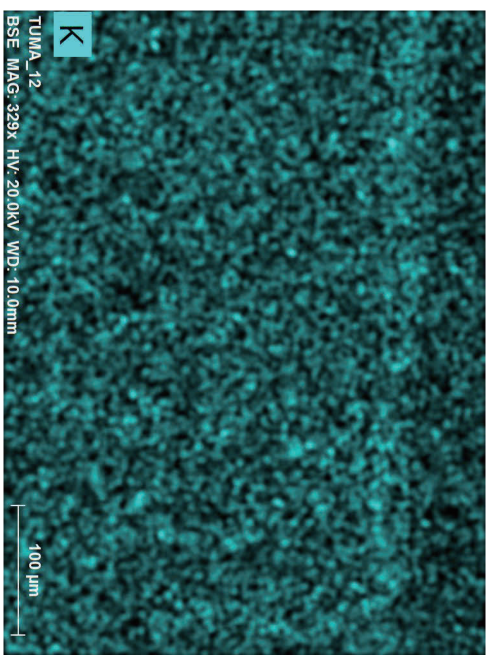
TUMA_12 EDS Calcium (329x)



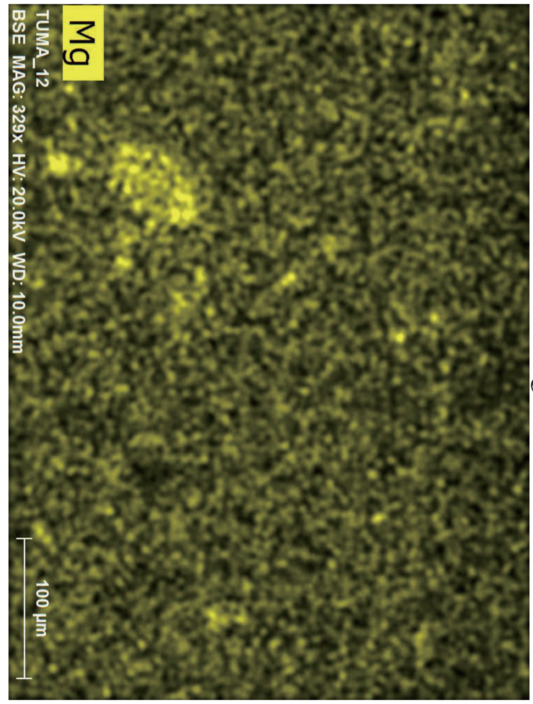
TUMA_12 EDS Iron (329x)



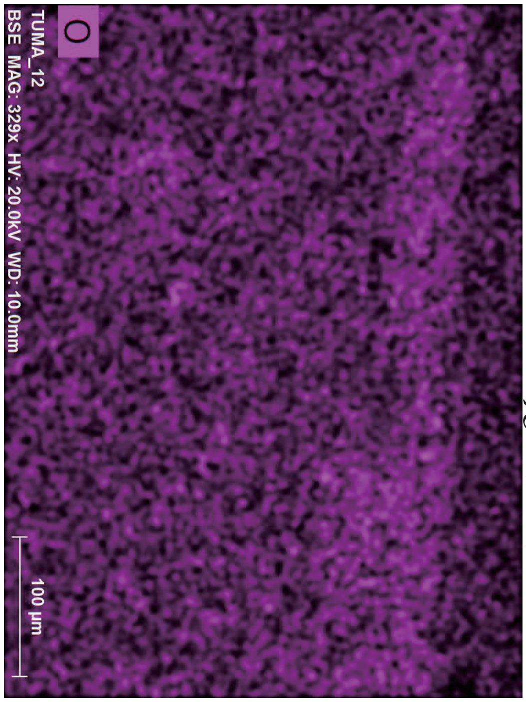
TUMA_12 EDS Potassium (329x)



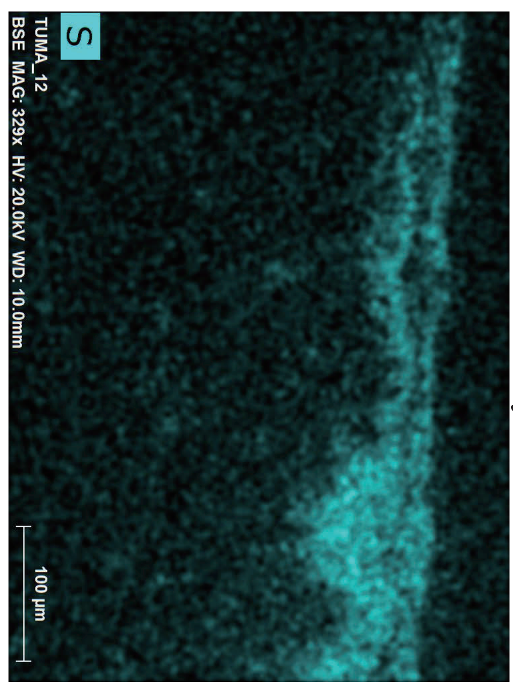
TUMA_12 EDS Magnesium (329x)



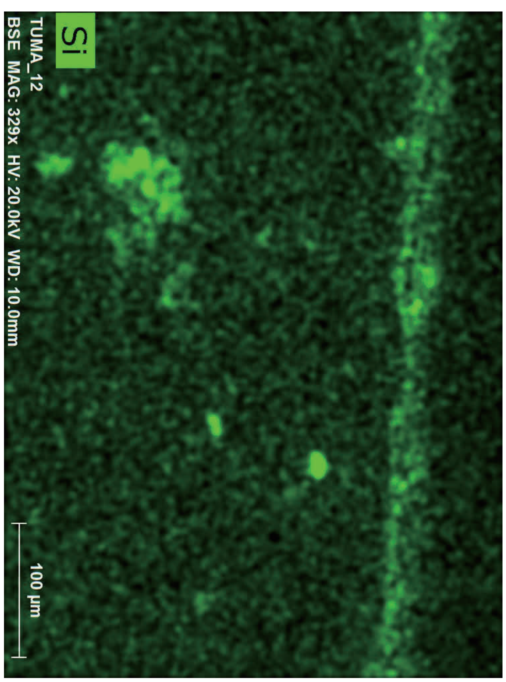
TUMA_12 EDS Oxygen (329x)

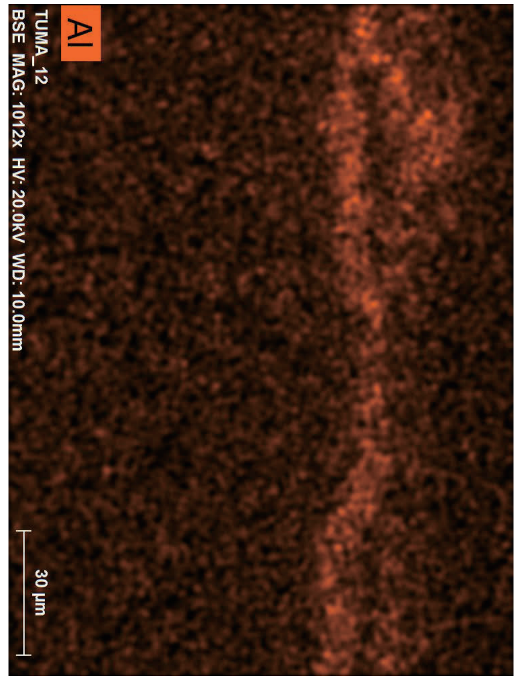


TUMA_12 EDS Sulfur (329x)

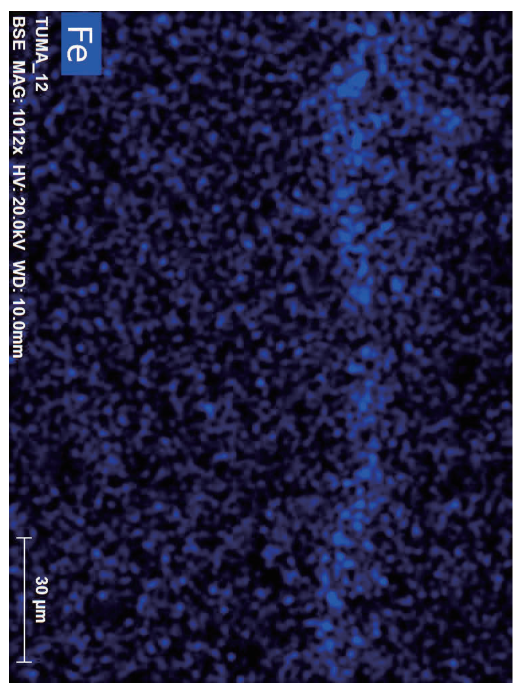


TUMA_12 EDS Silicon (329x)

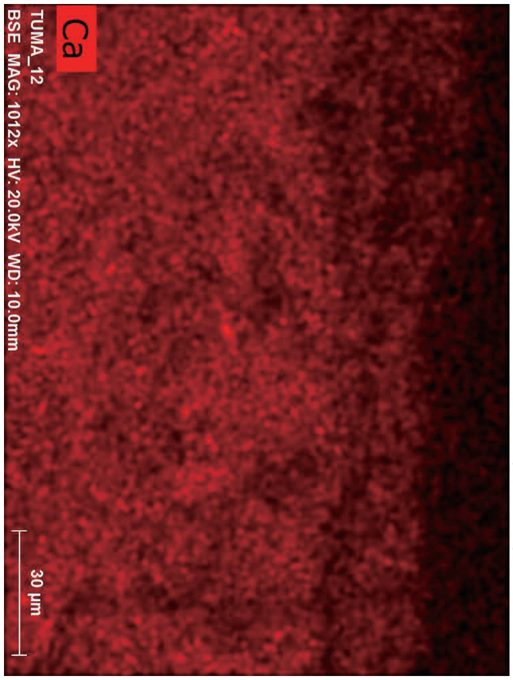




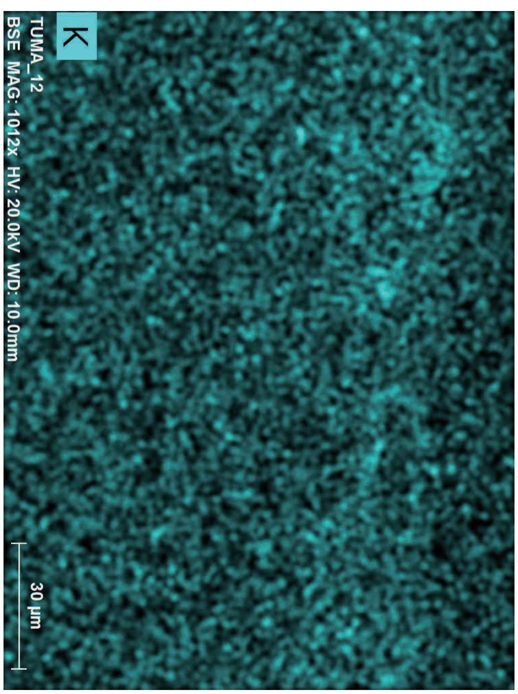
TUMA_12 EDS Aluminum (1012x)



TUMA_12 EDS Iron (1012x)

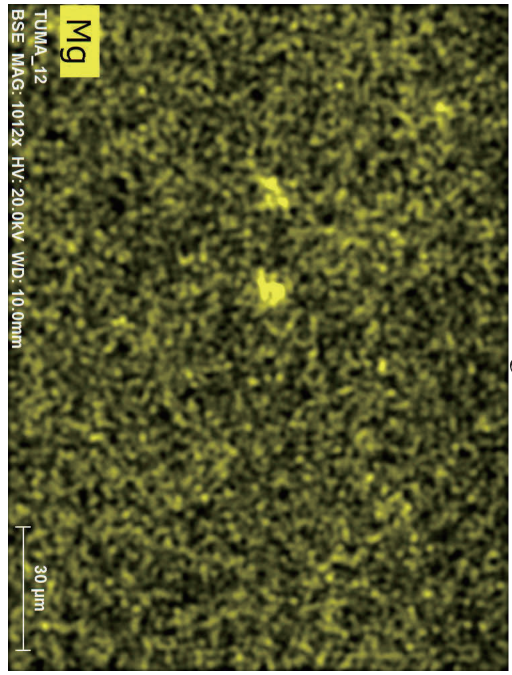


TUMA_12 EDS Calcium (1012x)

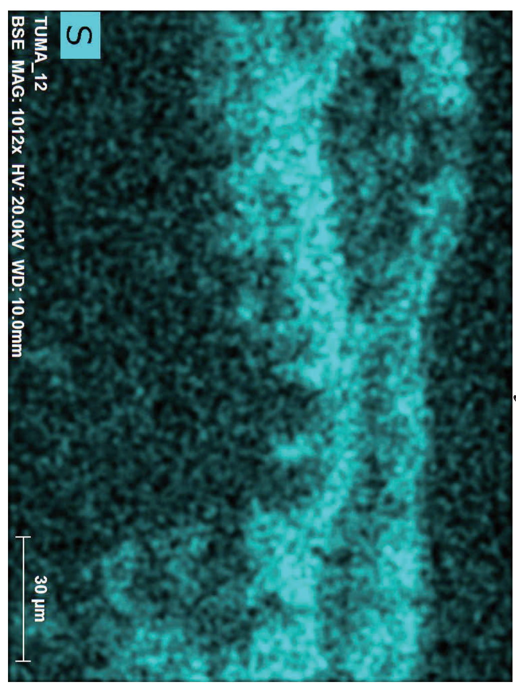


TUMA_12 EDS Potassium (1012x)

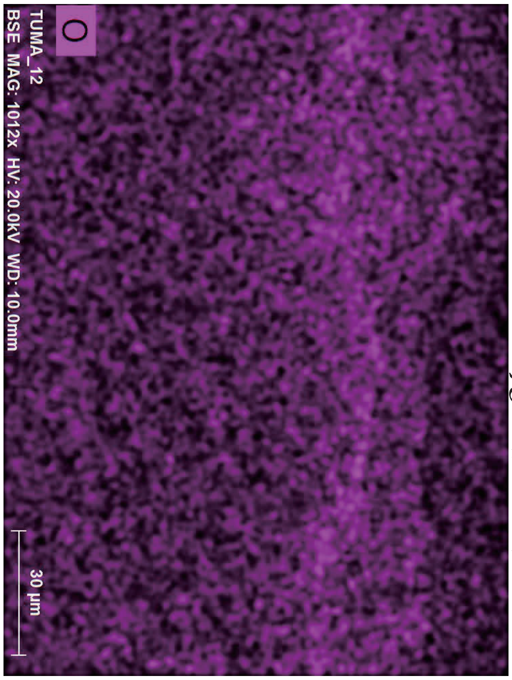
TUMA_12 EDS Magnesium (1012x)



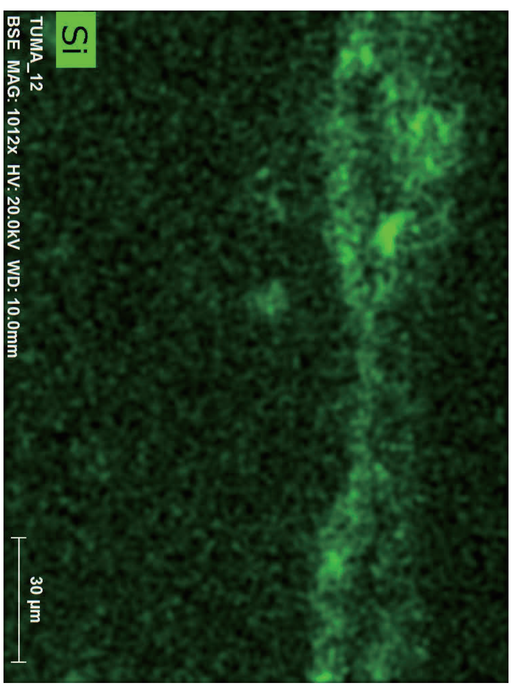
TUMA_12 EDS Sulfur (1012x)



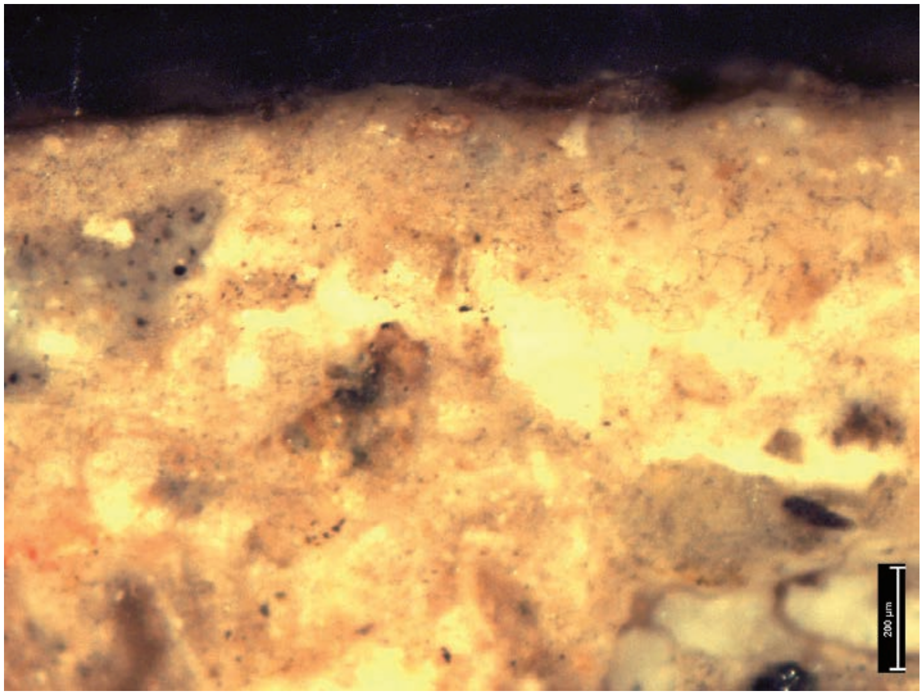
TUMA_12 EDS Oxygen (31012x)



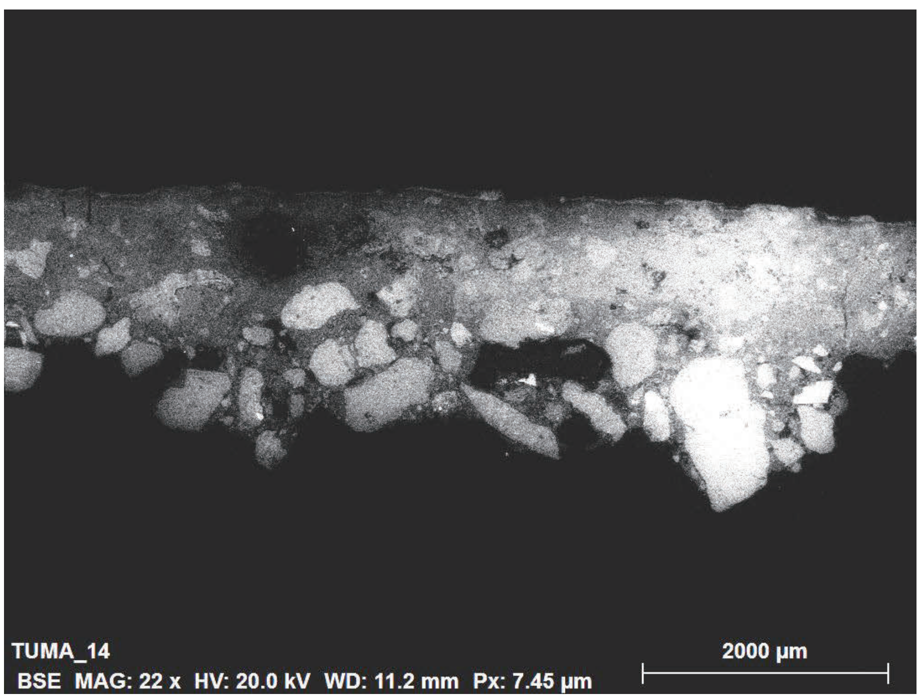
TUMA_12 EDS Silicon (1012x)



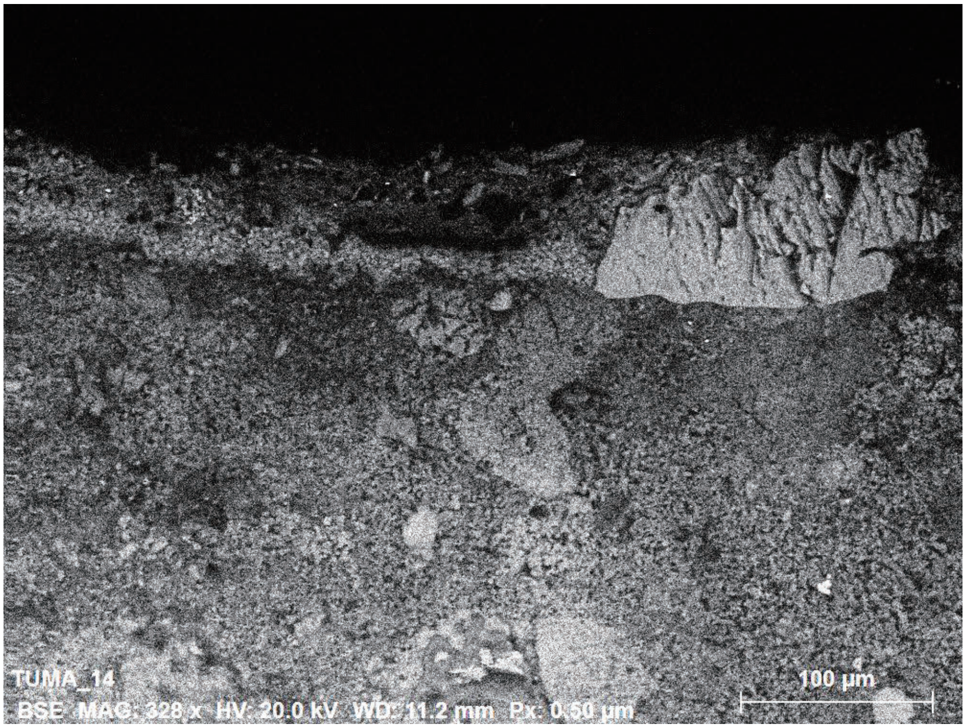
Scientific Research & Analysis Laboratory, Winterthur Museum
TUMA_14 SEM-EDS Data



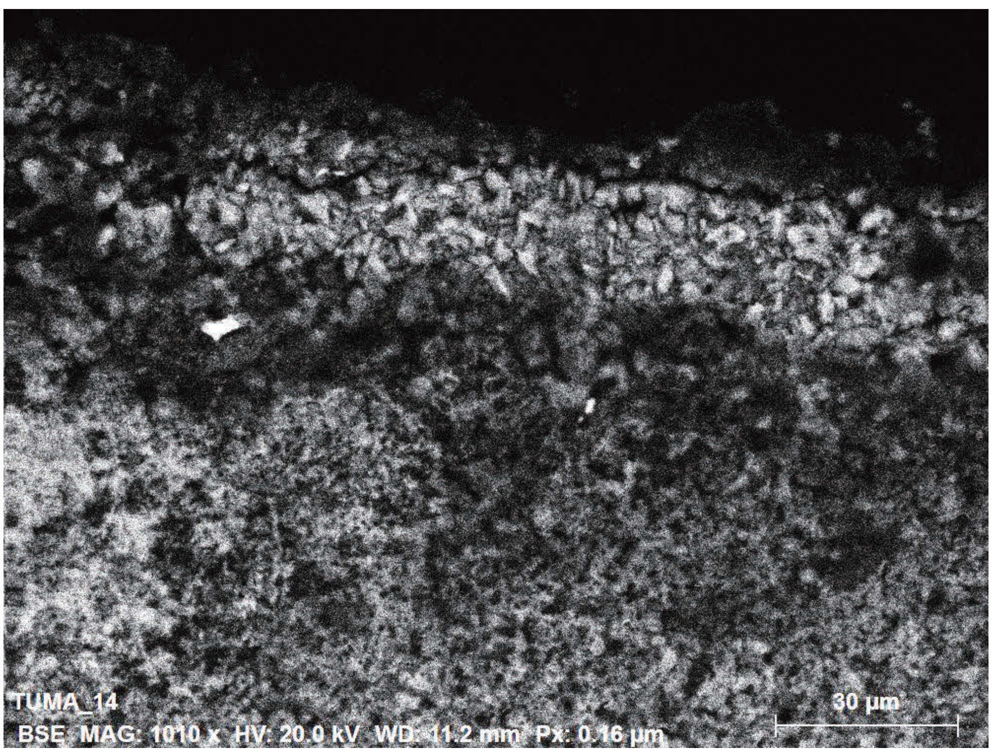
TUMA_14 in visible light at 40x



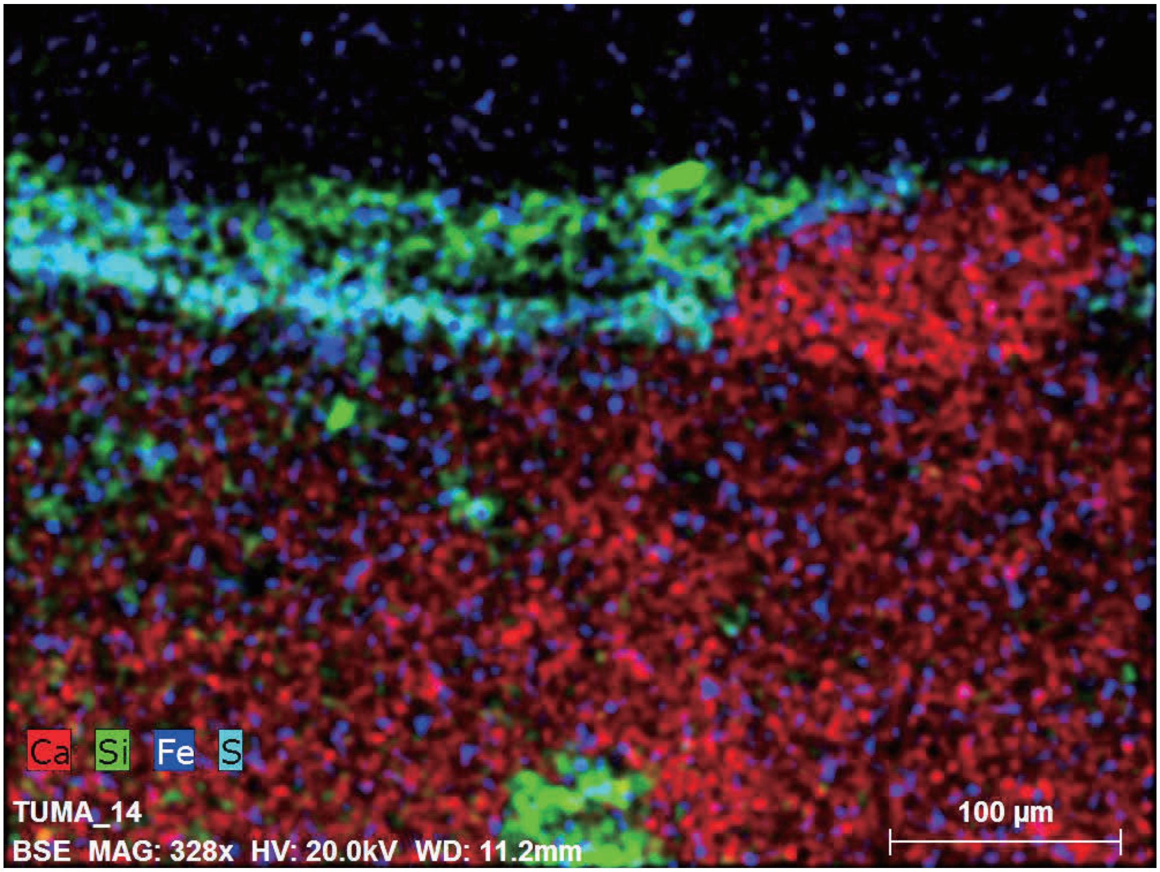
TUMA_14 backscattered electron image from SEM



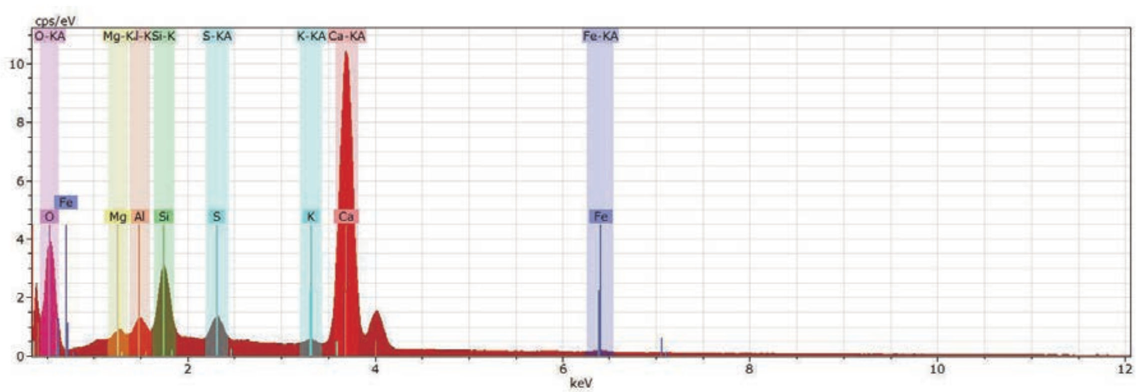
TUMA_14 backscattered electron image at 329x



TUMA_14 backscattered electron image at 1012x

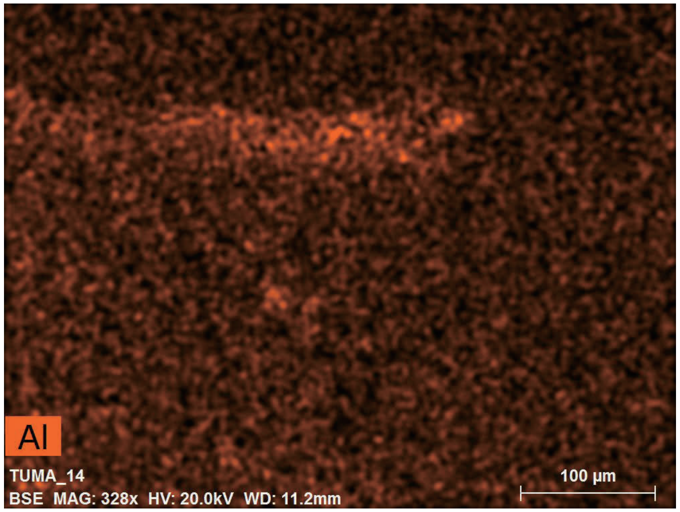


TUMA_14 most abundant elements at 328x

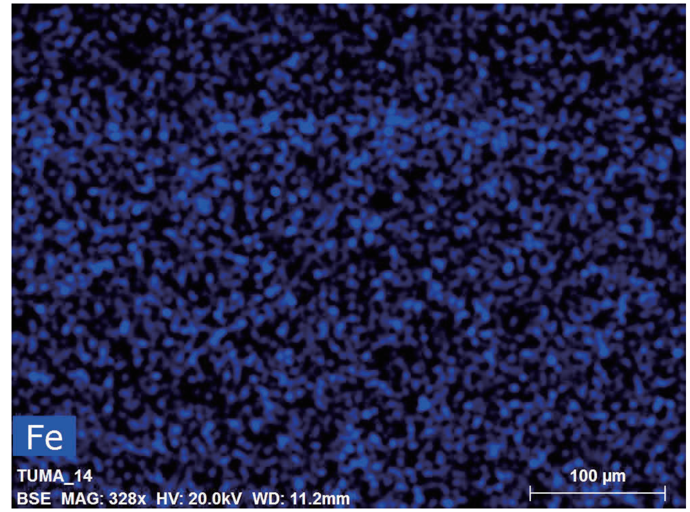


TUMA_14 elemental mapping

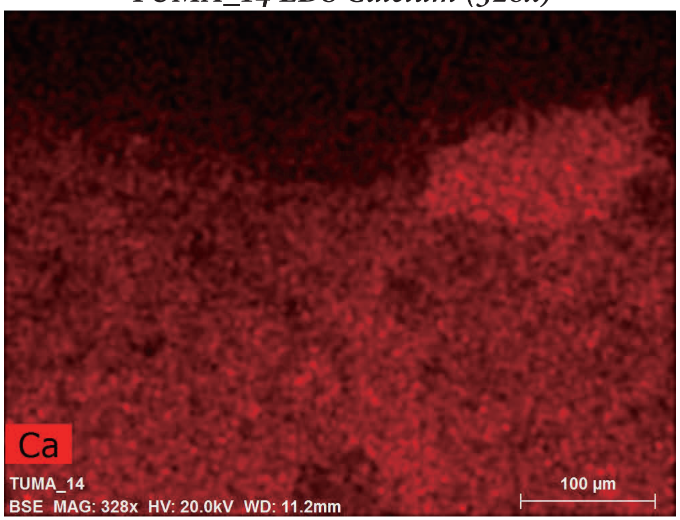
TUMA_14 EDS Aluminum (328x)



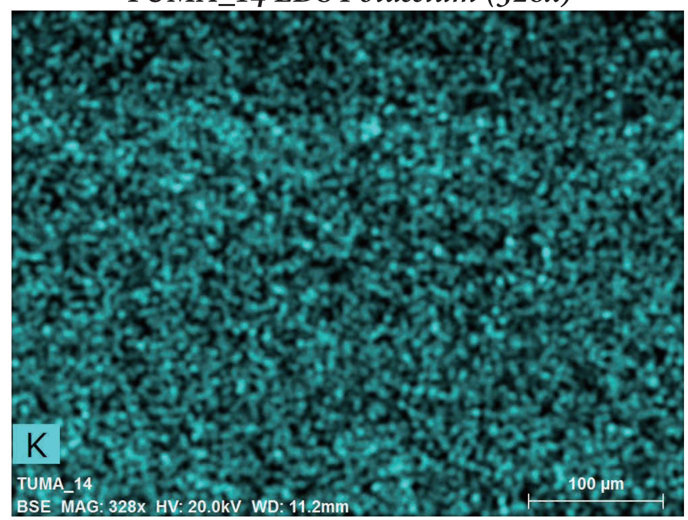
TUMA_14 EDS Iron (328x)



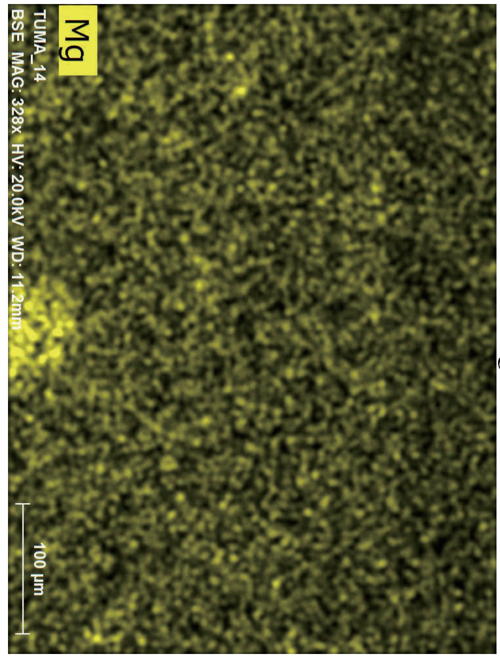
TUMA_14 EDS Calcium (328x)



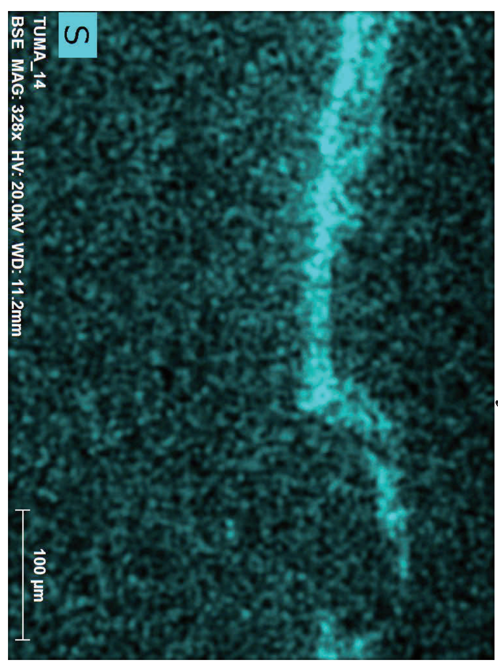
TUMA_14 EDS Potassium (328x)



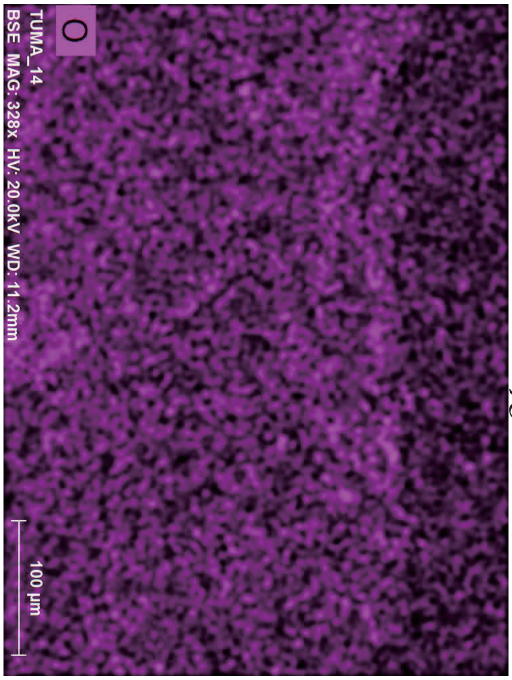
TUMA_14 EDS Magnesium (328x)



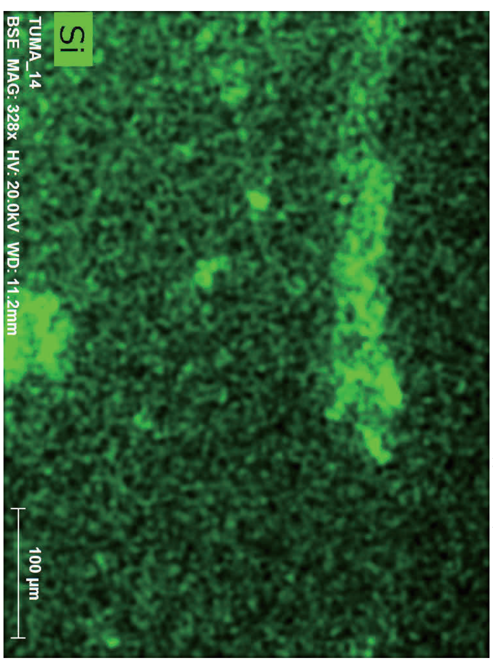
TUMA_14 EDS Sulfur (328x)



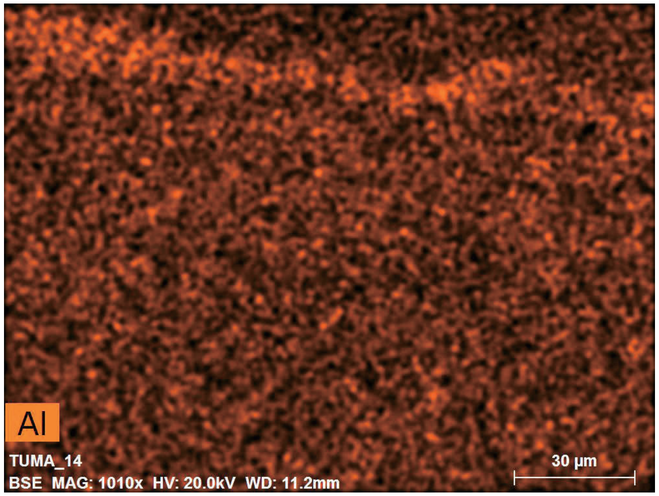
TUMA_14 EDS Oxygen (328x)



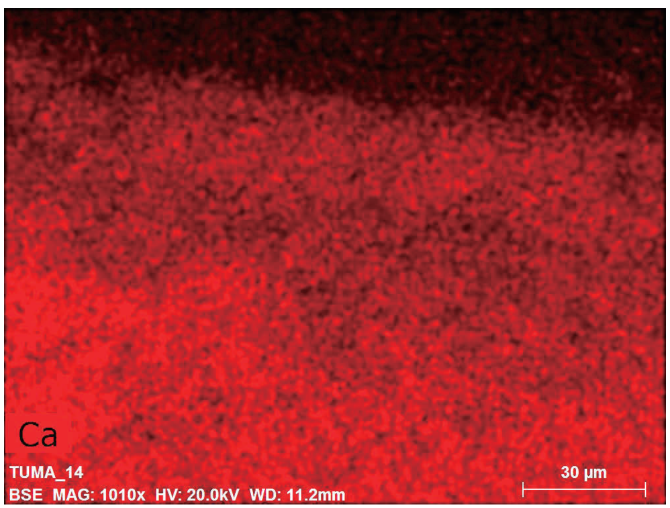
TUMA_14 EDS Silicon (328x)



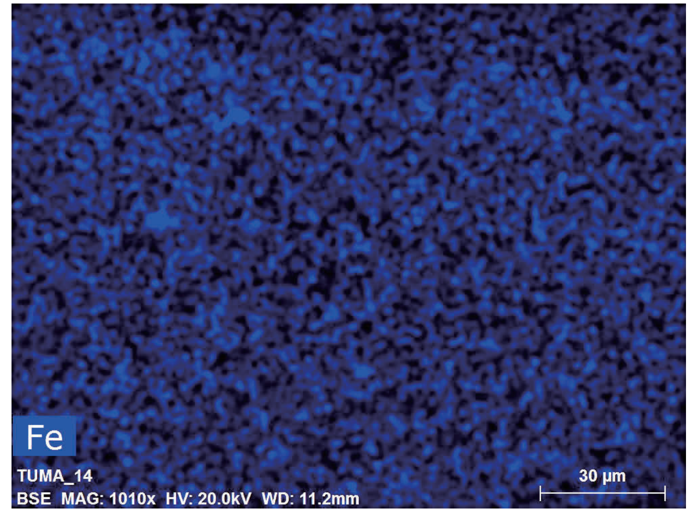
TUMA_14 EDS Aluminum (1010x)



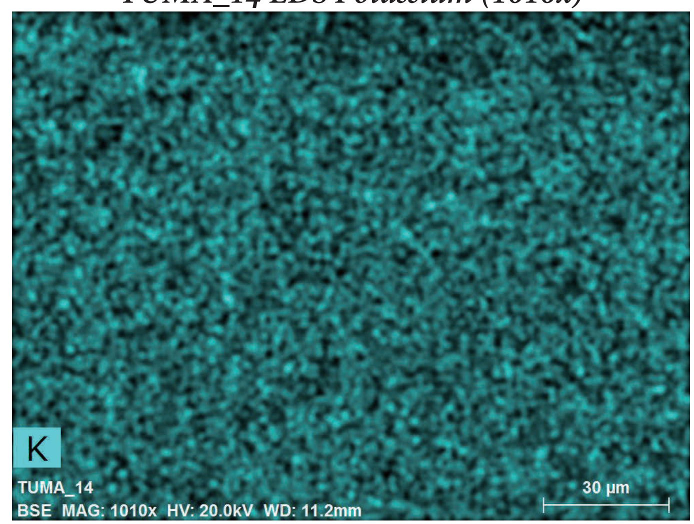
TUMA_14 EDS Calcium (1010x)

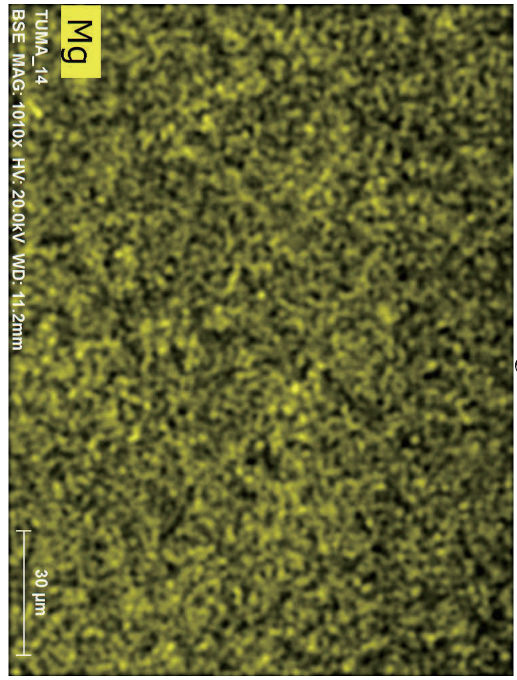


TUMA_14 EDS Iron (1010x)

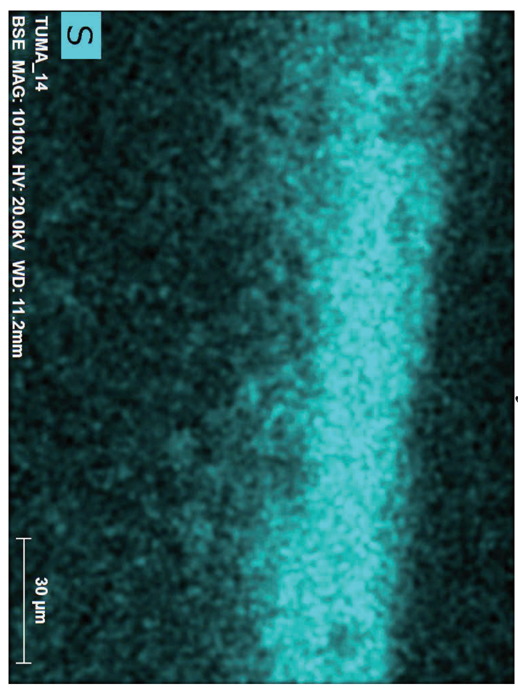


TUMA_14 EDS Potassium (1010x)

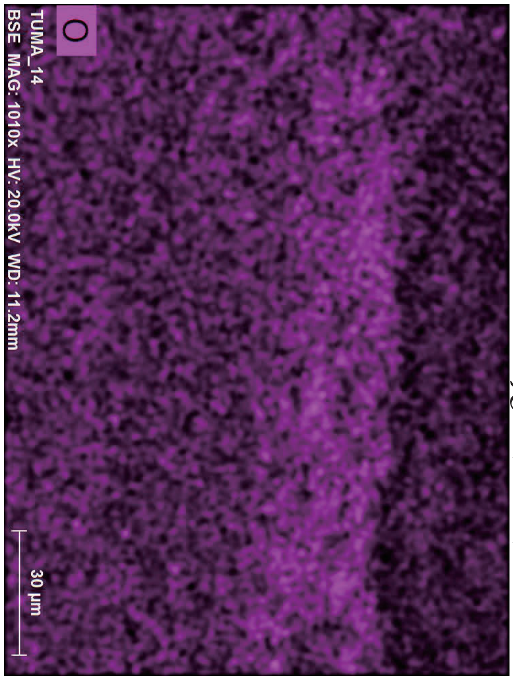




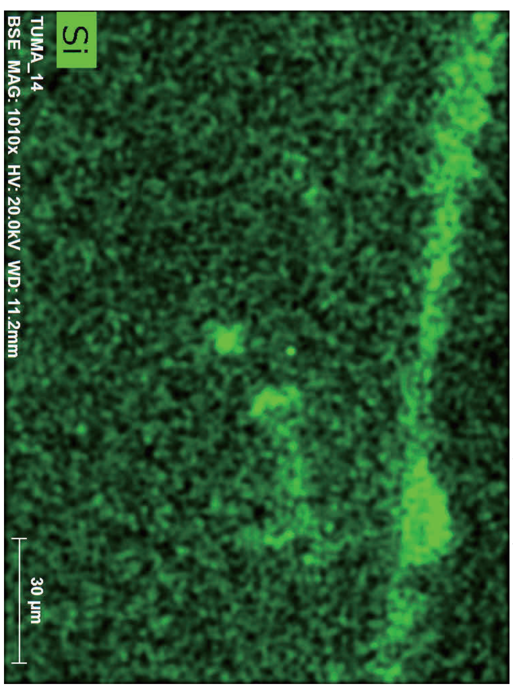
TUMA_14 EDS Magnesium (1010x)



TUMA_14 EDS Sulfur (1010x)



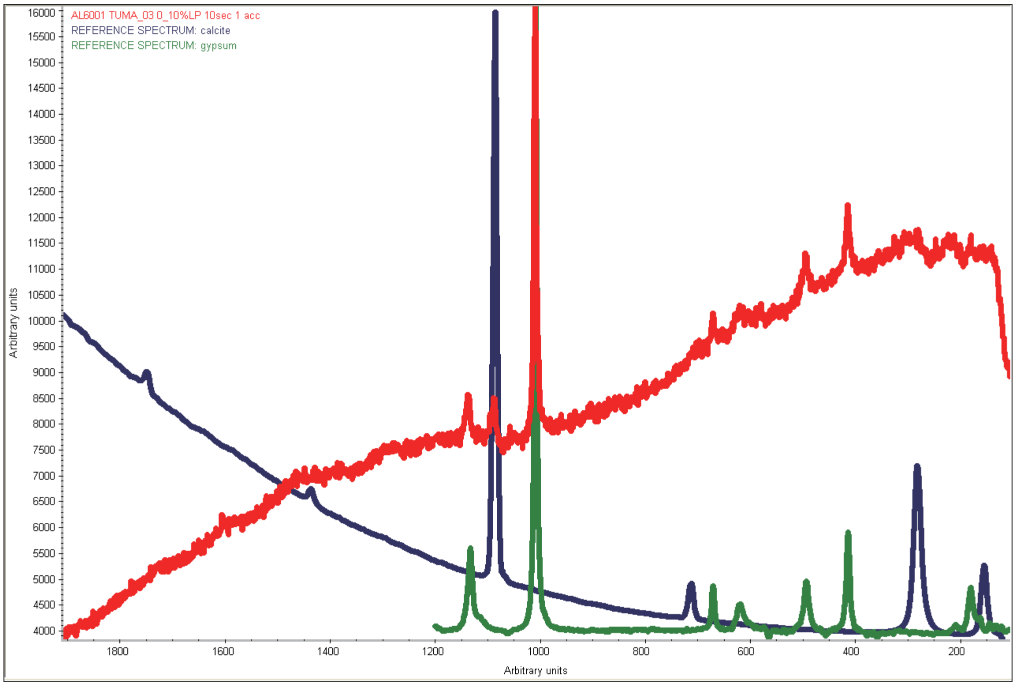
TUMA_14 EDS Oxygen (1010x)

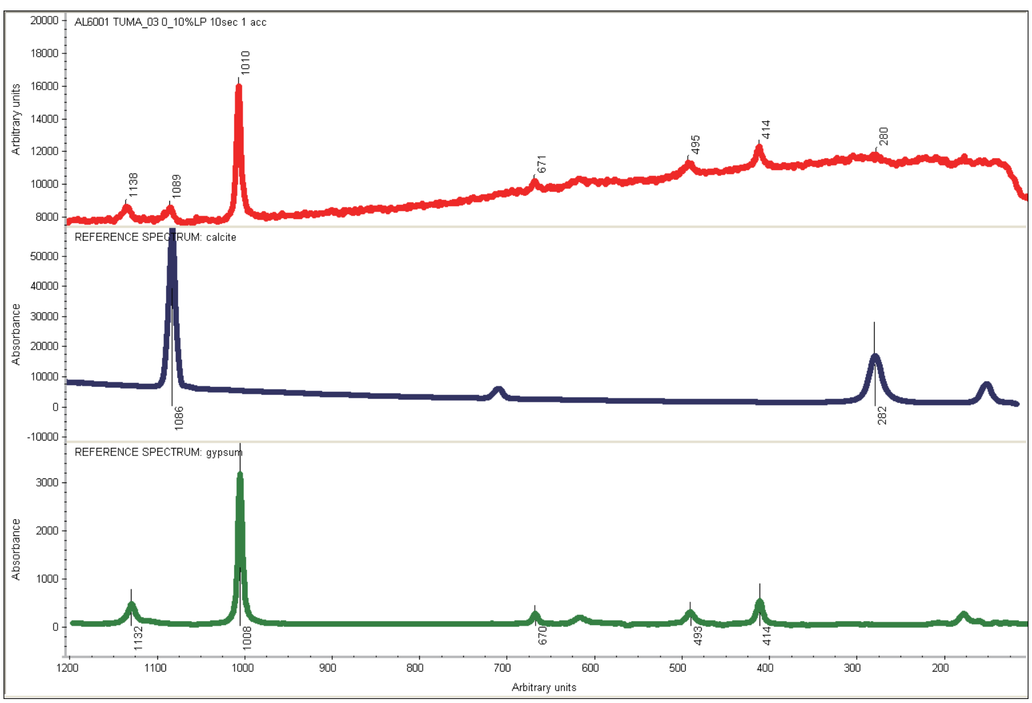


TUMA_14 EDS Silicon (1010x)

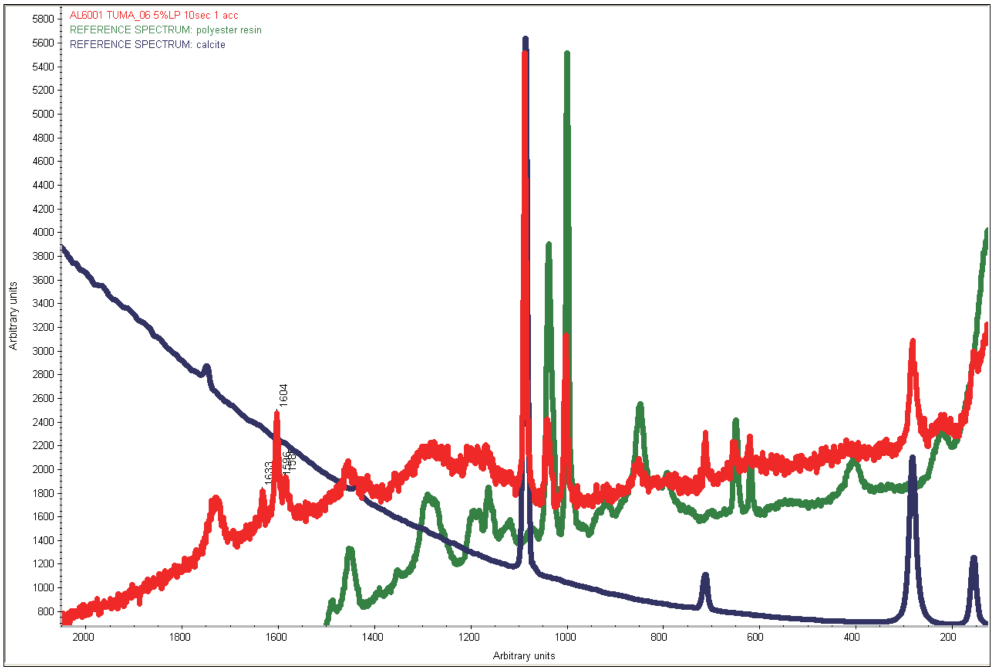
Appendix F: Raman Microscopy and FTIR Data Sets

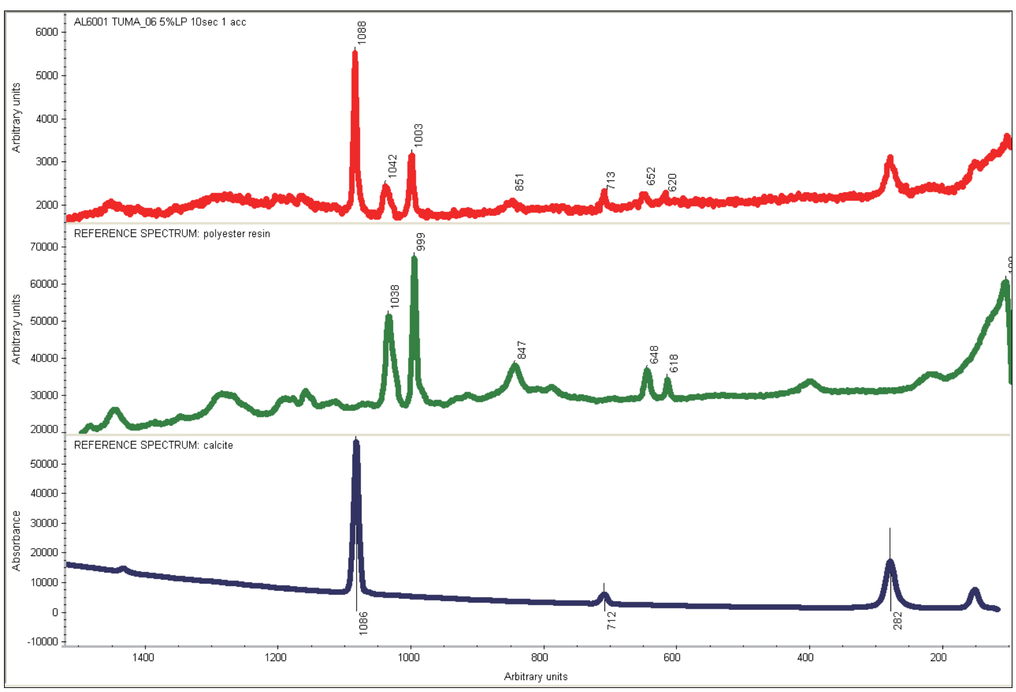
Scientific Research & Analysis Laboratory, Winterthur Museum
TUMA_03 Raman Microscopy Data



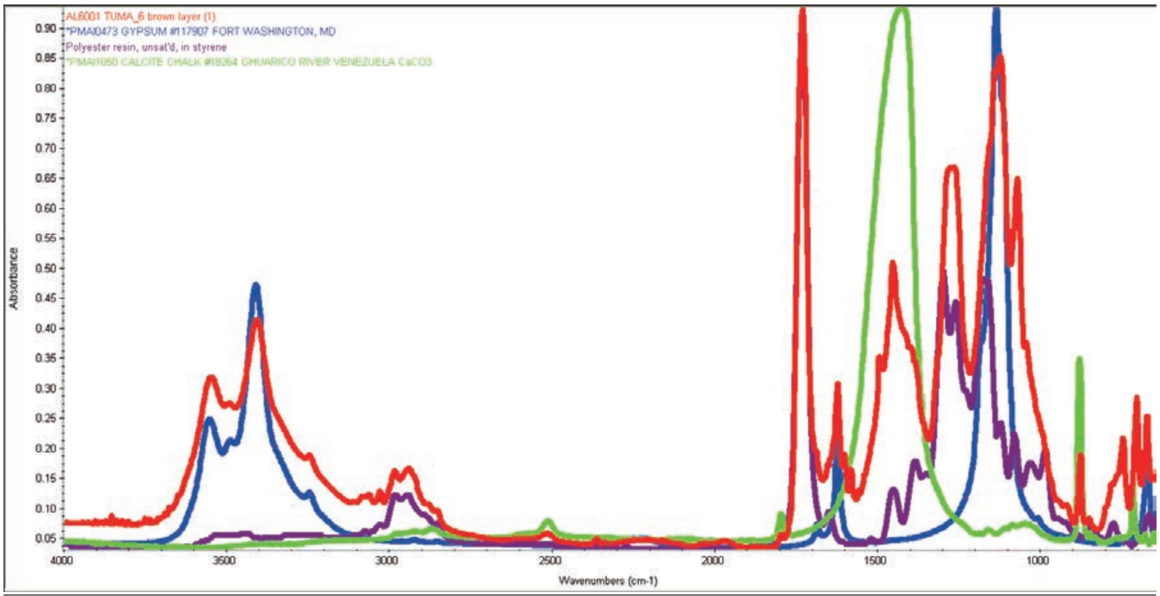


Scientific Research & Analysis Laboratory, Winterthur Museum
TUMA_06 Raman Microscopy Data

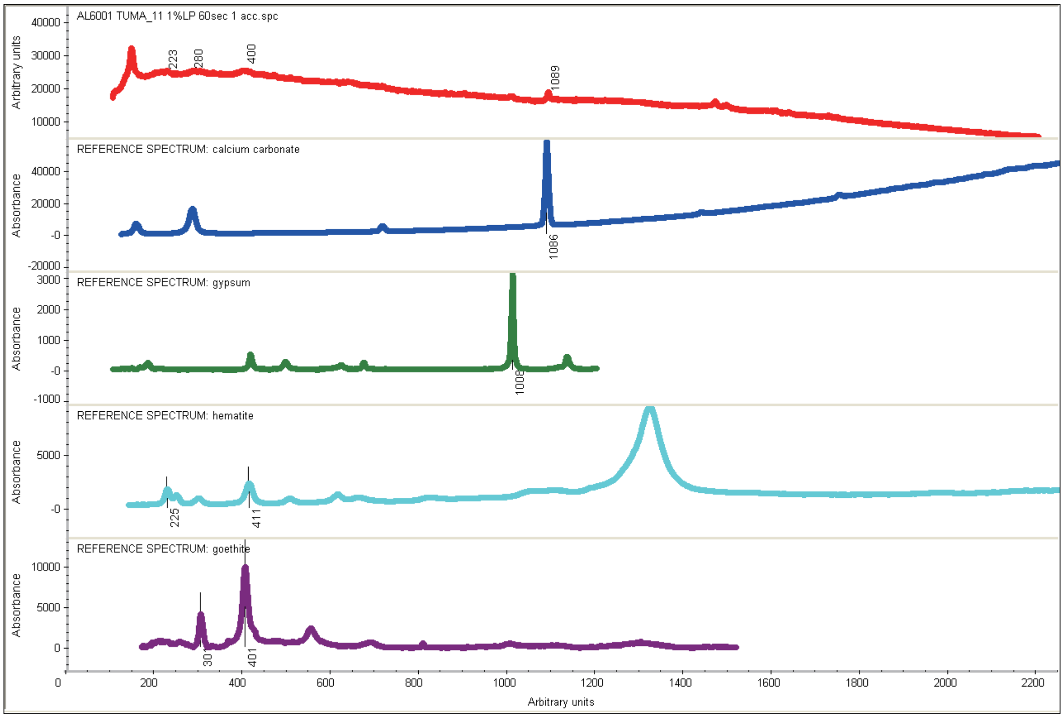




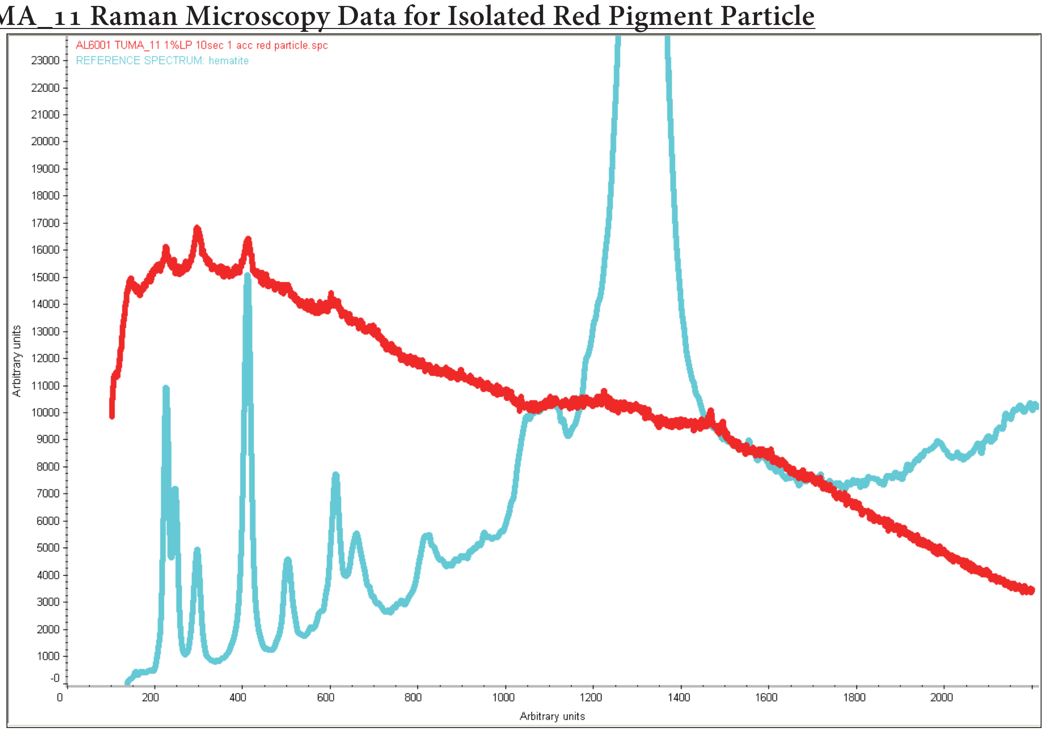
TUMA_06 FTIR Data



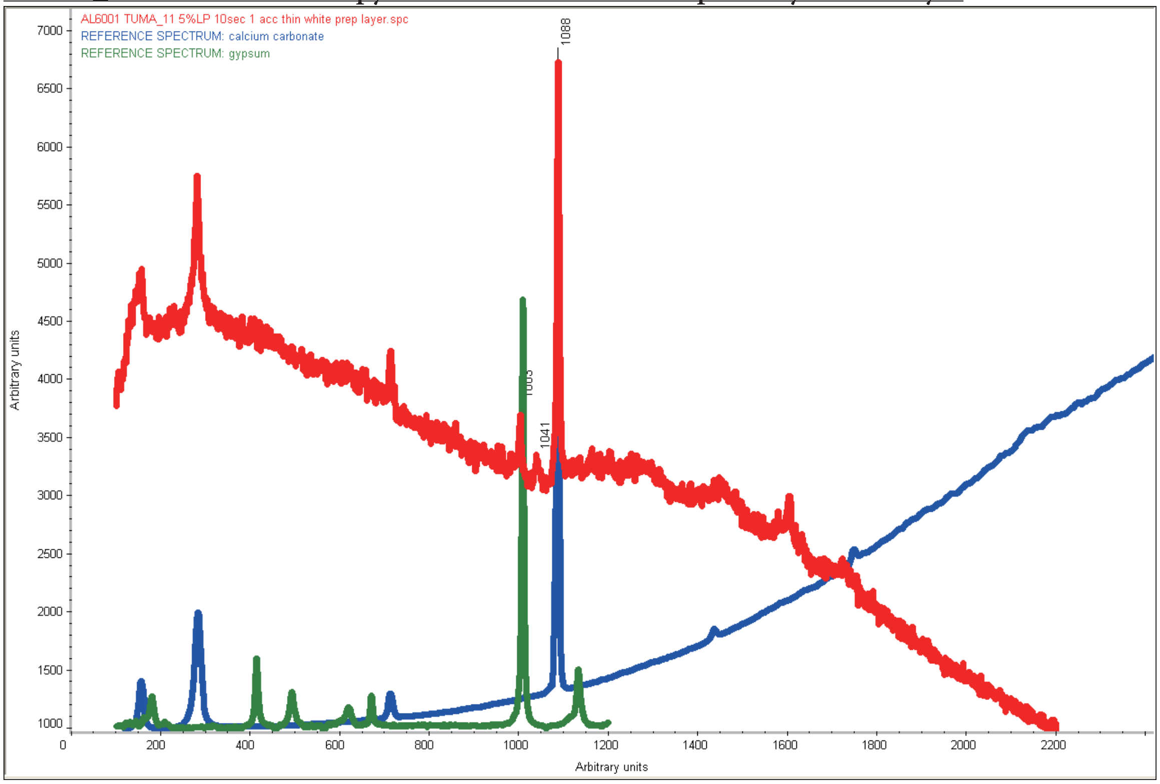
Scientific Research & Analysis Laboratory, Winterthur Museum
TUMA_11 Raman Microscopy Data



TUMA_11 Raman Microscopy Data for Isolated Red Pigment Particle

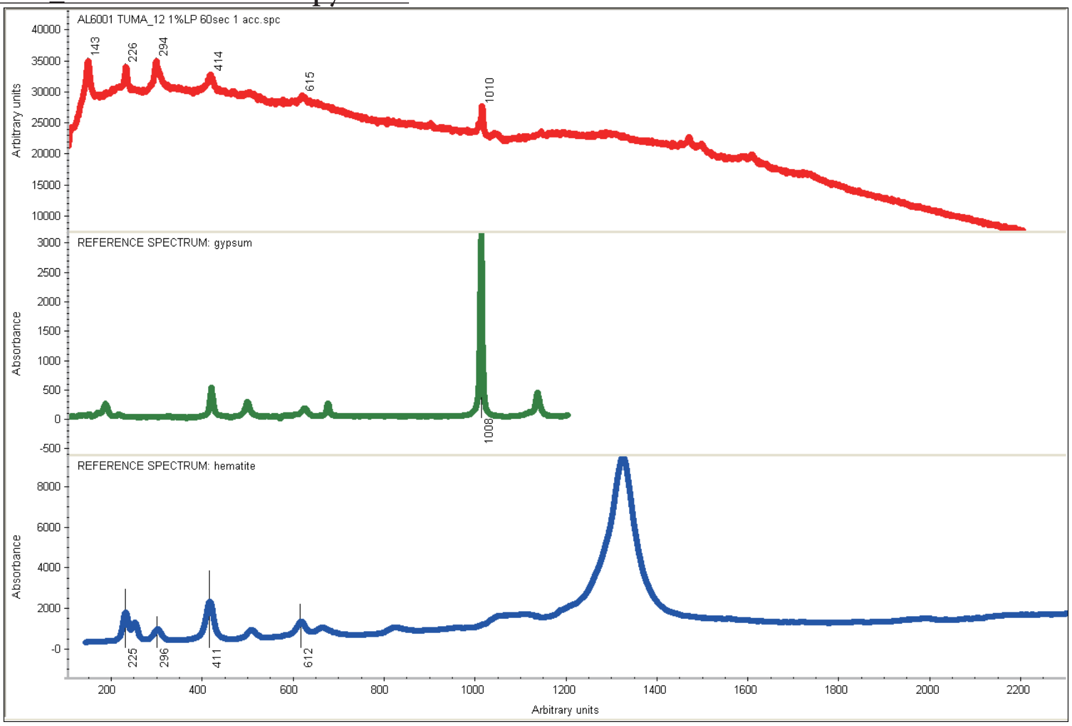


TUMA_11 Raman Microscopy Data for Thin White Preparatory Finish Layer

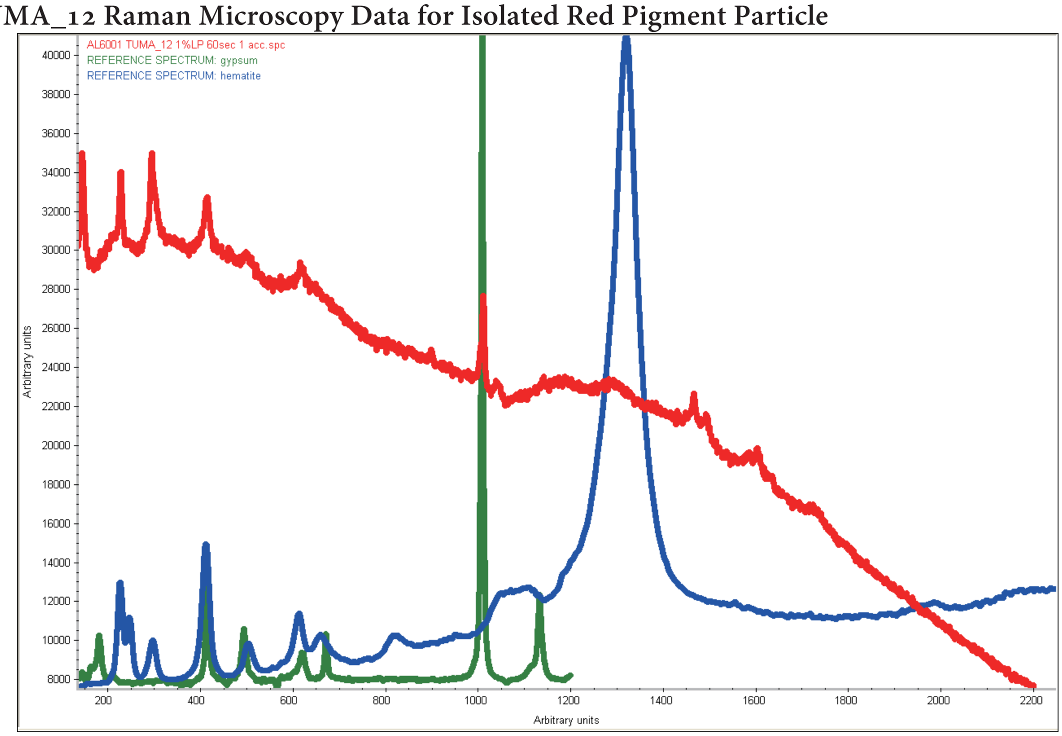


Scientific Research & Analysis Laboratory, Winterthur Museum

TUMA_12 Raman Microscopy Data



TUMA_12 Raman Microscopy Data for Isolated Red Pigment Particle



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