2013

Unveiling Ancestral Iconography: An Analysis of 13th C. AD Earthen Finishes Through Infrared Thermography at Fire Temple, Mesa Verde National Park

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Abstract

Infrared thermography has been an increasingly applicable diagnostic tool in the nondestructive testing of heritage objects. By measuring the surface temperature and emissivity, infrared thermography is measures heat radiation. Thermography has the ability to investigate objects without contact or causing any deleterious effects. This thesis aims to apply infrared thermography technology to evaluate earthen architectural finishes, and with the intent for subsurface identification of over-painted images. Evidence-based results from both passive and active thermography methods on test facsimiles will inform the efficacy of the technique on earthen finishes, and its applicability to in-situ testing on the north wall of Fire Temple at Mesa Verde National Park.

Keywords

infrared, thermography, nondestructive, fire temple, finishes

Disciplines

Historic Preservation and Conservation

Comments

Suggested Citation:

Castele, Daniel Stuart (2013). *Unveiling Ancestral Iconography: An Analysis of 13th C. AD Earthen Finishes Through Infrared Thermography at Fire Temple, Mesa Verde National Park*. (Masters Thesis). University of Pennsylvania, Philadelphia, PA.

UNVEILING ANCESTRAL ICONOGRAPHY:
AN ANALYSIS OF 13TH C. AD EARTHEN FINISHES THROUGH INFRARED THERMOGRAPHY AT FIRE TEMPLE, MESA VERDE NATIONAL PARK

Daniel Stuart Castele

A THESIS

In

Historic Preservation

Presented to the Faculties of the University of Pennsylvania
in Partial Fulfillment of the Requirements of the Degree of

MASTER OF SCIENCE IN HISTORIC PRESERVATION

2013

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To my mother,
whose labor with me has lasted these 25 years.

Acknowledgments

I would like to thank Frank G. Matero for all of his teaching, direction, and guidance throughout my years at the University of Pennsylvania. Without Professor Matero, this thesis would not be possible.

I would like to thank the National Park Service, especially Kay Barnett and Tim Hovezak.

A special thanks is owed to Walter Molishus II and the University of Pennsylvania Utilities Operations for lending me the infrared camera to use.

Victoria Pingarron-Alvarez has been a crucial and integral part of the process from beginning to end. I would like to thank her for all the time she committed problem solving with me.

Joe Torres has been a trusted colleague and has helped countless times with computer issues, computer processes, and image processing. Thanks Joe.

Molly Lester has been infinitely patient in reviewing the formatting for this thesis. Thanks Molly for all your help.

Amanda Bloomfield has been an integral liaison by scheduling appointments with my thesis advisor (Frank Matero).

I would also like to thank John Hinchman for being an advisor on digital processes.

Lindsay Falk is owed thanks due to his construction mentoring during our time at Gordion, Turkey.

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Chapter 1: Nondestructive Testing

1.1 Established Nondestructive Testing Techniques

Optical Examination

The oldest nondestructive testing method is visual observation. A trained conservator can accurately identify material pathologies and discern deterioration mechanisms beginning in the field. Visual observation is always the first method applied, and in most cases is the most informative about the test object before other instrumental methods are employed. Visual field inspection may be augmented by instrumental aids such as boroscopes, crack and tilt-meters, high-resolution cameras, and fiber optics for documentation.

Ground Penetrating Radar

Ground Penetrating Radar (GPR) has been utilized in conservation and preservation of heritage for quite some time. Also known as surface penetrating radar, GPR can detect subsurface anomalies by inducing the material with pulses of electro-magnetic waves in the microwave (approximately 10^{-2} meters). This long wavelength about 0.8 ns long, low frequency energy is then reflected back to a receiving device. (Figure 1.1).[1]

[1] Frank B. Holt, and Roy A. Eckrose, *The Application of Ground-Penetrating Radar and Infrared Thermography to Pavement Evaluation*, ASTM International (1989), 105-115.

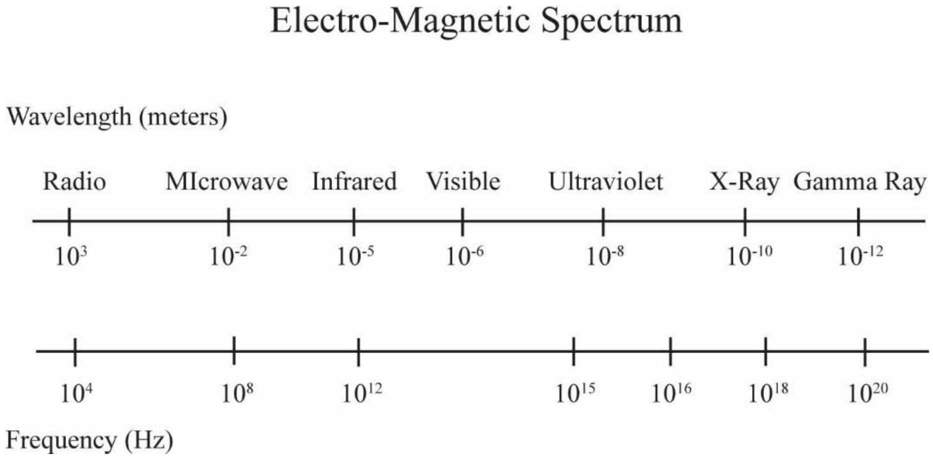

Figure 1.1 Diagram of electromagnetic spectrum. Illustration done by author.

Where the energy encounters voids or anomalies, the reflected pattern is different than the surrounding material. This is because of differential dialectic constants in different materials. By measuring the time of flight of the reflected pulse, the depth of the object is discernible. For instance, the frequencies used during for most masonry testing are generally accurate to 24 inches.[2]

Buried foundations, soil displacement, pavement evaluations, and hidden concealed graves are just a few of the many applications of GPR. GPR can also reveal blind headers, embedded veneer headers, and fluxes in moisture content. It is often the test chosen when detecting buried objects because results are interpreted in real time, contact with surface.

[2] Donald W. Harvey and Michael P. Schuller, *Nondestructive Evaluation Structural Performance of Masonry* (Association for Preservation Technology International: 2010), Vol. 41, No. 2/3, 1-8.

Radiography

Radiography is familiar to anyone who has had an X-ay at a hospital, or been to the dentist.[3] And similar to other testing techniques, its applications to architectural conservation have benefitted from advancements of the technology due to its demand in the medical profession. Radiation in the X-ray spectrum, or gamma rays, has been used to reveal subsurface details in historic materials.

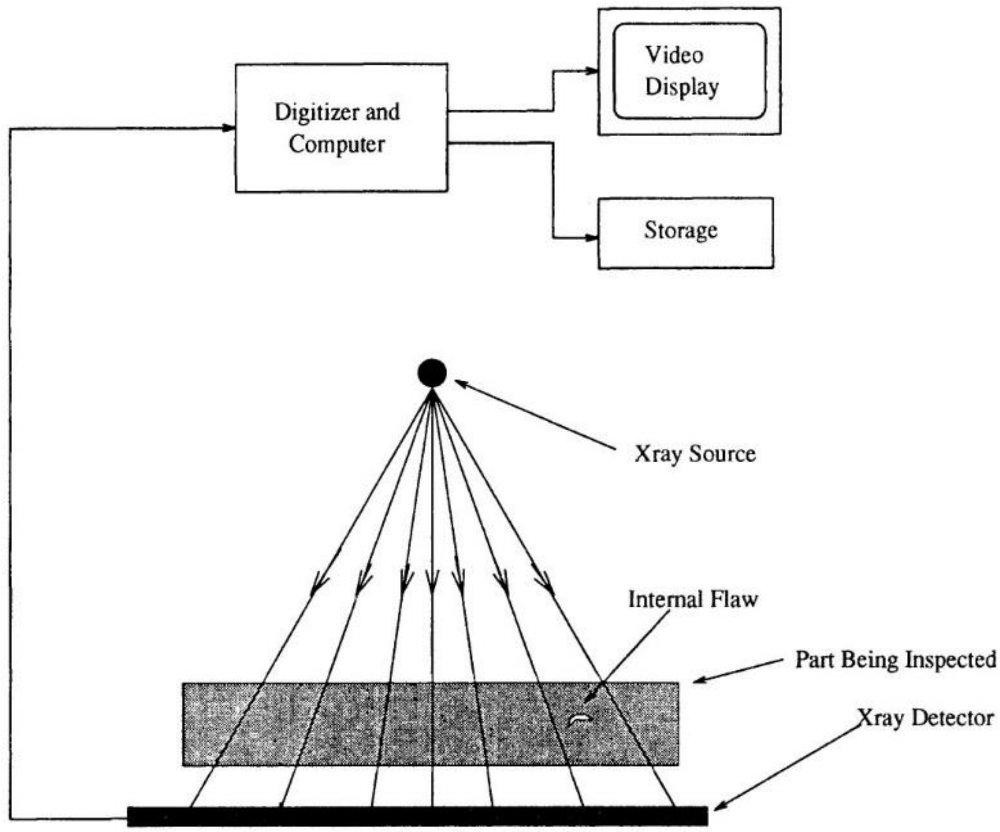

Figure 1.2 Diagram detailing the process of radiography. Image published in *Applications of Statistital Methods to non Destructive Evaluation*.

Radiography, unlike infrared thermography and GPR, does not have a receiver that detects the reflection of gamma rays, but rather the transmitter and receiver must be placed on opposite sides of the object. Radiography detects the density of matter due to

[3] The difference between radiology and radiography is that radiography is the process of acquiring an image, while radiology is the study of the images themselves.

gamma rays traveling at different intensities through different material densities. This means that objects that are opaque to light can be revealed from transmitter (usually a X-ray vacuum tube or natural source of gamma rays) to receiver (a Geiger counter or digital film), depending on the variations in intensity.[4] The emerging intensities are then recorded as a visual image (figure 1.2).

Radiography is utilized in subsurface detection of internal discontinuities, internal cracks, voids, location of embedded objects. It is especially useful in diagnosing grain patterns, moisture content, and indications of insect infestation in wood.[5] The disadvantages, however, cause problems in its application in the field. While radiography has been done in-situ since the 1970's, gamma rays can be harmful and pose health risks in public places.

Eddy-Current Testing

Eddy-current testing has special applications to electrically conductive materials. Alternating current-carrying coils are passed over the object. The probe passes an alternating current, and in turn induces an alternating magnetic field (eddy-currents). Deviations in the eddy-current are according to Faraday's and Ohm's Law and are measured in corresponding changes in the electrical resistance of the coil. Bivariate data is produced because both physical and imaginary components of coil resistance are

[4] Bryan D. Olin and William Q. Meeker, *Applications of Statistical Methods to Nondestructive Evaluation* (American Statistical Association & American Society for Quality) Technometrics, Vol. 38, No. 2 (May, 1996), 97.
[5] Susan Hum-Hartley, *Nondestructive Testing for Heritage Structures*, (Association for Preservation Technology International: 1978), 8.

recorded. At every point probe position and frequency are measured, and the resultant data is plotted as magnitude vs. spatial location.

Olin and Meeker give an excellent summation of the efficacy of eddy-current testing in stating,

> Eddy-current methods are most effective for detecting surface and near-surface flaws and characterizing surface properties (e.g., skin thickness) of electrically conductive materials. Effective inspection depth depends on materials properties and AC frequency. For example, with a one kilohertz inspection, effective depth for pure aluminum would be 2.6 mm. For titanium…effective inspection depths would be about 11 mm.[6]

<u>Ultra Sonic Testing</u>

Another well-established nondestructive evaluation technique is ultra-sonic testing. Ultra-sonic testing uses sound waves, a very high frequency particle vibration. These frequencies are conducted through a material by coupling. At boundaries and interfaces between materials and states of matter the sound waves are reflected back to the receiver. Very similar to sonar, ultra-sonic pulses reflect from discontinuities, making their location known.[7]

Equipment of contemporary practices includes a pulse generator (receiver), a transducer, and an oscilloscope. The test subject is treated with a liquid couplant or is immersed in water (known also as a water bath). Currently the digitization of the signal for processing, display, and storing data is carried out by an analog-to-digital converter

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[6] Olin and Meeker, *Applications of Statistical Methods*, 97.
[7] Hum-Hartley, *Nondestructive Testing for Heritage Structures*, 10.

electricity to a digital image.[8]

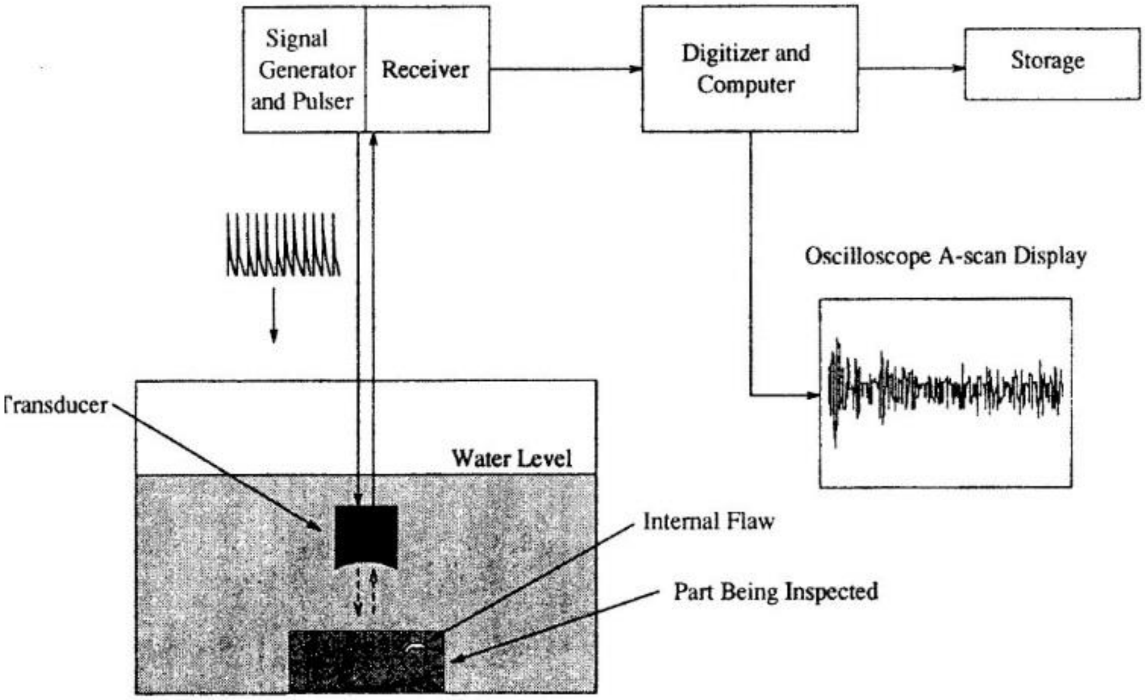

Figure 1.3 Diagram showing the acquisition of ultra-sonic energies. Image published in *Applications of Statistital Methods to non Destructive Evaluation*.

Ultra-sonic applications in the evaluation of structures are much like Radiography: location of embedded items, voids, cracks, cavities in wood, and even density and thickness measurements. Ultra-sonic testing, although, has the ability to penetrate thick materials, is safe to operate, and the equipment is relatively inexpensive and simple to use.[9]

[8] Olin and Meeker, *Applications of Statistical Methods,* 98.
[9] Hum-Hartley, *Nondestructive Testing for Heritage Structures*, 10.

The major disadvantage of ultra-sonic testing is that one needs to touch the object in order for the coupling to work. So while it is nondestructive, it requires contact with the test subject.

Examinations into masonry structures have been carried by Modesto Montoto et. Al. utilizing a method of acuesto-ultrasonic testing developed by the National Aeronautics and Space Administration. Flaws were successfully located and ranked by severity. The conservation team used a Schmidt hammer to generate pulsed impact signals. A lightweight and portable machine, the equipment consisted of a dry coupling probe with 40 KHz to 1.5 MHz band width, and a pulse mode ranging from 1 to 2,000 pulses per second. Due to the success of the tests, it was then recommended by the Getty Conservation Institute to be used on the investigations into the tomb of Neferati, the Great Wife of the Egyptian Pharaoh Ramesses II.[10]

Impulse Radar

Impulse radar receives less attention as a nondestructive test method than perhaps it deserves. It is extremely effective in determining faults in construction assembly and cracks in masonry; as has been proven at Fallingwater, Frank Lloyld Wright's elaborate masterpiece, and at Princeton's Whig and Clio Halls.[11]

The process contains drawing a transducer at a constant rate over the surface of the area being inspected. The transducer, a device with both a transmitter and receiver of

[10] Montoto, Modesto, "Nondestructive Testing." *Wall Paintings of the Tomb of Nefertiti*, 108.
[11] Robert Silman, *Applications of Non-Destructive Evaluation Techniques in Historic Buildings* (Association for Preservation Technology International), 71.

the signals, induces radio waves into the material and records the reflected waves. The pattern of the reflected radio waves fluxes when the rays encounter different materials, defects, or structural changes. The reflective rays are dependent upon the materials' permittivity or dielectric constant. Common frequency range for heritage structures is 900 MHz to 1000 MHz.[12]

Liquid-Penetrant

Liquid-penetrant, or fluorescent-penetrant inspection, can be used in the evaluation of surface flaws and crack identification.[13] The object is first cleaned from surface deposits and any foreign material. Thereafter a fluorescing liquid penetrant is introduced for capillary absorption. After the capillaries are saturated, the object is left to dry. The fluorescent penetrant is then visible under ultraviolet light.

Because there are a variety of variables inherent in this method—such as material, liquid penetrant type, developer type, temperature, relative humidity, type of ultraviolent bulb, detection method, and method of acquisition (camera or trained expert)—meaningful quantitative data is hard to proof. For instance, a fluorescent reactivity under ultraviolet light identifies the location of a crack. While the crack location might be known it is difficult to judge the depth or the size of the crack.[14]

[12] Ibid, 71.
[13] Olin and Meeker, *Applications of Statistical Methods*, 96.
[14] Olin and Meeker, *Applications of Statistical Methods*, 96.

X-ray Fluorescence

X-ray fluorescence, or XRF, is a test that for years required sampling and testing in a laboratory. Today, however, portable XRF machines are produced for in-situ testing. The process works by recording the emission characteristic, or secondary, x-rays after the material has been introduced to high-energy gamma rays. It is mainly used for elemental chemical analysis.

Infrared Thermography

Infrared Thermography falls in-line with the contents of this chapter but will be discussed in further detail in Chapter 2.

Impact Echo

Impact echo is the "high tech" method in acoustical tests for nondestructive testing.[15] Either by a carpenter's hammer or a spring-loaded device, the test object is struck with a hammer. Both the input energy and the reflected compression wave energy are recorded by computers. There must be multiple test points taken across the surface of the object under investigation. The information that impact echo can reveal is thickness and integrity of concrete and masonry (i.e. cavities, delaminations).

[15] Silman, *Applications of Non-Destructive Evaluation*, 71.

Non-Destructive Test	Does It Require An Experienced, Trained Operator	Does Interpretation of Results Require An Expert	Approximate Daily Rental Cost (with operator, if required)
Radar	Yes	Yes	$6,500.00*
Acoustical Methods	Yes	Yes	$6,000.00*
Infrared Thermography	Yes	No	$3,500.00*
Fiber Optics	No	No	$600.00 or $6,000.00**
Electro-Magnetic Devices	No	No	$550.00**

* Includes the cost of the interpretation and report by experts.
** Purchase Costs.

Table 1.1 1996 data on the cost of common nondestructive testing techniques. Table published in Silman's, *Applications of Non-Destructive Evaluation Techniques in Historic Buildings*.

	Test Method for Investigating Condition													
	Destructive		Nondestructive w/ Minor Repairs			Nondestructive								
General	Sampling (Cores)	Bond Wrench Test	Flatjack / Shearjack	In-situ Load Testing*	Petrography	Visual / Optical**	Ground Penetrating Radar (GPR)	Ultrasonic Pulse Velocity (UPV)	Impact Echo (IE)	Rebound Hammer / Surface Tests	Metal Detection (Induction)	Radiographic	Infrared Thermography (IRT)	Half-Cell Potential
Relative Cost ($, $$, or $$$)	$$	$$	$$	$$$	$$$	$	$$$	$$$	$$$	$	$	$$$	$$$	$$
Complexity/Experience Needed (L=Low, M=Medium, H=High)	L	M	M	H	H	M	H	H	H	L	L	M	M	L
Condition														
In-place strength?	G	G	E	E	A			A	A	A				
In-place uniformity?	G		G		G	A	G	G		G		G	G	
In-place deformability?			E	E				A	A	A				
In-place stress?			E											
Crack location?						A		E	E			G		
Crack movement?									G					
Performance under load?		E	E	E										
Rebar size, location, cover?	E						G				E	E	A	
Anchor and tie locations?								E			E	E		
Voids in grout?						A	E	A	A			E	G	
Voids in masonry?						A	E	A	A			E	G	
Corrosion of rebar?						A								G
Durability problems?				E		A		G						

E = Excellent information, reliable method
G = Good information, somewhat variable or vague results
A = Approximation only, highly variable or inexact

* Generally Load Testing is conducted at service levels that do not result in significant damage to the structure. If loads are taken to levels near failure, more significant repairs may be required.

** Visual / Optical Testing can involve minor repairs for borescope and small probe observations or significant repairs for larger openings.

Table 1.2 Table 2 is a list of destructive, minimally destructive, and nondestructive evaluation. It details the relative cost and functionality of different testing methods.

Mechanical Pulse Velocity

In mechanical pulse velocity a calibrated hammer hits the surface under examination while an accelerator measures the pulse on the opposite side of the test subject. This introduces large amounts of low frequency energy. Mechanical pulse velocity is useful in finding voids and other discontinuities in thick materials (applied primarily on masonry walls).

1.2 Evolving Nondestructive, Noninvasive Testing Techniques

Today, advances in technology are occurring at an exponential rate and newly discovered sciences and methods are changing the face of conservation almost daily. By the time new articles on advancements in conservation for heritage structures are published, they are practically outdated. The following few pages delve into emerging technology and acquisition in the heritage realm.

Optical Coherence Tomography (OCT)

Optical coherence tomography (OCT) is a valuable resource to use on materials that absorb light moderately. A nondestructive, noninvasive technique, OCT provides a precise profilometry based on incoherent light interferometry. Its advantages are longitudinal resolution on the micron scale, precision, extremely high sensitivity, and noncontact procedure.[16] Notably, OCT has been successful in inspecting wall paintings by applying an acoustic wave to induce displacement.[17]

Experts in OCT's application to conservation; Targowski, Rouba, Wojtkowski, and Jiwakczyk explain the science as a "sequential double registration of holographic (or speckle) images. If the object undergoes induced displacement between making the two images (due to external stresses) superimposition of these images produces a fringe pattern."[18] Inhomegeneities from defects create inhomogeneous strain distribution across the test surface and as a result, disturbs the consistent fringe pattern. Areas where the fringe pattern is perturbed or distorted may correlate with defects. If thermal or moisture content fluctuations induce the stress, "the investigation of the resulting strain leads to an understanding and quantification of the influence of the environment of a work on art."[19]

The technique requires a highly trained technical expert. In order to detect flaws the set-up geometry has to be stable within a fraction of a wavelength between measurement points. Often, changes between distance of the optical system and the test subject create undesired fringes.[20] To mitigate these issues versions of OCT have progressed the science. One such version is Fourier Domain Optical Coherence Tomography.

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[16] Piotr Targowski, Bogumila Rouba, Maciej Wojtkowski, Anrdrzej Jiwakczyk, *The Application of Optical Coherence Tomography to Non-Destructive Examination of Museum Objects,* Stidies in Conservation, Vol. 49, No. 2 (2004), 108.

[17] Fricke-Begemann, T., Gulker, G, Hinsch, K.D., and Joost, H., *Mural inspection by vibration measurements with TV-holography*, Potics and Lasers in Engineering 31 (2000), 537-548. Cited in *The Application of Optical CoherenceTomography to Non-Destructive Examination of Museum Objects, Studies in Conservation.*

[18] Targowski, Rouba, Wojtkowski, and Jiwakczyk, *The Application of Optical Coherence Tomography,* 107.

[19] Ibid, 108.

[20] Ibid, 108.

Fourier Domain Optical Coherence Tomography (FDOCT) is a novel version that utilizes the relatively wide spectrum of the super-luminescent diodes, about 20 nm at half maximum.[21] An open-air Michelson interferometer illuminates the test subject with a narrow light beam. A fixed mirror is stationed in a reference path (figure 1.4).

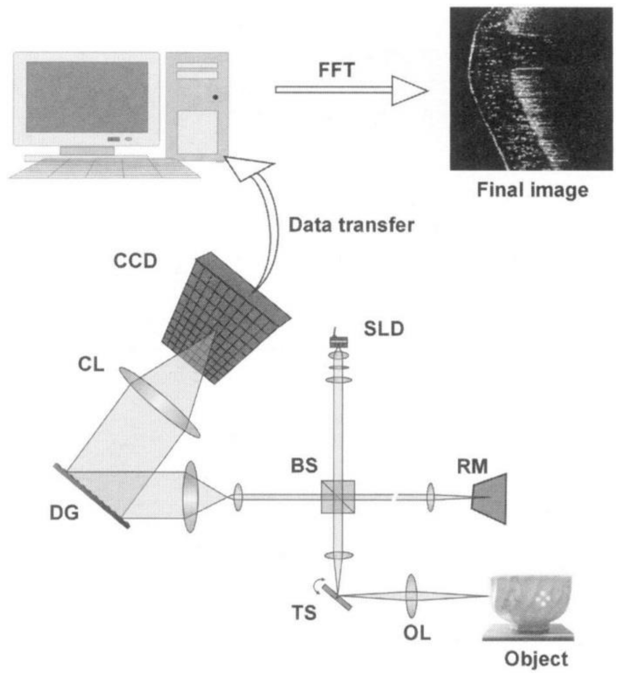

Figure 1.4 A diagram of the Fourier domain OCT acquisition device. (SLD) super-luminescent diode, (RM) reference mirror, (BS) beam splitter, (OL) objective lens, (TS) transverse scanner, (DG) diffraction grating, (CL) camera lens, (CCD) camera, (FFT) data processing. Image published in *Applications of Optical Examination of Museum Objects*.

Light scattered from the test object and reflected light from the reference mirror come into interference and are propagated to a spectrograph. The spectrograph is equipped with the diffraction grating and the charge coupled device (CCD camera). The pattern resulting from the interference contains data on the stratigraphy in the item along the path

[21] Wojtkowski, M. Bajraszewski, T. Targowski, and A. Kowalczyk, *Real time in vivo imaging by high-speed spectral optical coherence tomography*, Optics Letters 28 (2003), 1745-1747.

of the illumination beam. The information can then be converted mathematically according to a Fourier transform to discern stratigraphy of an object[22]

TV Holography

Portable TV holography testing is a novel technique also known as electronic speckle pattern interferometry (ESPI) or TV speckle interferometry. A solid-state camera connected to a computer uses fiber-optic illumination to inspect test subjects. In 1995 D. Paoletti and G. Schirripa Spagnolo publish successful results in using TV Holography to document wall paintings.

Data or image acquisition occurs before and after warming the painting slightly with an infrared lamp. Differential speckle patterns indicate anomalies such as cracks and incipient detachment. This portable, in-situ testing may be used for examining wall paintings both internally and externally.[23]

Testing emits light from a helium-neon laser, registering a power of 10mW and a wavelength of 0.63µm. A gradient index (GRIN) rod micro-lens is coupled to a single-mode fiber, and subsequently split by a bi-directional coupler (10:90) into the test subject and reference illuminating beams. As Paoletti et. al. explain,

> The object beam, reflected off the rough surface of the wall painting, produces a pattern of granular appearance, a speckle pattern, that is characteristic of the illuminated surface. A CCD (charge coupled device) camera, with 510 x 492 pixels, records the speckled image of the object. The reflectance waves are

[22] Targowski, Rouba, Wojtkowski, and Jiwakczyk, *The Application of Optical Coherence Tomography*, 108.
[23] D. Paoletti and G. Schirripa Spagnolo, *The Potential of Portable TV Holography for Examining Frescoes In Situ* (International Institute for Conservation of Historic and Artistic Works), 1995.

coherently combined through a beam-splitter cube with the speckled image at the imaging device surface to form a holographic speckle pattern (figure 1.5).[24]

Computer image-processing is capable of digitizing and storing the record in its unperturbed position. A continuous recording of the speckle pattern shows real-time correlation patterns relative to discontinuities. The fringes are representative of contour lines or path differences induce by out-of-plane deformation of the test surface at the same order of magnitude as the wavelength of the emitted light utilized in the holographic interferometry.[25]

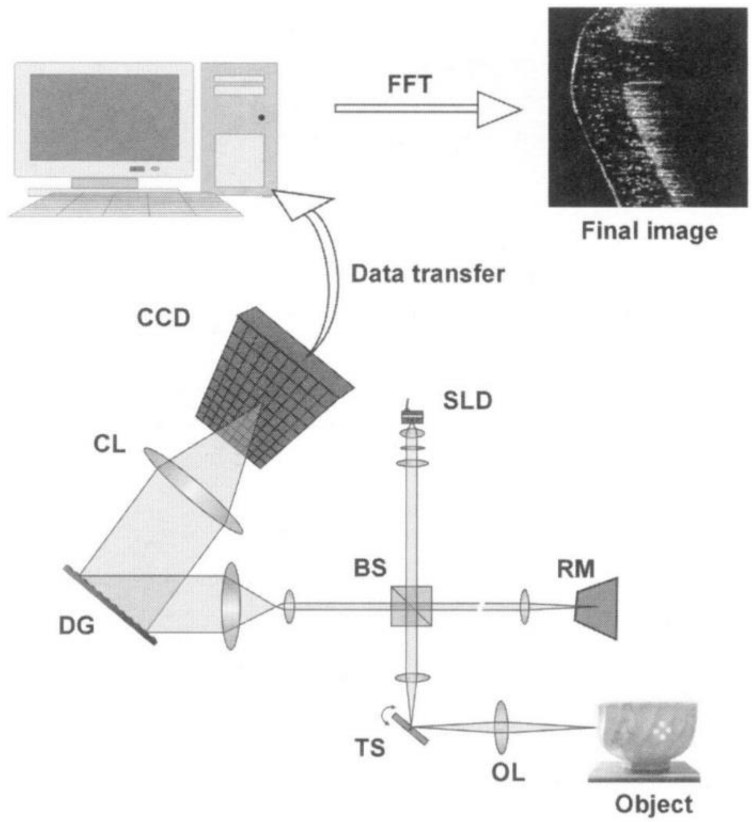

Figure 1.5 The out-of-plane TV holographic interferometer configuration. Image published in *The Potential of Portable TV Holography for Examining Frescoes in Situ*.

Like other nondestructive techniques, TV holography is useful in monitoring test objects over time. Timed interval recordings following the same procedures provide a

[24]Paoletti and Spagnolo, *The Potential of Portable TV Holography*, 127.
[25] Ibid, 127.

documentation of the deterioration rate. Testing is also appropriate outdoors, and portable in-situ testing is possible.

Trans-illumination and Trans-irradiation with Digital Cameras

Trans-illumination and trans-irradiation with digital cameras has become more prevalent in the heritage and cultural preservation field over the past decade. Increasing technology of digital cameras has allowed increasing applications. With the ability to detect the visible and near infrared spectra a high-resolution digital camera can now become an integral investigative tool to determine hidden images and reveal palimpsest in artwork.

Trans-illumination and trans-irradiation have been successfully applied to oil on canvas—e.g. "*Le bagnanti"* by Vicenzo Cabianca (1868); "*Diego Martelli allo scrittoio*" by Federico Zandomeneghi (1870); "*Il salto delle pecore*" by Giovanni Fattori (1887). Cucci, Picollo, and Vervat applied commercial digital night-shot-cameras and digital cameras with their IR filters removed. These imaging devices had a sensitivity from 350-1100 nm spectral range.[26]

The camera chosen for analysis of Giovanni Fattori's was a Nikon Coolpix, and for investigations into the other two paintings the conservation team used a Sony Cyber-

[26] C. Cucci, et al., *Trans-illumination and trans-irradiation with digital cameras: Potentials and limits of two imaging techniques used for the diagnostic investigation of paintings*, Journal of Cultural Heritage (2011).

Shot F 828 camera fixed with a Hoya R72 infrared filter. Two incandescent tungsten lights with 3200 K color temperature were used as the light source (figure 1.6).[27]

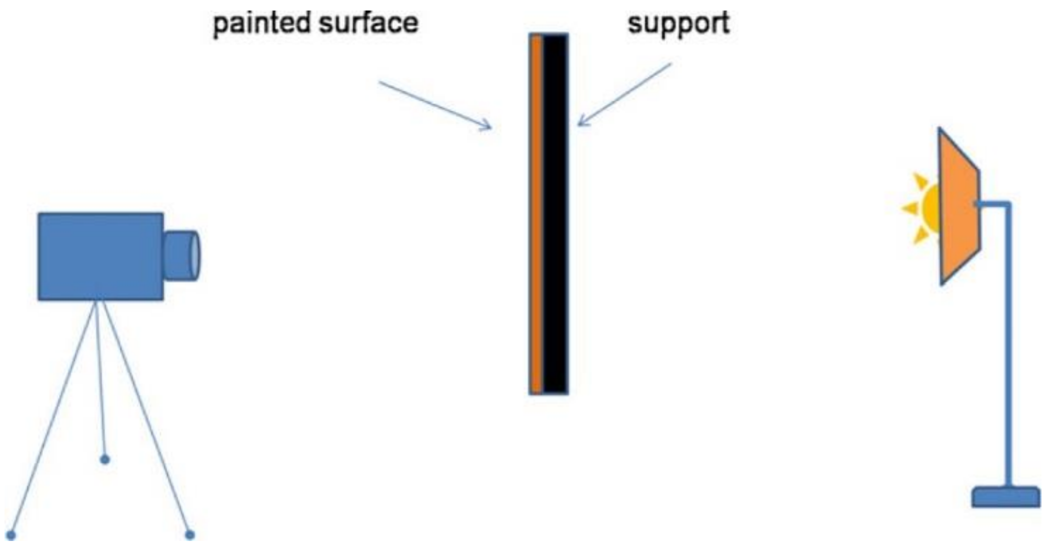

Figure 1.6 Experimental configuration for the acquisition of transmitted images. Image published in *Trans-illumination and Trans-irradiation with Digital Cameras: Potentials and Limits of Two Imaging Techniques used for the Diagnostic Investigation of Paintings*.

Hyper-Spectral Imaging Systems

Hyper-spectral imaging has progressed significantly since 2000. Advances in the field owe special thanks to members of Forth Photonics Ltd, the Institute of Electronic Structure and LASER (I.E.S.L.), and the Department of Electronic and Computer Engineering. A decade ago, these members— Costas Balas, Vassilis Papadakis, Nicolas Papadakis, Annonis Papadakis, Eleftheria Vazgiouraki, and George Themelis—pushed the field's applications to noninvasive testing of heritage conservation.   Their publication, *A Novel Hyper-Spectral Imaging Apparatus for Non-Destructive Analysis of*

[27] C. Cucci, et al., *Trans-illumination and trans-irradiation with digital cameras*, 127.

Objects of Artistic and Historic Value, is a literary cornerstone of hyper-spectral imaging systems and their applications to conservation.[28]

There have been many earlier attempts at developing a spectral imaging system capable of advances diagnostics. Most test applications have been in remote analysis, however the diagnostic tasks have been complicated.

Utilizing a hyper-spectral imaging (HySI) system developed at Forth-Photonics, multiple spectral investigations on cultural objects have revealed overwritten text on a palimpsest from the 11th century AD; pigment identification on a 12th century AD illuminated manuscript; and have assessed the effects of laser cleaning on manuscripts.[29]

The hyper-spectral acquisition device is invaluable in nondestructive evaluation of cultural objects, due to its ability to capture the spectral range 380 nm to 1000 nm. Unlike any other time before, these hyper-spectral cameras have the ability to perform the tasks of what would have taken several acquisition devices to perform the diagnostic evaluation. This provides a comprehensive study of the test object. In evaluating across the spectral range, data can be confirmed to a certainty like nothing before. With the added advantage of real time imaging and high spectral resolution, the possibility of hyper-spectral imaging becoming a must for nondestructive testing is not only apparent, but palpable.

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[28] Costas Balas, Vassilis Papadakis, Nicolas Papadakis, Antonis Papadakis, Eleftheris Vazgiouraki, and George Themelis, *A Novel Hyper-Spectral Imaging Apparatus for the Non-Destructive Analysis of Objects of Artistic and Historic Value* (Journal of Cultural Heritage, 2003), 330.
[29] Ibid, 336.

1.3 Nondestructive Testing Conclusions

Nondestructive testing methods have progressed immensely over the past decade. Nonvisible spectra can reveal unimaginable hidden images, over-drawings, embedded architectural details as well as structural anomalies such as damage. Thanks to commercializing agents, these technologies are becoming less expensive, more reliable, and more applicable to in-situ, subsurface testing. With advances in the science such as hyper-spectral imaging systems and portable TV Holography, the potential for future testing methods is greatly expanded.

What differentiates these techniques are the energies used. The nonvisible spectra can reveal a variety of phenomena, depending on the wavelength that the instrument is recording, and the material characteristic under study (e.g. thermal properties, dielectric constant, material density).

Chapter 2: Infrared Thermography

Investigations into the infrared spectrum have their origins well back to the end of the 19th century. In 1882, Abney and Festing photographed the absorption spectra of 52 compounds to 1.2 microns.[30] By 1905 infrared technology flooded medical and scientific journals. Early investigations and major advances in thermographic acquisition have since pushed forward. Infrared thermography has been applied to heritage structures since the 1970's. A decade later in the 1980s, portable and in-situ investigations with thermographic scanners were sensitive enough to detect a change in radiation as delicate as 0.18 degrees Fahrenheit.[31] In large part thanks to private companies such as FLIR and MUSIS, the technology has become more accurate, affordable and applicable. In 2011 Elisabetta Rosina and Jonathan Spodek described the technology at that time as "among nondestructive testing techniques…gaining popularity."[32] The day has come where, for a nominal amount, researchers can purchase or rent a thermographic cameras for condition diagnostics and construction forensics.

Infrared thermography has multiple advantages in architectural conservation. It is a non-contact, noninvasive, in-situ testing method that produces results in real time. It is versatile, fast, and reliable. And unlike other nondestructive testing methods, infrared thermography is friendly to the environment and completely safe.

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[30] Abney & Festing: Phil Tans., 172, p 887, 1882. Forhandl, Stockholm, S. 549, 1889: s. 549 1889: s.331, 1890.

[31] Holt and Eckrose, *The Application of Ground-Penetrating Radar and Infrared Thermography,* 110.

[32] Rosina, Elisabetta & Jonathan Spodek, *Using Infrared Thermography to Detect Moisture in historic Masonry: A case Study in Indiana* (APT Bulletin: 2011), 11.

2.1 Infrared Thermography Introduction

> *Definition*: A technique for producing heat (thermal) pictures from the invisible radiant energy emitted from stationary or moving objects at any distance and without in any way influencing the temperature of the objects under view.[33]

Infrared thermography is a measurement of emitted electro-magnetic waves. As an object or material absorbs radiation, it then reemits radiation at specific wave lengths. Any matter above absolute zero emits infrared radiation, and the intensity and wavelength of which is directly proportional to its temperature.[34] The infrared spectra ranges in wave length from the near infrared (0.7-2.0 microns), to the medium infrared (2.0-4.0 microns), and to the far infrared (4.0-1,000 microns). The wave length of the emitted radiation can be measured and monitored over time with special thermal imaging devices. Succinctly put in Hum-Hartley's *Nondestructive Testing for Heritage Structure*s,

> all bodies radiate energy continuously in the form of electromagnetic waves, the strength of the radiation being related to the thermal properties of the body and its surface temperature. A record of this radiation produces an accurate picture of the qualitative temperature distribution on the body being investigated.[35]

This approach is deeply rooted in monitoring how surfaces heat up and cool down. Perhaps the concept is better explained by E. Rosina and E. C. Robison in *Applying Infrared Thermography to Historic Wood-Framed Buildings in North America*; wherein, they state that infrared technology is based on the change in the heat flux as it

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[33] Hum-Hartley, *Nondestructive Testing for Heritage Structures*, 9.
[34] Cited in Bruce F. Miller, *The feasibility of Using Thermography to Detect Subsurface Voids in Painted Wooden Panels* (The American Institute for Conservation of Historic & Artistic Works: 1977), 38; as, Vanzetti, R. *Practical Application sof Infrared Techniques: A New Tool in a New Dimension for Problem Solving.*pp. 33-34. New York: John Wiley and Sons, 1972.

[35] Hum-Hartley, *Nondestructive Testing for Heritage Structures*, 9.

passes through building materials, brought about by the presence of anomalies. These include voids, delamination, or repairs using different building materials. The changes in heat flux cause localized temperature differences on the surface of the material. A change in heating conditions (warming or cooling) is the key mechanism in revealing those anomalies.[36]

Emissivity and Reflected Apparent Temperature

Emissivity and reflected apparent temperatures are two significant thermal properties that must be accounted for, and are integral in distinguishing between different materials. Emissivity in particular is the revealing characteristic of a material that will either prove or disprove on-site testing at Fire Temple.

Emissivity as defined by FLIR is, "a property that specifies how much radiation an object emits, compared with the radiation of a theoretical reference object at the same temperature (called a 'blackbody')."[37] Emissivities of materials are measured relatively on a scale from 0-1, and are dependent on the substances chemical composition and physical state. Emissivity is important for recording temperature measurements, but has no effect on the image produced.

Reflected apparent temperature is also important in analyzing thermal optics. The reflected apparent temperature is a compensation for radiation from the surrounding

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[36] Rosina, Elisabetta and Robinson, Elwin C., *Applying Infrared Thermography to Historic Wood-Framed Buildings in North America*, APT Bulletin, Vol. 33, No. 4 (Association for Preservation Technology International: 2002) 38.

[37] FLIR systems, Inc. 1999-2013, www.flir.com (October 2012).

environment, being reflected by the object under examination. While this principle also does not change the image, it can give false temperature readings if not accounted for. An experienced technician will recognize and record the variation of emissivity and reflectivity of the surface.[38]

2.2 Active and Passive Thermography

Infrared thermography is conducted in generally two different ways, the passive approach and the active approach. Passive thermography relies on heat flux based on the sun's radiation throughout the day (especially during sunrise and sunset where surface temperatures heat and cool). Active thermography is carried out by applying an artificial heat source to the surface being studied, most commonly a halogen lamp. While passive thermography must be done outside with uncontrollable environmental factors, i.e. wind, clouds, relative humidity, etc...; active thermography can be conducted in a laboratory or other controlled environment where the energy source can not only be measured but also adjusted to best fit the experiment and thermal properties of the materials.[39]

Passive Thermography

Passive thermography is valuable in assessing walls, cellars, roofs, and other large surface areas in a short amount of time. The approach takes advantage of the large

[38] FLIR systems, Inc. 1999-2013, www.flir.com (October 2012).
[39] Elisabetta Rosina and Jonathan Spodek, *Using Infrared to Detect Moisture in Historic Masonry: A Case Study in Indiana* (APT Bulleti: 2003).

amounts of solar energy to evaluate a building assembly as a whole (up to 1,000 W/m^2). For instance, with 3 hours of solar exposure the temperature difference of pavement is approximately 3 degrees Fahrenheit. The amount of back radiation during this period is more than enough to read delaminations and debonded areas.[40]

Leaks in cavity wall construction, moisture diffusion through building envelopes, and the end of trusses and floor division in adobe or masonry constructions are just a few examples of applying passive IR imaging in the field today. The technique is qualitative and relative in nature; but is invaluable in understanding construction and wall asssembly.

An application of IR imaging by Rosina and Spodek in Indiana is an exemplar case study for using infrared thermography in a conservation scenario.

Active Thermography

Often, traditional building materials have too similar thermal properties to be distinguished from one another by passive techniques. In these cases, a more significant increase of heat flow in a specified time can be successful at unveiling more about anomalies. This is called active thermography.

Just as it sounds, active thermography takes place during or right after the surface has been heated with an alternative heat source. Heating of the material can be done by placing the material in an oven, exposing it to a halogen lamp, placing the sample on a

[40] Holt and Eckrose, *The Application of Ground-Penetrating Radar and Infrared Thermography*, 111.

hot plate, etc...--depending on the size of the object and its fragility. For this reason, active thermography is usually carried out on localized areas (such as a single wall, wooden panels or an oil painting).[41]

2.3 Previous Infrared Thermography Applications: Case Studies

One of the earliest applications of IR thermography was in 1977, just as the technology begins to be used on heritage sites or objects. Bruce F. Miller published an article on the feasibility of utilizing thermography to reveal subsurface voids in painted wood panels. Backing on the principle that the thermal coefficient of air is less than that of wood and paint, Miller was able to discern voids and their depths.[42]

In 2011 Elisabetta Rosina and Jonathan Spodek successfully applied infrared thermography to detect moisture in a Masonic Temple in Muncie, Indiana. Utilizing the passive method, the study aimed at evaluating the interior finishes to verify the distribution of moisture in the masonry. Testing was possible due to the cooling effect of evaporation (each gram of evaporated water absorbs 2,500 Joules of energy). This means moist areas were colder than dry ones. Their procedure for acquiring the thermogram was:

- The surface being scanned was kept out of direct artificial heating for

[41]Elisabetta Rosina and Elwin C. Robinson, *Applying Infrared Thermography to Historic Wood-Framed Buildings in North America*, APT Bulletin, Vol. 33, No. 4 (Association for Preservation Technolofy International: 2002) 38.
[42] Bruce F. Miller, *The feasibility of Using Thermography to Detect Subsurface Voids in Painted Wooden Panels* (The American Institute for Conservation of Historic & Artistic Works: 1977), Journal of the American Institute for Conservation, Vol. 16, No. 2.

twelve hours prior to, and during the scan

- Environmental conditions at the air surface boundary allowed for a medium to high transpiration rate
- The thermocam was set at maximum sensitivity for detection of the smallest temperature difference
- The position of the camera was held perpendicular to the surface being scanned.[43]

Infrared thermography has even been applied to locate termite infestations in historic buildings. In 2003, Mark Gilberg et.al. evaluated termite activity in a Catholic church in New Orleans (St. Alphonsus). Remarkably, they confirmed subterranean termite activity with thermograms, and identified problem areas where termite baits should be placed (figure 2.1).[44]

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[43] Elisabetta Rosina & Jonathan Spodek, *Using Infrared Thermography to Detect Moisture in historic Masonry: A Case Study in Indiana* (APT Bulletin: 2011), 11.
[44] Mark Gilberg, Claudia Riegel, Bob Melia, and Jack Leonard, *Detecting Subterranean Termite Activity with Infrared Thermography: A Case Study* (Association for Preservation Technology International: 2003), Vol. 34, No. 2/3.

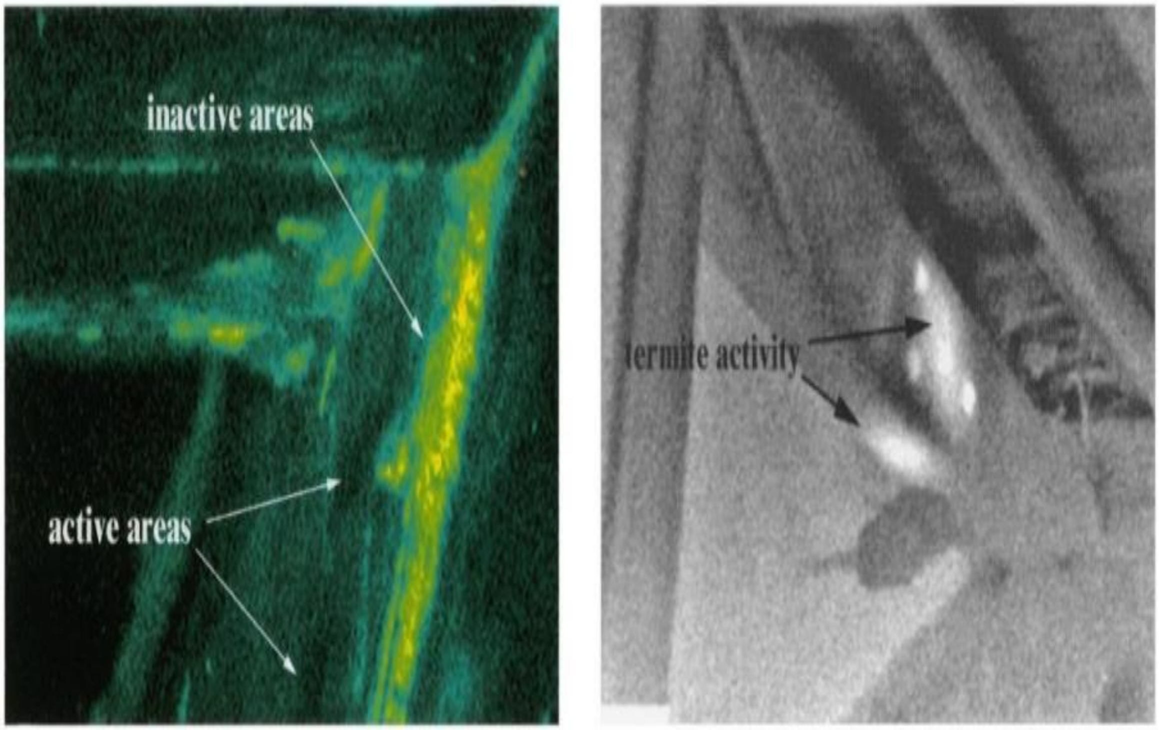

Figure 2.1 Two thermograms from *Detecting Subterranean Termite Activity with Infrared Thermography: A Case Study.* Visible in the two images are inactive and active termite infestation.

2.4 Thermographic Application at Fire Temple

Infrared thermography in essence measures the temperature at which a surface radiates heat, a form of energy. The acquisition device, a camera, then translates the temperatures into a two dimensional graphic representation known as a thermogram (i.e. a picture). The image produced will provide relative information on the temperatures of different surfaces, and with most thermal cameras can provide exact temperature readings of a surface. The principle is thus; surfaces radiate different amounts of heat depending on their thermal properties. But how can this be useful in stratigraphic analysis of earthen samples at Fire Temple?

Hypothetically, the stratigraphic layers will produce different thermal patterns based on their composition, color, and stratigraphy. The fine calcium carbonate (calliche) used in creating the white field should react differently than the darker, coarser red plaster and yellow wash when influenced by the same amount of heat energy. The different emissivities should be observable with a thermographic camera of efficient resolution. Therefore, iconographic images that have been painted over with time should produce a unique thermal pattern. In this regards, the subsurface investigation of the iconographic layers should be delineated. Perhaps better stated, an area with two red loess images on top of each other would react differently to heat radiation than two white washes overlaid on each other. Idealistically the minuscule differences created across the surface by different layers superimposed on each other should create a discernable pattern with a FLIR high-resolution thermal camera, resolution 600 x 400.

While the camera can read these subsurface anomalies, there are many other factors that need to be taken into consideration, such as delaminated and debonded areas. As Holt and Eckrose explain, "thermography works on the principle that given the same input of solar energy, the delaminated or debonded area, which is thinner than the surrounding area, will heat and cool faster than the adjacent."[45] This fact is integral in understanding the wall holistically. Delaminated wash or detached plaster that may not have been successfully treated in the 2011 field-season may also complicate the thermograms. The location of air-pockets poses a problem because the thermal coefficient of air is different than the earthen architectural finishes. In fact, it is rather low and restricts the flow of heat.[46]

[45] Holt and. Eckrose, *The Application of Ground-Penetrating Radar and Infrared Thermography*, 110.
[46] Miller, *The feasibility of Using Thermography to Detect Subsurface Voids in Painted Wooden Panels*.

Chapter 3: Fire Temple

3.1 Site Description

Carved out of Chapin Mesa's cliff walls, the alcove site known as Fire Temple is located in Fewkes Canyon and is clearly visible from the mesa at Sun Point View. Constructed of the same stone and soil as the alcove, Fire Temple has two side chambers and a central grand room (figure 3.1). The central room, termed Kiva A, is the largest of the spaces with the most architectural features. Two large, rectangular foot-drums are in Kiva A, with a circular pit in between them. The easternmost part of the floor has another subterranean square pit.[47] Finally, a papu shaped hole along the North wall, and a bench running along the east wall complete the floor plan.

The North wall at Kiva A contains the most intactof the applied wall finish schemes. The wall displays a vast horizontal white field with red dado overlap at the base. Ancestral iconography decorates the white field in red and yellow, while a series of red triangles demarcate the dado.

In Fewkes' early writings he gives a unique description of the space,

> In the walls of the canyon below this wonderful building [Sun Temple], in a large cave with overhanging roof to shield it from the weather, there is situated another religious building, Fire Temple, in which both the form of the rooms and the accompanying pictographs or paintings on the walls show good evidence of an elaborate fire cult. This is in fact another sun temple, for the worship of fire is connected with the worship of the sun.[48]

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[47] The exact function of this hole is not known. Perhaps it functioned as a sort of papu, or portal to ceremonial figures and ancestor's spirits.

[48] J. Walter Fewkes, *The chronology of the Mesa Verde* (Archaeological Institute of America: 1926) American Journal of Archaeology, Vol. 30, No.3., 278.

While Fire Temple is no longer believed to be the site of an elaborate fire cult, its significance in Ancient Puebloan culture is rarely disputed. Both its location, perplexity of form, and vibrant iconographic campaigns suggest that the site served a special, probably religious function and one for a large group of attendants.

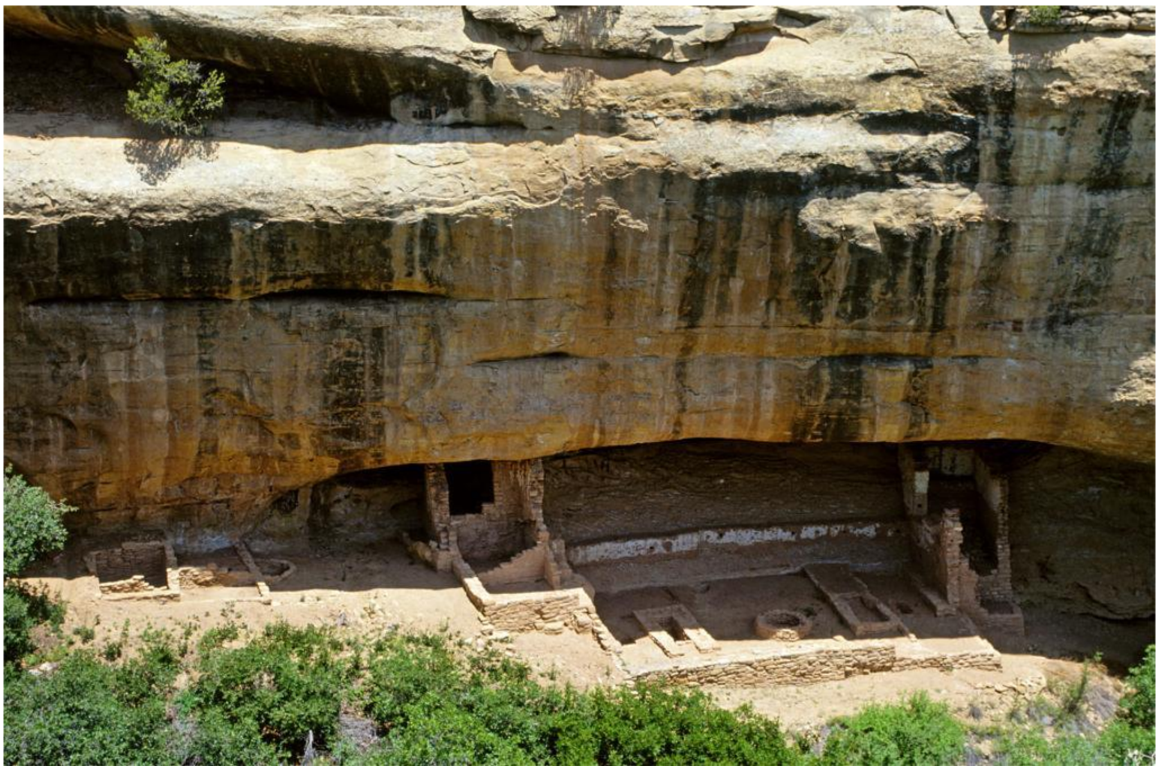

Figure 3.1 Fire Temple, Mesa Verde National Park. Image and original data provided by Canyon lights World Art Slides and Image Bank. Photographer: Susan Silberberg-Peirce.

Fire Temple's exact creation date is not known, but it does follow a larger pattern in Ancestral Puebloan (Anasazi) building practice. For reasons that are debated and unknown, around 1200 C.E. the Ancestral Puebloans started moving down from the mesa top and began building on the talus slop. Termed by many as "Cliff Dwellings," these alcove sites signify a major shift in habitation.

3.1 Conservation Treatments

The first efforts to mitigate deterioration came in the same year of its excavation, 1920. J. Walter Fewkes, witnessing the dire state of the ruins, stabilized the site. Other than that and seasonal maintenance work (e.g. sweeping and weeding), the site has gone relatively untouched by human hands, until recently.

In the August of 2011, a University of Pennsylvania architectural conservation team began a stabilization program for the architectural finishes at Fire Temple. Conservation of the North wall at Kiva A was stabilized during that summer. While most wall surfaces show remnants of indigenous occupation, the North wall of Kiva A was chosen first because it is the public face of the building. Treatments of 5% and 10% gelatin, and hydraulic lime grout were used to reattach the earthen finishes and plaster back to the bedrock (Appendix A: sheet number 3.1). The program carried out the following summer with conservation of the east wall at Kiva A, and further work is currently planned for June 2013.

Chapter 4: Methodology

Due to Fire Temple's deep alcove location, the earthen finishes have survived remarkably well over the past 800 years. With its painted and embellished wall plasters, Fire Temple provides a rare opportunity to examine the religious/communal symbology and aesthetic of the Ancestral Puebloans. Furthermore, the lack of living space and other features associated with full time occupation suggest that Fire Temple was a space of ritual and ceremonial significance. As an integral aspect of the public face of Mesa Verde, continued research at Fire Temple is much needed. And while stabilization work was recently done this summer by the University of Pennsylvannia's Architectural Conservation Laboratory; a comprehensive understanding of the colors, placement and stratigraphies (schemes), and figural representations is still lacking. The following research phases outline how research will be conducted..

Phase 1: Site Investigation

Eight samples of the North Wall at Fire Temple have already been taken during the 2011 field season for cross-section analysis to determine basic stratigraphy, composition, and paint condition These samples will provide the basis for understanding the overall succession of layers and finish schemes before returning to the site in summer 2013 with an infrared camera.

Phase 2: Research & Historical Discussion

An integral component to the thesis is an expanded discussion about the current technology of nondestructive, noninvasive, noncontact, and subsurface testing. As exemplified in infrared thermography, subsurface testing techniques have made exponential advancements over the past decades. Both in terms of diagnostics and monitoring, non-destructive testing has the potential to supply conservators with critical information that can inform interventions without disturbing original fabric.

Phase 3: Facsimile and Thin-Section Preparation and Analysis

Facsimiles replicating the finishes and finish campaigns at Fire Temple were prepared with materials collected from Mesa Verde. Infrared thermography on these prepared "knowns" with served as a way to test the possibilities and limitations of the infrared camera to detect painted over schemes and images as well as detachment. Coupled with studies of the material characteristics of the different colors, facsimile testing sharpened the technical operator expertise needed for data acquisition in the field.

Phase 4: On-Site/Data Acquisition

Data acquisition (infrared thermography) will be carried out in June, during a season of increased solar exposure. Given several days, the environmental conditions should be right to provide the adequate fluctuation in thermal properties to produce the best results by passive thermography. In a case where solar radiation does not provide sufficient thermal differences in materials, in may be necessary to apply a controlled heat source from halogen lamps (known as active thermography). The data can then be brought back to Philadelphia for interpretation and production in a final report.

Phase 5: Discussion, Synthesis of Results, and Conclusions

To advance the technology of in-situ, nondestructive, subsurface testing; a discussion of the results of the experiment – whether conclusive or inconclusive and as to why – is imperative. More important than the success of the infrared thermography onsite is the understanding of the limitations and applicability of such technology. In other words, this thesis aims more importantly to continue to apply infrared technology to new contexts and materials.

In conclusion, this study seeks to bolster the hypothesis that earlier finish campaigns and subsurface imagery can be discerned with IR technology. By utilizing facsimiles, cross-sections, and in-situ testing, the thesis aims to prove or disprove the efficacy of stratigraphic analysis using infrared thermography.

Chapter 5: Testing Program

There are generally three preparatory evaluations before embarking on IR testing of the actual mural: stratigraphic analysis of samples taken from Fire Temple, IR on facsimiles of like-material, and the digitization of potential false variables.

5.1 Stratigraphic Analysis

Understanding the architectural finish stratigraphy at Mesa Verde is imperative. A comprehensive analysis of the layers will inform the location and number of washes used in the wall. This is important because understanding the stratigraphy of the plaster mural (i.e. the number of layers, the color scheme of the layers) will give the interpreter an understanding of what to expect with the infrared camera. The location at which the eight samples were taken was recorded. With this evidence one can better understand how high the individual dados rise, where there may be hidden iconographic imagery, and whether or not thermal images will be able to discern the stratigraphy.

Since the mural has such an immense cultural value, only eight samples were collected and processed (Table 5.1). Embedding of and cutting earthen samples from previous ACL projects often resulted in damage to the samples.

RESEARCHER	DATE COLLECTED	LOCAL NUMBER	SAMPLE TYPE	SITE SAMPLE LOCATION	TESTING STATUS
D. Castele	31-Aug	01	Finish	upper field, west end; finish and substrate	Cross - Section Microscopy
D. Castele	31-Aug	02	Finish	Lower field, west end; zigzag embellishment	Cross - Section Microscopy
D. Castele	31-Aug	03	Finish	First set of triangles with dado overlap, west end	Cross - Section Microscopy
D. Castele	31-Aug	04	Finish	Red dado on mortar; west end	Cross - Section Microscopy
D. Castele	31-Aug	05	Finish	Yellow embellishment with mortar substrate; east end; between two easternmost niches	Cross - Section Microscopy
D. Castele	31-Aug	06	Finish	Final white over red zigzag, on mortar; east end; between two easternmost niches	Cross - Section Microscopy
D. Castele	31-Aug	07	Finish	White field on stone; jog of wall	Cross - Section Microscopy
D. Castele	31-Aug	08	Finish	Dado and plaster; jog of wall	Cross - Section Microscopy
D. Castele	31-Aug	09	Finish	Loose pieces in west niche of east end	N/A

Table 5.1 2011 Sample Matrix. Due to the scarcity of samples, only samples 01-08 were cast.

5.2 Vacuum Embedding: Trial Samples

The previous method of preparing samples was according to the University of Pennsylvania Architecture Conservation Laboratory requirements. A Buehler release agent was applied to each cell of the casting tray and set to dry for 1/2 hour. During drying of the release agent, a mixture of Ward's Bioplast casting resin and Ward's catalyst (methyl ethyl ketone peroxide) was made and set for several minutes to allow trapped air to float to the top. Thereafter, the support layer of Bioplast was poured in the correlating number of cells and placed in a fume hood to cure for no more than 48 hours.

After curing, the samples were placed substrate down atop the support layer. Another mixture of Ward's bioplastand catalyst was made following the same steps as above and poured over the samples. The tray was then placed in a fume hood to cure for 3-4 days.

After complete curing, the samples were cut with a Buehler's low-speed Isomet microsaw. Polishing was carried out on an Ecomet 6 variable speed grinder-polisher with 0.05 micron micropolish and water as a lubricant. Samples were then mounted on slides with Cargille Meltmount, which has a 1.662 refractive index at 25 degrees Celsius.

Experimental Phase

To mitigate former embedding issues—such as depth-of-penetration and plucking—four samples, mostly plaster substrates, underwent experimental embedding methods under vacuum. Testing procedures varied in respect to samples and variables in the casting process (Appendix B: trial samples T1A-T4C).

Sample 1: Not soaked in bioplast for a week, but soaked in bioplast ½ hour before undergoing vacuum.

- Shows prevalently more bubbles than sample 4
- Rose in tray position (bioplast sunk around, encasing)

Sample 2: Soaked in non-catalyzed bioplast for one week, not placed under vacuum.

- Shows greater depth of penetration, however not the greatest

Sample 3: Not soaked and not placed under vacuum.

- The least effective, minimal depth of penetration

Sample 4: Soaked approximately 1 week in non-catalyzed bioplast and under vacuum.

- Showed very little bubbles under vacuum
- Sunk a bit in the casting tray instead of rising
- Shows a much better embedding

<u>Experimental Phase II</u>

After observing the four trial samples it was decided that further testing was needed to perfect the procedure. While samples soaked in bioplast showed greater penetration and less plucking, the samples placed under the high pressurized vacuum became segmented by interconnected micro-cracks (Appendix C: trial samples MVFT01-MVFT08). It is evident that the vacuum pressure was too aggressive and forced the samples to pull apart. To assuage this issue a hand-crank vacuum pump was tried. This was believed to still provide the depth of penetration that the high pressured vacuum provided, but without introducing a system of micro-cracks. Two additional samples were soaked in non-catalyzed bioplast, and subsequently placed under vacuum with the hand-crank vacuum. The procedure is thus:

1) Allow the sample(s) soak in non-catalyzed Ward's bio-plastic for two weeks. This gives adequate time for the bioplast to penetrate fully into the material.
2) Pour the base layer of catalyzed bioplast. Allow curing fully (3 days or longer). Fully curing of the base layer will prevent the sample from sinking to the bottom of the embedding tray when placed under vacuum.
3) After soaking for two weeks, transfer the samples atop the base layer, substrate down.
4) Make another mixture of Ward's bio-plastic and catalyst (letting sit for 30 minutes to allow time for the bubbles of trapped air to be released). Pour mixture over the samples and coat them completely in the embedding tray.
5) Place embedding tray in the hand-crank vacuum pump chamber. Close the lid.
6) Pump continuously for two minutes. After two minutes, let samples sit for 5 minutes before releasing the pressure.
7) Release the pressure.
8) Repeat steps 6 and 7 twice.
9) After purging the samples, undo the lid of the vacuum pump. Let samples for 1-3 months (depending on the relative humidity at that time of year).

After complete curing, the samples were cut with a Buehler's low-speed Isomet saw. Polishing was carried out by hand on a polyurethane cloth using Stoddard Solvent as a

Lubricant. Samples were then mounted on slides with Cargille Meltmount, which has a 1.662 refractive index at 25 degrees Celsius.

Analysis of the samples cast following these procedures show that using the hand-crank method yields positive results (Appendix B: Samples T5A and T6A**)**. When using the hand-crank pump, the samples remain intact—unlike the high pressurized vacuum, where many interconnected micro-cracks segment the sample. In this method the bioplast shows full depth penetration throughout the sample. There is no plucking, and the earthen substrates remain whole. Samples TS5 and TS6 yield the best results.

Recommendations

Preparation and casting of earthen architectural finishes should follow the steps laid out under the Experimental Phase II, summarized here within.

5.3 Fire Temple Facsimile Preparation

In order to interpret thermograms successfully, practice and traning with an IR camera was undertaken on facsimile panels. Facsimiles were made of like soils donated by Mesa Verde National Park. The facsimiles were made from a gypsum board substrate upon which a plaster layer, and various wash schemes applied on top of each other. The construction of the facsimile is as follows:

1) 1’ x 2’ x ½” gypsum board panels were cut.
2) A basswood frame was constructed around the gypsum board against which the thicknesses of applied finishes and the ¼” plaster layer could be gauged (Appendix D).

3) Preparation of the plaster was pursuant to ASTM 421 standards, *Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constant* (Appendix E). Soil used for the plaster is the Mesa Verde red loess. Soil was sieved to obtain the correct ratio of sands: fines or particles 4.75 mm-75µm: <75µm. Soil plaster mean for sand: fines is 60:40 and washes 16:84.

4) The gypsum board was coated with 3 coats of Zinsser Co.'s Bulls Eye Shellac to stop water suction and premature drying and cracking.

5) Plaster was applied according to the recommended ratio of soil mass to water content (180ml of soil to 50 ml of deionized water).

6) After application of the plaster the facsimiles were set to dry in a humidity chamber that slowed the rate of evaporation for one week (Figure 5.1).

7) Also critical at this point is to dampen a towel and place it over the substrate.

8) Another sheet of gypsum board should be shellacked and laid atop the plaster. This provides a downward pressure and also helps the facsimile dry equally on all surfaces.

9) Thereafter, subsequent layers of finish were applied according to the facsimile schemes and keeping the sands to fines ratio at 16:84. (Appendix F).

10) Facsimiles were allowed to dry for at least 20 days or until complete drying has occurred.

Figure 5.1 Humidity chamber. Photo taken by author, 2013.

Didactic Preparatory Models

The majority of testing during this phase was done in terms of the plaster, while the finishes were applied with no difficulty. Over 20 smaller scale facsimiles were constructed at first in order to perfect the water to soil ratios and cure time that would yield the best results for the plaster (i.e. minimal cracking). Major faults in the ratios proved too much for the plaster. Cracks were more than an issue; but finally, with time, the correct process was discovered. 5"x 5" x ½" panels of gypsum board were used as the substrate.

5.4 Digitization of Potential Variables

Understanding the wall holistically is a critical preparatory measure. There are a number of deterioration mechanisms present in the architectural finishes. Salt deposits, blistering, delamination, and areas of complete loss are just a few of the sixteen recorded conditions that may produce a false positive thermogram. Each of these conditions shed light onto how the surface dries, where it retains moisture, where there are areas without plaster or wash. The digitization of potential valuable gives yet another base layer of information.

Conditions Assessment: North Wall, Kiva A

Due to its state of condition and integrity, the North Wall of Fire Temple was chosen for conservation by the National Park Service. In 2011 an architectural conservation team from the University of Pennsylvania, under direction of Professor Frank G. Matero, started conservation work on the earthen mural. The project underwent two phases, documentation of the wall and treatment of deterioration phenomena.

The conditions assessment began with preliminary observations. During this phase rectified photography, with the use of measurements from a Total Station, was completed and relevant deterioration mechanisms were identified. The rectified photography was then tiled into forty-eight 8.5x11 tiles, printed, and placed in plastic sleeves. Thereafter, in August 2011, a subsequent site visit was made and conditions where color coded and recorded atop the rectified photography.

The assessment of conditions aids the conserver in deciding which conservation procedures to apply on the mural. The team recorded the areas where grouting, 5%

gelatin, and 10% gelatin treatments were used to reattach the mural back onto the sandstone masonry.

The hand-drawings are then digitized in AutoCAD overtop the rectified photography using polylines and boundaries. Each condition or treatment is drawn on different layers. The procedure for AutoCAD is thus:

1. Insert rectified, high-resolution photography
2. Scale the image to be life-sized
3. On different layers draw individual conditions and treatments with closed polygons, boundaries, and polylines

ArcGIS: Importation Process

A few things need to be made sure are done correctly before importing the CAD file into ArcGIS. This is to ensure GIS can read the data and the shapes drawn in CAD correctly.

1. Every polygon needs to be closed in AutoCad.
2. All desired layers need to be turned on.
3. The CAD file must be saved as a 2004.dwg drawing (later versions are not as compatible with GIS software).

To import the CAD drawing into ArcGIS, follow the steps herein:

1. Add data

2. Navigate to the CAD file, and when prompted, import polygons and polylines.

3. Right click the polygon CAD layer in the table of contents, open the attribute table and then choose select by attribute.

4. Under Method select create a new session, double click on “Layer”, click the “=” icon, click get unique values, and double click on a layer and then click apply. Now go back and right click the polygon CAD file again in your table of contents, go down to data, and then export data. Navigate to a folder that will contain all your shapefiles, rename the shapefile as the appropriate condition, and save as type as a shapefile.

5. Repeat steps 3 and 4, creating a shapefile for each set of conditions or treatments.

<u>ArcGIS: Statistical Analysis</u>

The final step—and the main reason behind importing the drawing in the first place—is utilizing the quantification tools provided by the ArcGIS software. GIS has the ability to provide the conserver with numerical data as to the extent of a certain condition and its locality on the wall’s surface. The most useful and relevant tools in GIS can be found under “calculate geometry.” The area, x coordinate of the centroid, and the y coordinate of the centroid were quantifications represented in the statistical section of each drawing sheet (Appendix G).

<u>Area:</u>

Area gives vital information as to how severe the problem is, or how much treatment was used in mitigating the issues. It can also be used to tell how much of the indigenous plaster remains. One question commonly asked in tour groups is, how much of this is original and not reconstructed or repaired? It is a question that in many people's eyes validates the historic integrity and authenticity of a site. With the use of GIS this question can be answered with a certainty as never before.

X and Y Coordinate of Centroid:

Finding the coordinates of the x centroid and y centroid of each polygon can give a spatial description of the deterioration of the surface. A relatively higher amount of repair on the east side of the wall (found from the x centroid) indicates that this end of the wall is being lost at a faster rate than the west. This could be explained by the shape of the alcove, the porous nature of the bedding planes, the condition the site was discovered in, and many other things. It also tells us that the western half of the wall has more original mural left than the right.

The frequency of the y centroid coordinates tells us vertically where the problem is taking place. Take animal surface deposits as an example. The condition plagues the upper part of the wall, and is not found on the lower half. The y centroid coordinate of animal surface deposits, therefore, is a very distinct indication that the site has problems with birds nesting atop the wall, amongst the bedrock.

Conclusion

Many other similarity and patterns can be made from looking close at the data. But other than this, the quantification process serves as an historical record of accuracy against which the wall's deterioration can be monitored and the effectiveness of the treatments verified. In ten, fifty, or one-hundred years another conservation team can conduct the same survey of conditions, following the same steps. These results can explain whether the deterioration has stopped, slowed down, or continued. They can also verify the success of the treated wall by the 2011 conservation team (if areas treated in 2011 exhibit no further deterioration, than the treatments can be assumed to be successful).

In addition, these results are critical in understanding whether further conservation efforts are needed and in predicting how long the mural may remain.

Chapter 6: Infrared Thermography Testing

Figure 6.1 Completed facsimile on which thermographic study underwent. Materials are sands native to the American Southwest. The most over-pained area is the right third (where the white architectural finish is all that is visible currently). 1'x 2". Facsimile made by author. Photo taken by author.

6.1 Infrared Thermography Practice

During preparation of scheme 1 (Appendix F) experimental tests were conducted during application of the earthen finishes. Indicated in the following thermograms (figures 6.2 and 6.3), one can clearly distinguish between the applied layer of white wash and the red wash.

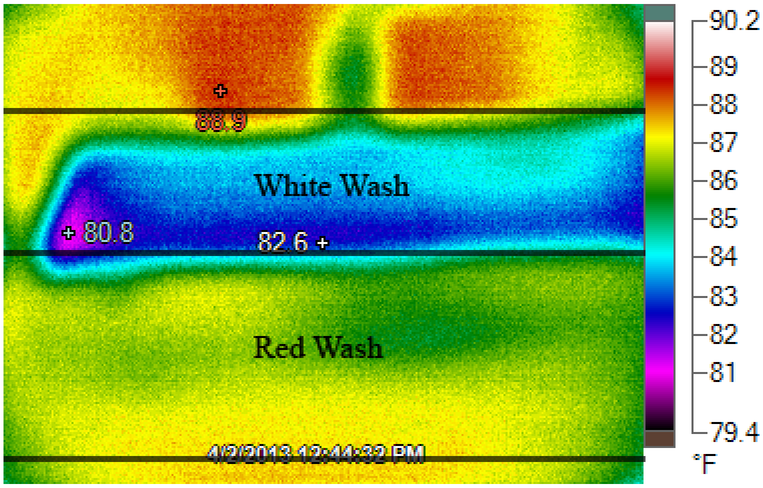

Figure 6.2 Infrared thermogram taken by author. Acquired after the application of a white wash and a red wash, during cooling.

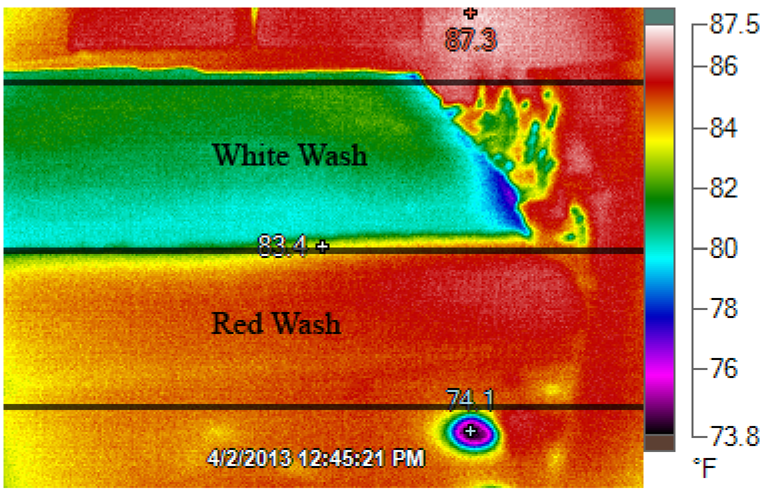

Figure 6.3 Infrared thermogram taken by author. Acquired after the application of a white wash and a red wash, during cooling.

The camera used to acquire these thermograms was a Fluke Ti 32, equipped with IR fusion technology and a full visual image (640 x 480). The camera has a resolution of .1 degrees Fahrenheit With the cameras IR fusion technology it is possible to toggle between the min, mid, and max infrared exposure. This ability produces different interpretive options. Figures 6.3 and 6.4 above have been captured at a max infrared setting.

No other tests were conducted until the facsimile was completed.

6.2 Infrared Thermography: Passive Thermography Approach

Early test on the completed facsimile was carried out using the passive thermography technique. While test conditions were not optimal, some success was had. Notice in figure 6.4 (infrared thermogram), that the top right corner of the central rectangle indicates the over painted red triangles and yellow dots from scheme 2.

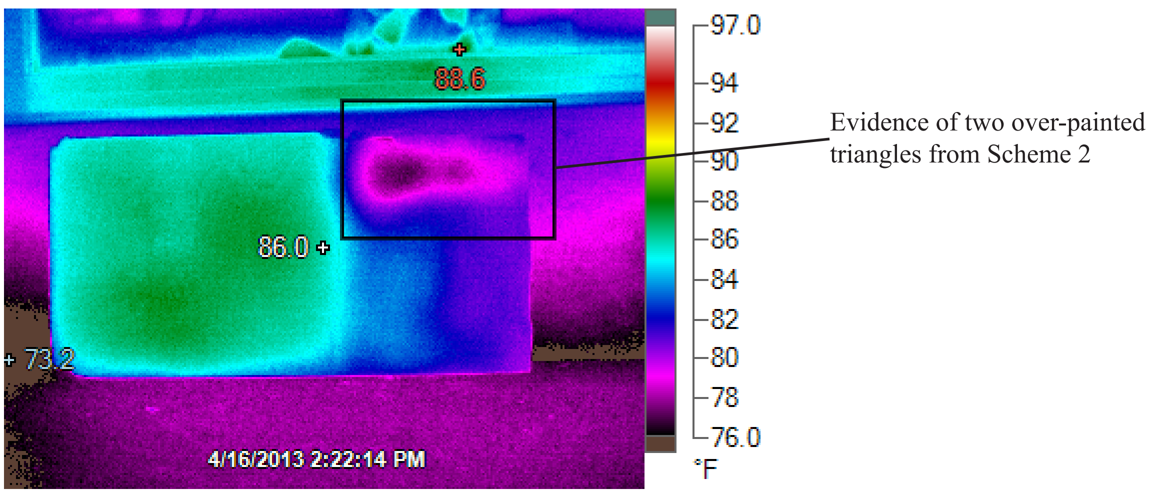

Figure 6.4 Infrared thermogram taken by author. Acquired utilizing passive thermography. Notice the box which highlights two distinct triangles underneath a coat of white wash.

This thermogram (figure 6.4) arguably captures the 2 underlying triangles from scheme 2. The box highlights two areas that are colder than the rest of the area. The colder areas are spaced the same as the triangles and the cut off at the bottom does correlate to the dado height from scheme 2.

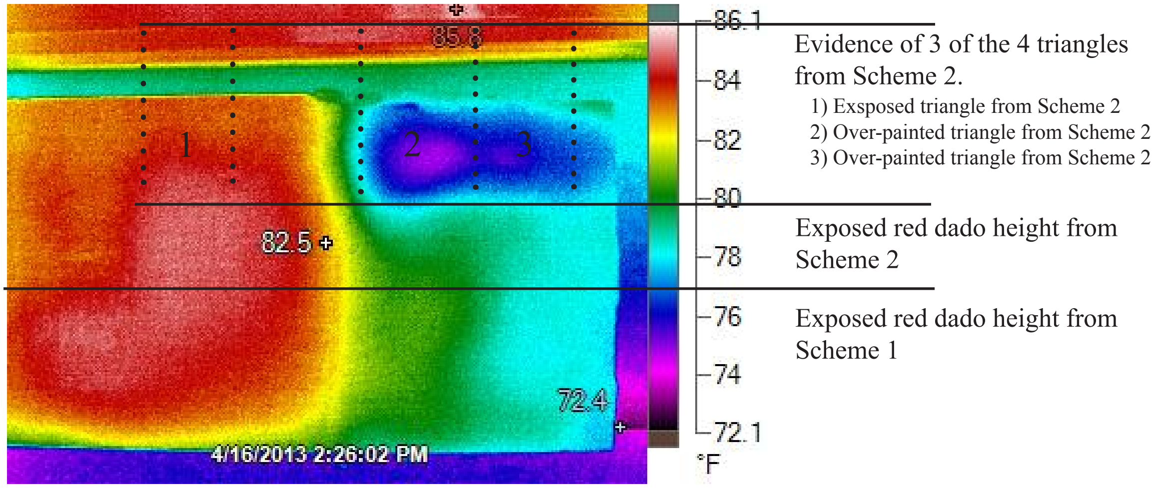

Figure 6.5 Infrared thermogram taken by author. Acquired utilizing passive thermography. Under-paintings are able to be discerned.

Perhaps the most informative thermogram taken on the first day is figure 6.5. One can easily see the revealed schemes on the left two-thirds of the facsimiles. Two different dado heights can be seen and even the two exposed peaks from scheme 2. The right third of the picture is more complicated. The yellow vertical line reading 82.5 on the spot temperature gauge is where scheme 2 and 3 meet. Scheme 3, with the white wash over painting has a colder surface temperature than the rest of the painting. In addition, in the top right corner two distinct triangles are discernable—these are the peaks from the red triangles in scheme 2.

5.3 Infrared Thermography: Active Thermography Approach

Due to poor environmental conditions, the second day of testing was carried out in a laboratory at the University of Pennsylvania utilizing the active thermography approach. On April 18, 2013, 3 halogen lamps positioned 30 in from the facsimile heated the surface of the mural to 150 degrees Fahrenheit. The combined wattage of the lamps was 300 watts. At time of thermography the temperature in the lab was 80 degrees Fahrenheit with a relative humidity of 34%. The emissivity during acquisition was set to 0.37.

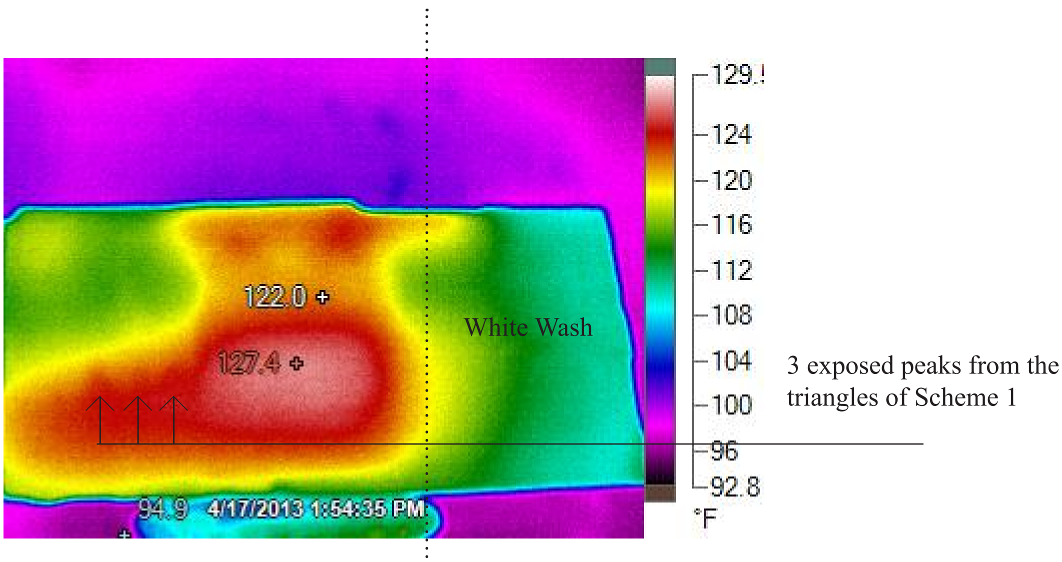

Figure 6.6 Infrared thermogram taken by author. Acquired by active thermography. Notice the three peaks from the first scheme on the left third of the panel. Two different dado lines also visible.

Thermography results were conclusive. In figure 6.7, a thermogram taken after the facsimiles was heated, some images can be discerned. Three distinct peaks can be seen on the left side of the thermogram (in red). These are the three exposed triangles from scheme 1. Around the 122.0 spot temperature reading we see the height of the second dado. And to the right third, scheme 3, we see that it is the coldest part of the painting and it corresponds to the white wash as the surface layer.

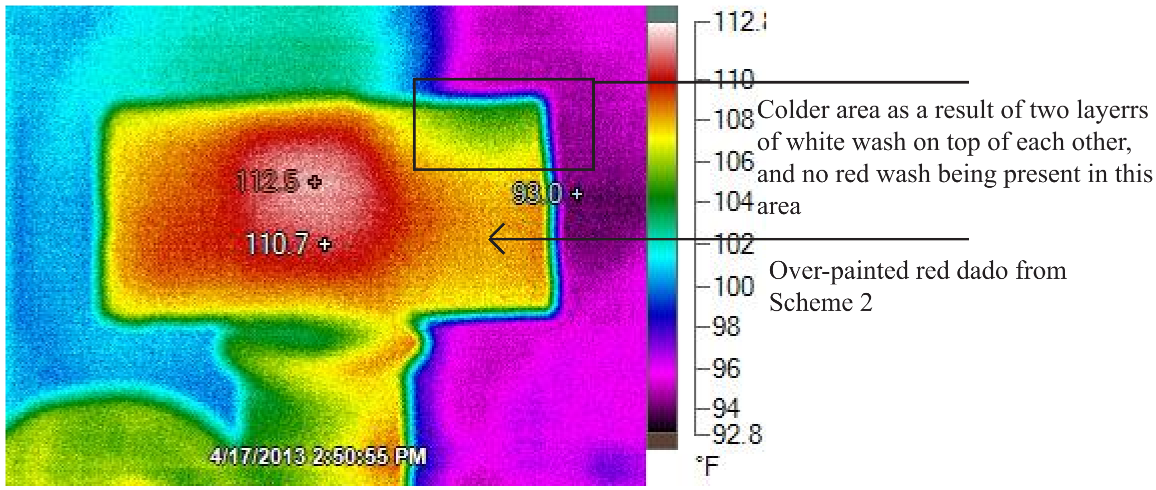

Figure 6.7 Infrared thermogram taken by author. Acquired by active thermography. Notice the colder area in the top right corner.

Figure 6.8 is a thermogram taken as the facsimile is cooling. Evident in the image is the central hot spot, which is the large red dado from scheme 2 retaining heat. Right of the central spot it radiates almost as much energy except for in the top right corner. The cooler area in the top right corner (green area) is where two white washes are overlaid, while the warmer lower majority is the continuation of the dado from scheme 2 under a layer of white wash.

Chapter 7: Conclusions/Results

7.1 Nondestructive testing

In conclusion, nondestructive testing of heritage and cultural objects is extremely important. The ability for the conservationist to analyze objects without sampling (or even touching) the object is what conservation is all about. Invaluable objects no longer have to be damaged or destroyed to figure out how they were made.

7.2 Infrared Testing at Fire Temple

It is now known how different types of soils and stratigraphic layers of earthen finishes react under thermal fluxes. It is also known how layering of earthen finishes create differential thermal patterns. Extensive research on how the finishes absorb and radiate heat energy have concluded that thermal investigations on earthen murals are possible. For instance, infrared thermography can positively distinguish between types of surface finishes. In addition, there is a plethora of scientific evidence that suggests subsurface investigation is also possible. Positive results with like-material in the laboratory only give more credence to the possibility of discerning hidden images at Fire Temple, Mesa Verde National Park.

It is recommended to apply infrared thermography to evaluations at the north wall of Fire Temple. Thermography testing should be able to reveal some subsurface images and details—especially if they are made of the red wash. At minimal, the infrared thermography should be able to discern surface embellishments that are faded or otherwise hard to see.

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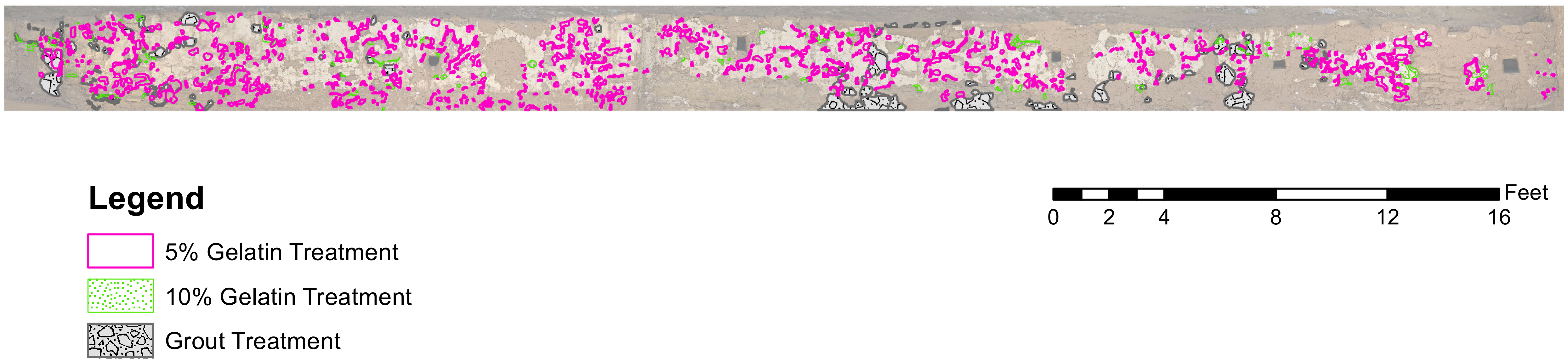
APPENDIX A:

CONDITIONS ASSESSMENT SHEETS, 2011



UNIVERSITY OF PENNSYLVANIA

Fire Temple [Mesa Verde National Park]

NORTH WALL

Conservation Treatments, 2011

DANIEL S. CASTELE

SHEET NUMBER:

3.1

APPENDIX B:
EXPERIMENTAL BIOPLAST EMBEDDING

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

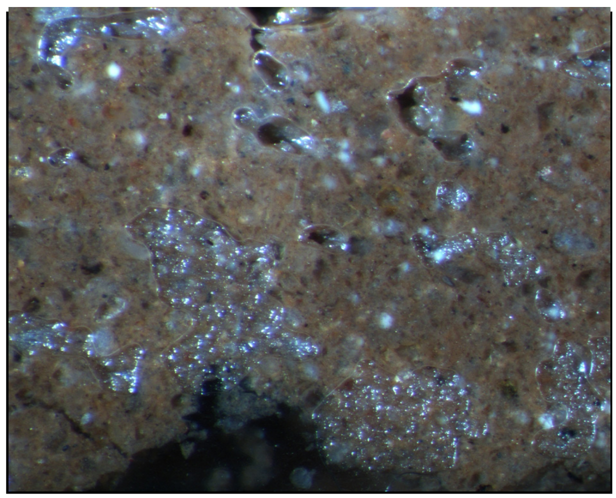
MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

Sample shows minimal micro-cracking. Where cracking occurs is around ground boundaries and especially the grain boundaries of larger inclusions. Plucking does not appear to be a major concern.

LOCATION

Plaster Substrate from Detached Plaster Sample

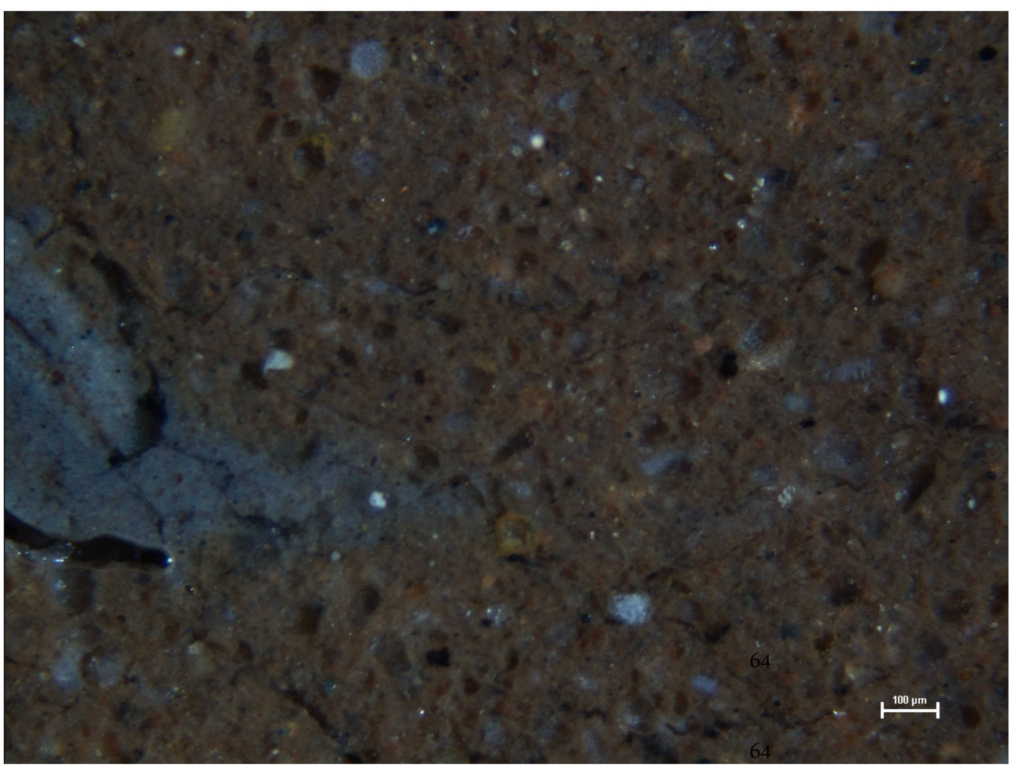


PHOTOMICROGRAPH:
Reverse Side
10x Magnification

EMBEDDING METHOD

Soaked in catalyzed bioplast 1/2 hr. before undergoing vacuum

PHOTOMICROGRAPH



64

T1A

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

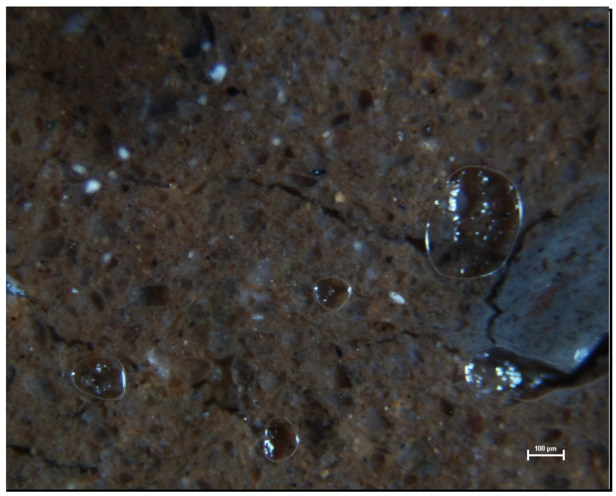
MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	10x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

Prevelant interconnected cracking which starts from the edge and and proceeds inward. Cracking happens both around ground bandaries and through some larger inclusions. Micro-cracks are quite wide ranging from _____ to ___ and some are _____ long.

LOCATION

Plaster Substrate from Detached Plaster Sample

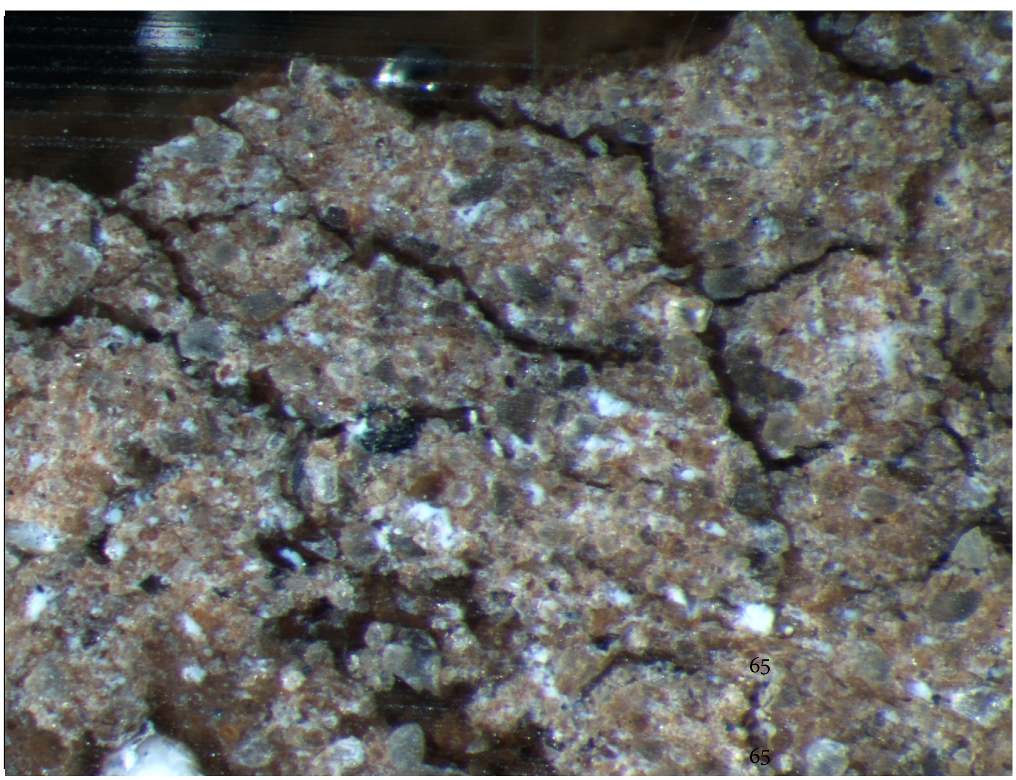


EMBEDDING METHOD

Soaked in catalyzed bioplast 1/2 hr. before undergoing vacuum

PHOTOMICROGRAPH:
Reverse Side
4x Magnification

PHOTOMICROGRAPH



T1B

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

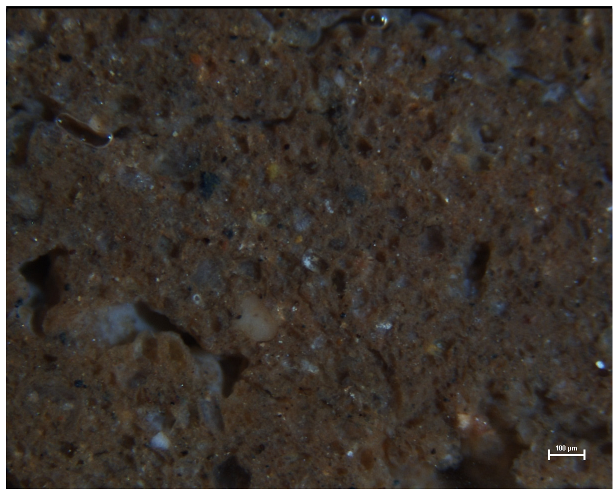
MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	10x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

A few interconnected micro-cracks. Usuallly starting from the edge and working inwards towards large inclusions.

LOCATION

Plaster Substrate from Detached Plaster Sample

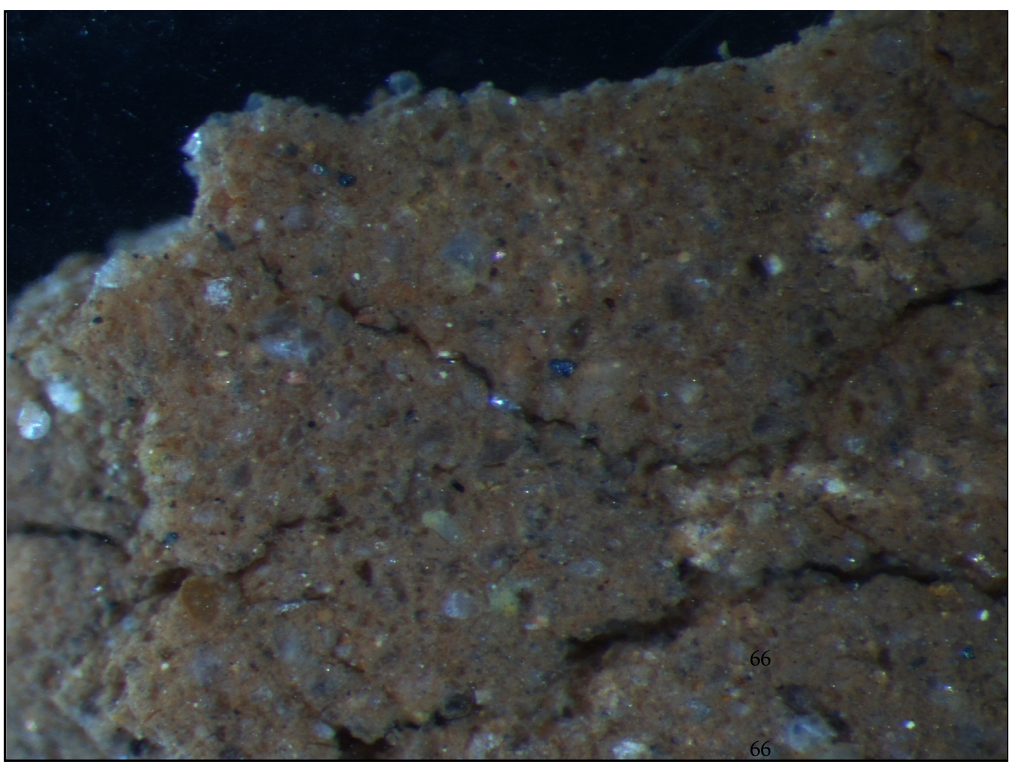


PHOTOMICROGRAPH:
Reverse Side
10x Magnification

EMBEDDING METHOD

Soaked in catalyzed bioplast 1/2 hr. before undergoing vacuum

PHOTOMICROGRAPH



66

T1C

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

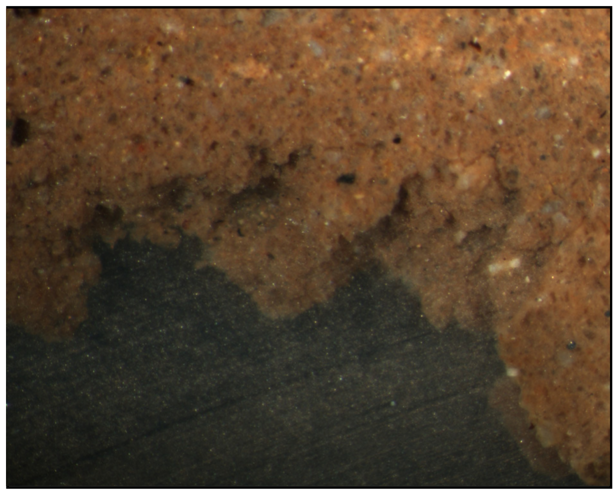
MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

Top photomicrograph shows the sample sectioned but before polishing. Distinguishable amounts of substrate are left in the saw grooves made by the isomet. Larger photomicrograph shows same area after polishing. No micro-cracking. No noticed plucking.

LOCATION

Plaster Substrate from Detached Plaster Sample

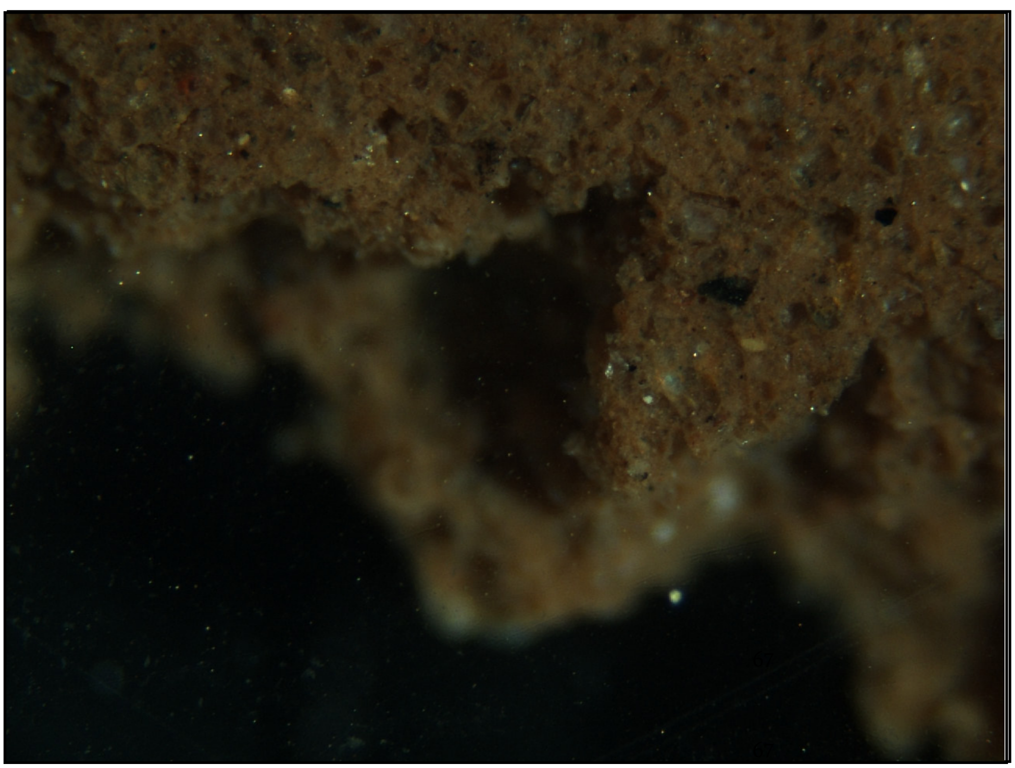


PHOTOMICROGRAPH:
After cutting but before polish
6.3x Magnification

EMBEDDING METHOD

Soaked in non-catalyzed bioplast for 1 week but not placed under vacuum

PHOTOMICROGRAPH



T2A

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

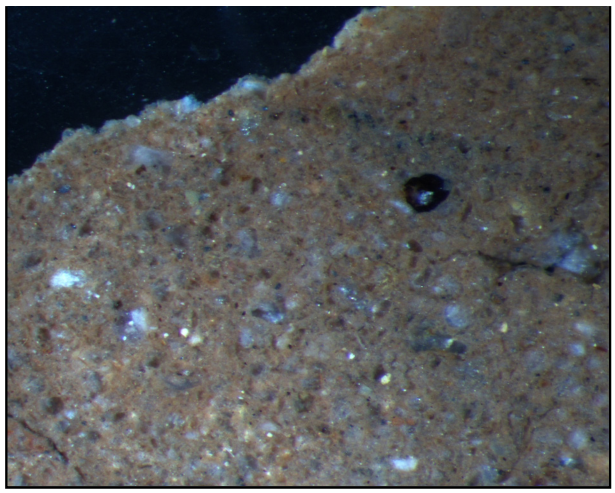
MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

Very minimal cracking. Where there are cracks they range from ___ to __ in width, and only ___ in length.

LOCATION

Plaster Substrate from Detached Plaster Sample

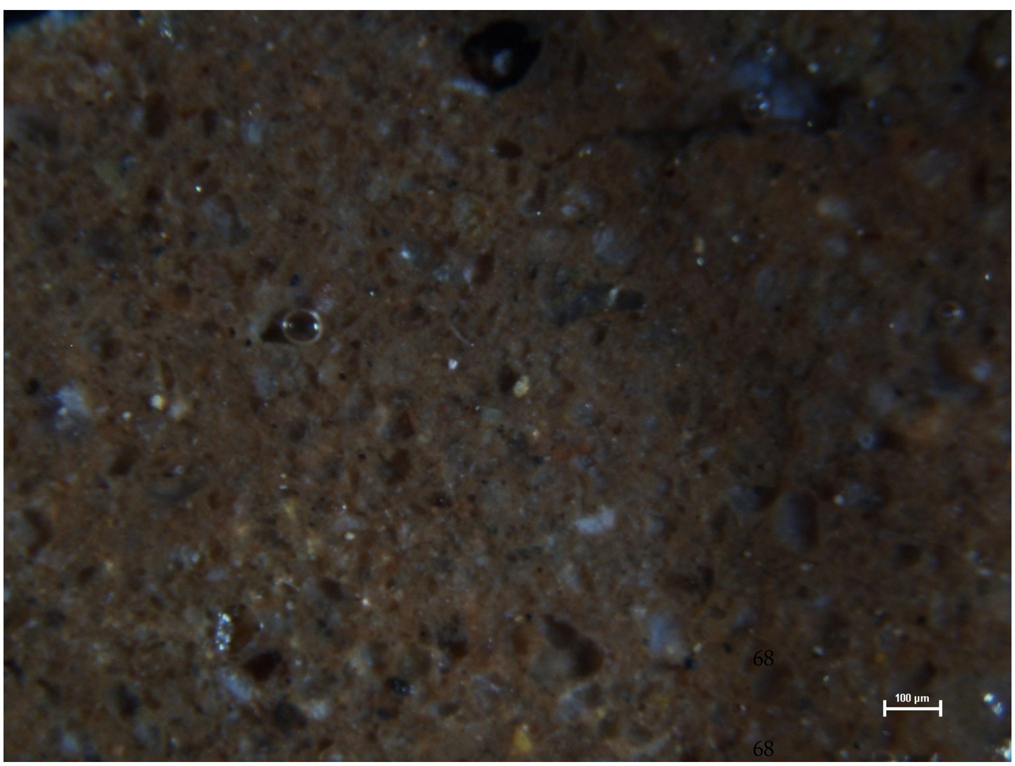


PHOTOMICROGRAPH:
Reverse Side

EMBEDDING METHOD

Soaked in non-catalyzed bioplast for 1 week but not placed under vacuum

PHOTOMICROGRAPH



T2B

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

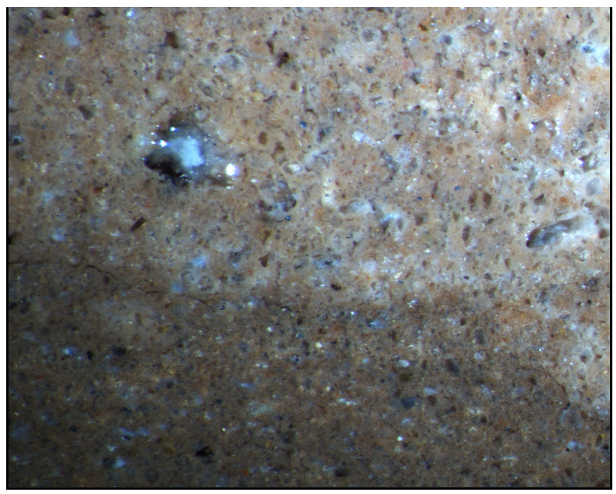
MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

No micro-cracking. No noticed plucking.

LOCATION

Plaster Substrate from Detached Plaster Sample

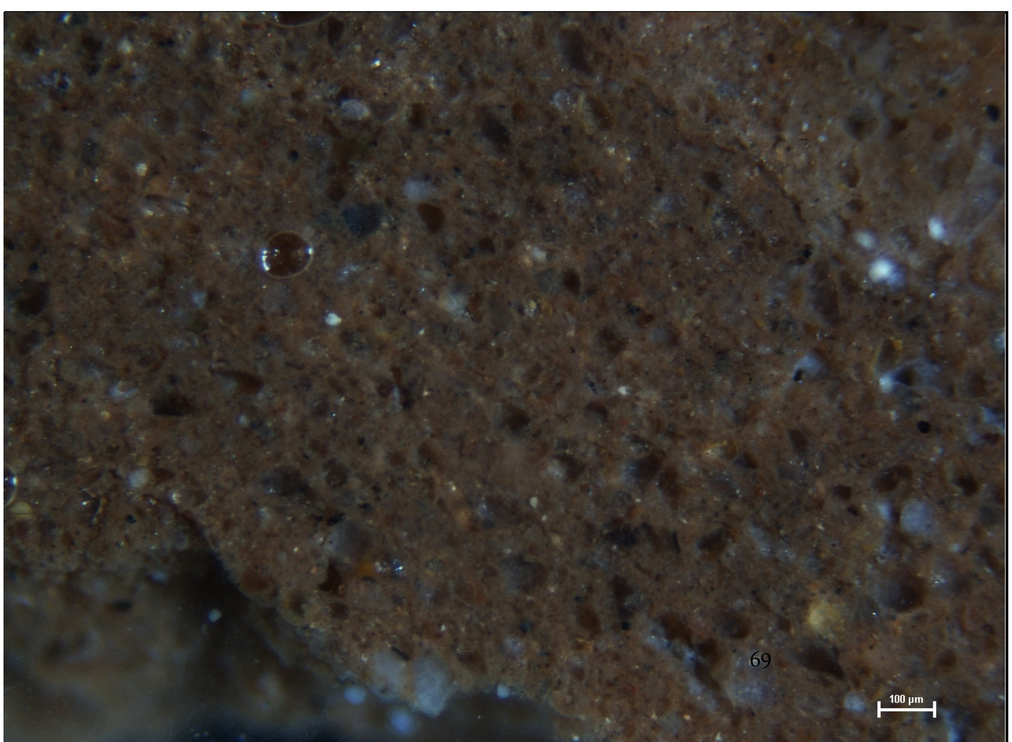


PHOTOMICROGRAPH:
Reverse Side
6.3x Magnification

EMBEDDING METHOD

Soaked in non-catalyzed bioplast for 1 week but not placed under vacuum

PHOTOMICROGRAPH



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T2C

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

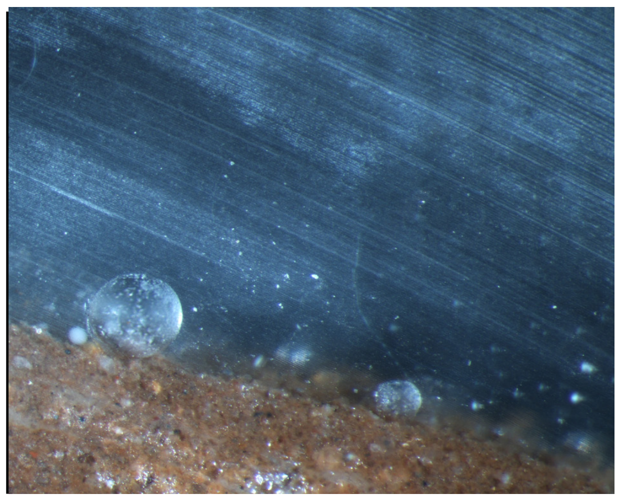
MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

Top photomicrograph shows the sample sectioned but before polishing. The saw marks from the blade run diagonally in the cured bioplast. Larger photomicrograph shows same area after polishing. No micro-cracking. No noticed plucking.

LOCATION

Plaster Substrate from Detached Plaster Sample

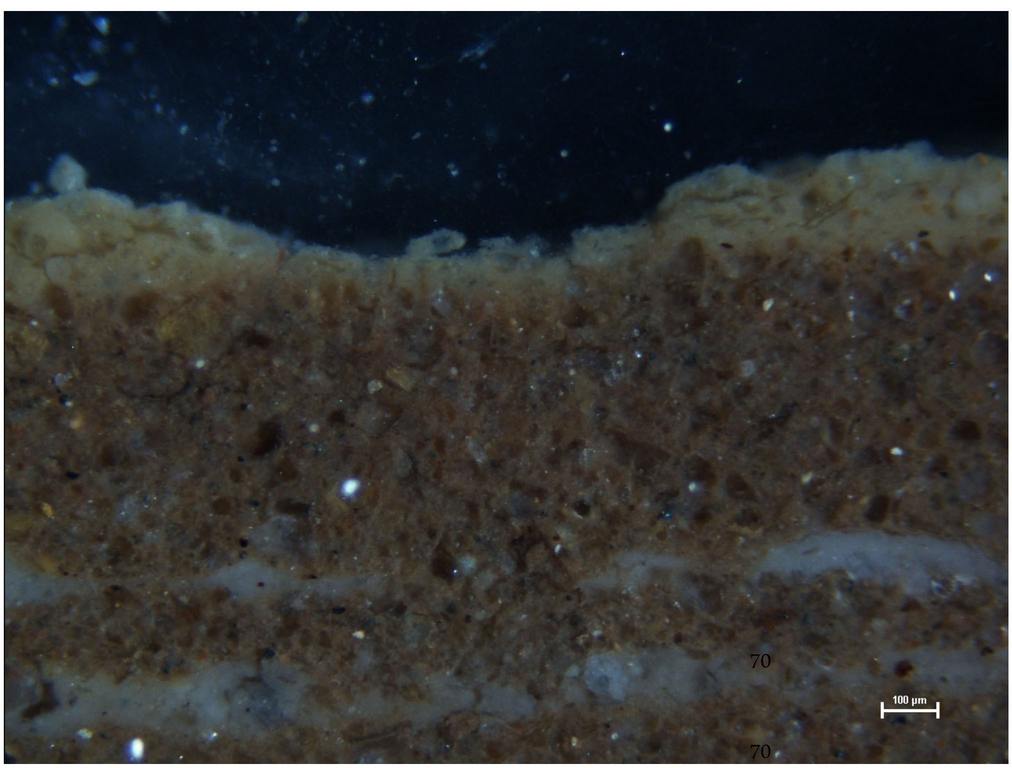


PHOTOMICROGRAPH:
After cutting but before polish
6.3x Magnification

EMBEDDING METHOD

Not soaked in bioplast and not placed under vacuum

PHOTOMICROGRAPH



T3A

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

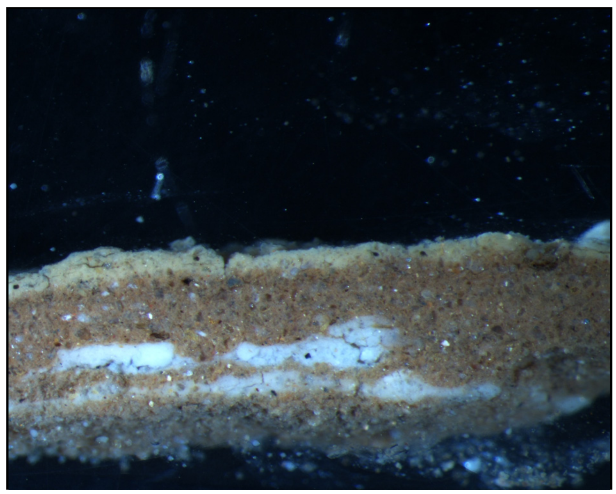
MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

No micro-cracks in the substrate. Sample looks very good. No noticed plucking.

LOCATION

Plaster Substrate from Detached Plaster Sample

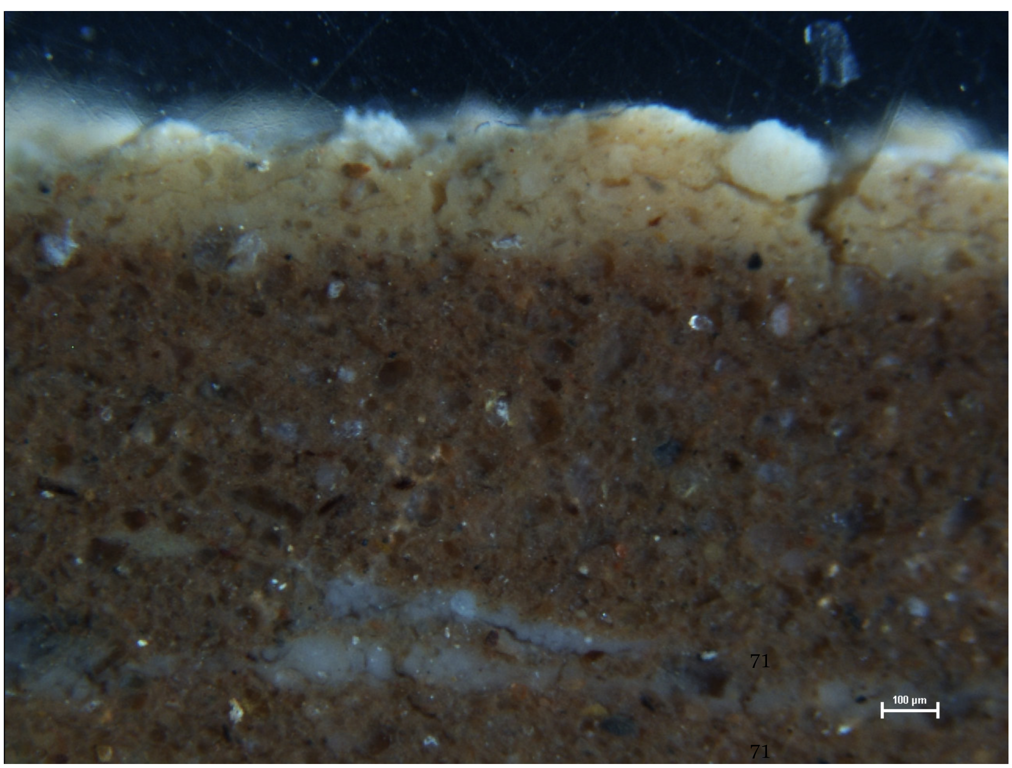


PHOTOMICROGRAPH:
Reverse Side
6.3x Magnification

EMBEDDING METHOD

Not soaked in bioplast and not placed under vacuum

PHOTOMICROGRAPH



T3B

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

A few, thin and short micro-cracks in the finish layer, non in the substrate. Sample looks very good. No noticed plucking.

LOCATION

Plaster Substrate from Detached Plaster Sample

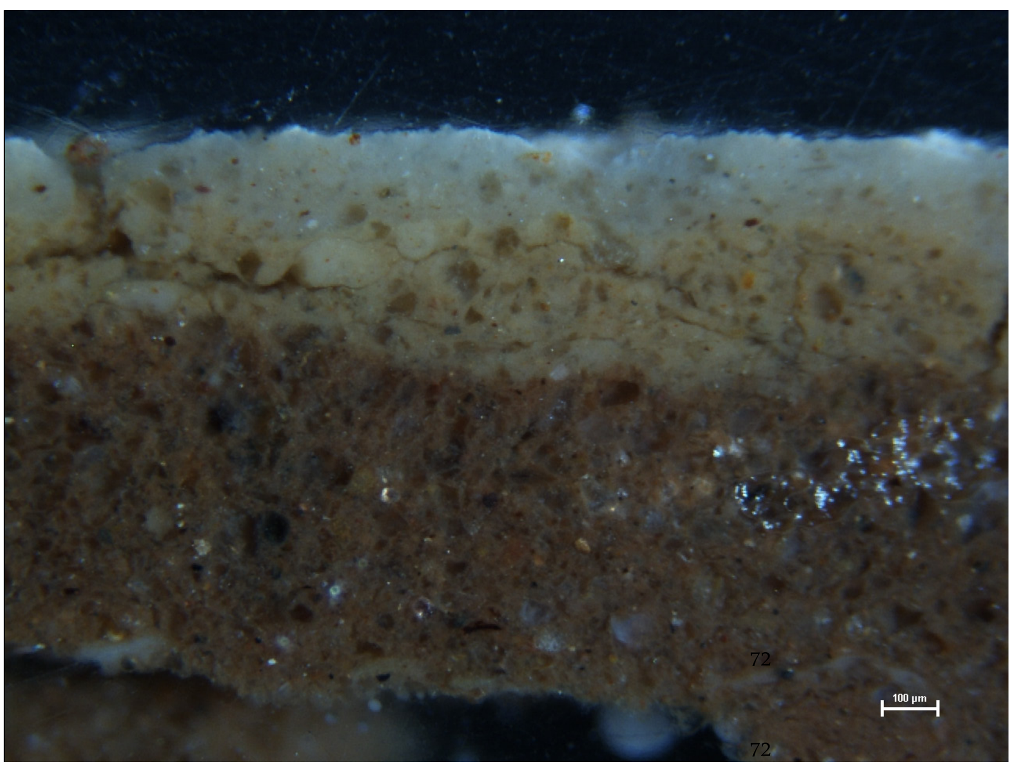
Not Available

EMBEDDING METHOD

Not soaked in bioplast and not placed under vacuum

PHOTOMICROGRAPH:
Reverse Side

PHOTOMICROGRAPH



T3C

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

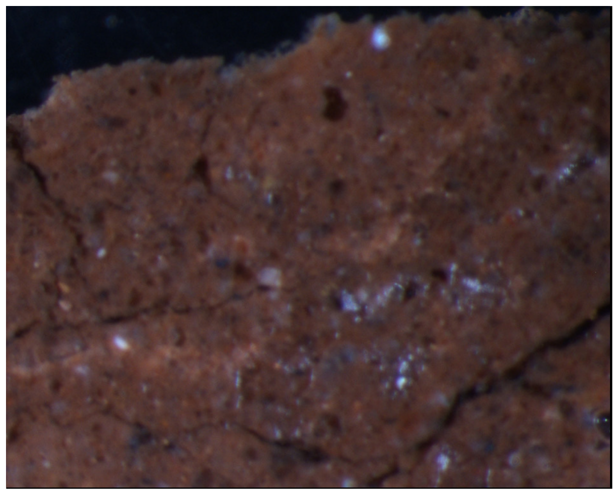
MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

Micro-cracks more severe than other samples. Wide interconnected cracks that bisect the sample.

LOCATION

Plaster Substrate from Detached Plaster Sample

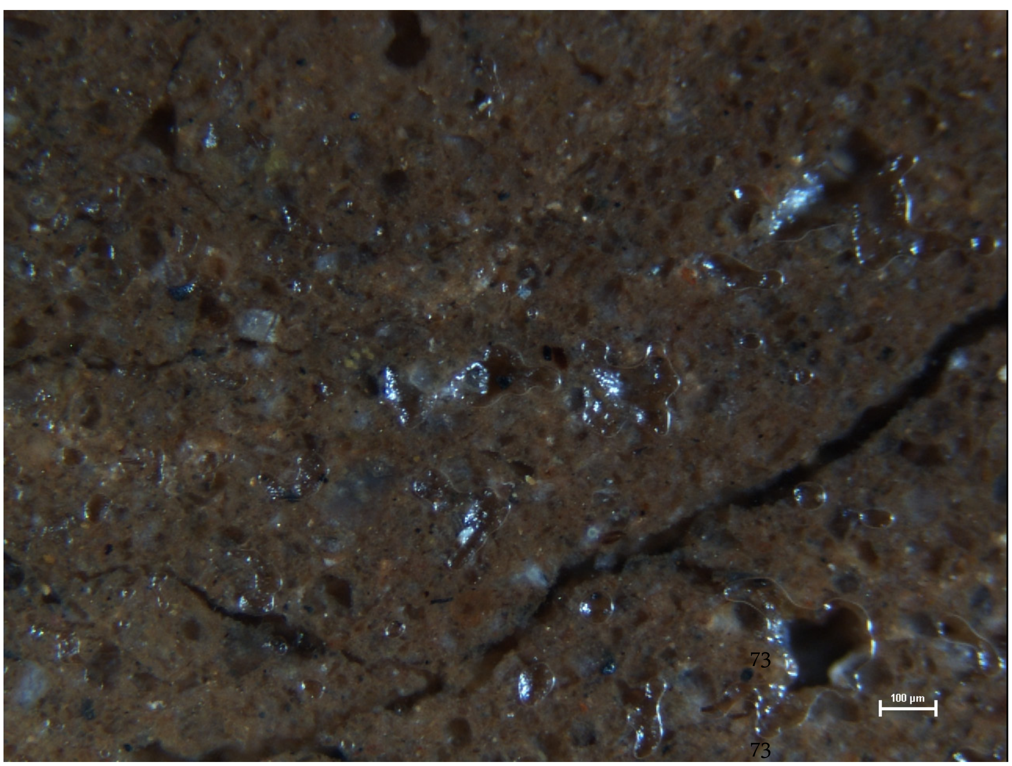


EMBEDDING METHOD

Soaked for 1 week in bioplast before undergoing vacuum

PHOTOMICROGRAPH:
Larger field of view than below
6.3x Magnification

PHOTOMICROGRAPH



T4A

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

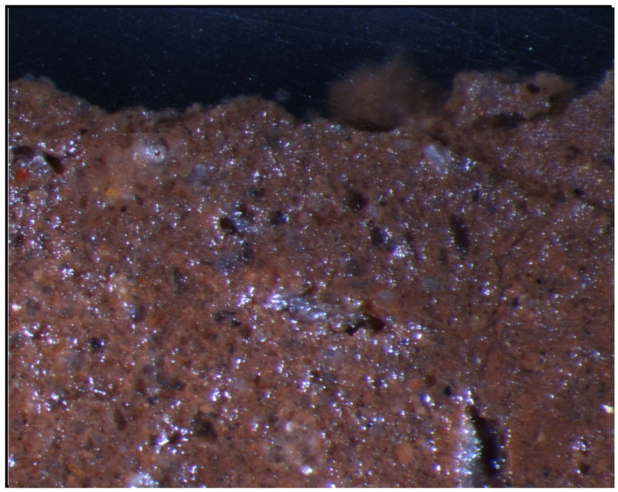
MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

Micro-cracks more severe than other samples. Wide interconnected cracks that bisect the sample.

LOCATION

Plaster Substrate from Detached Plaster Sample

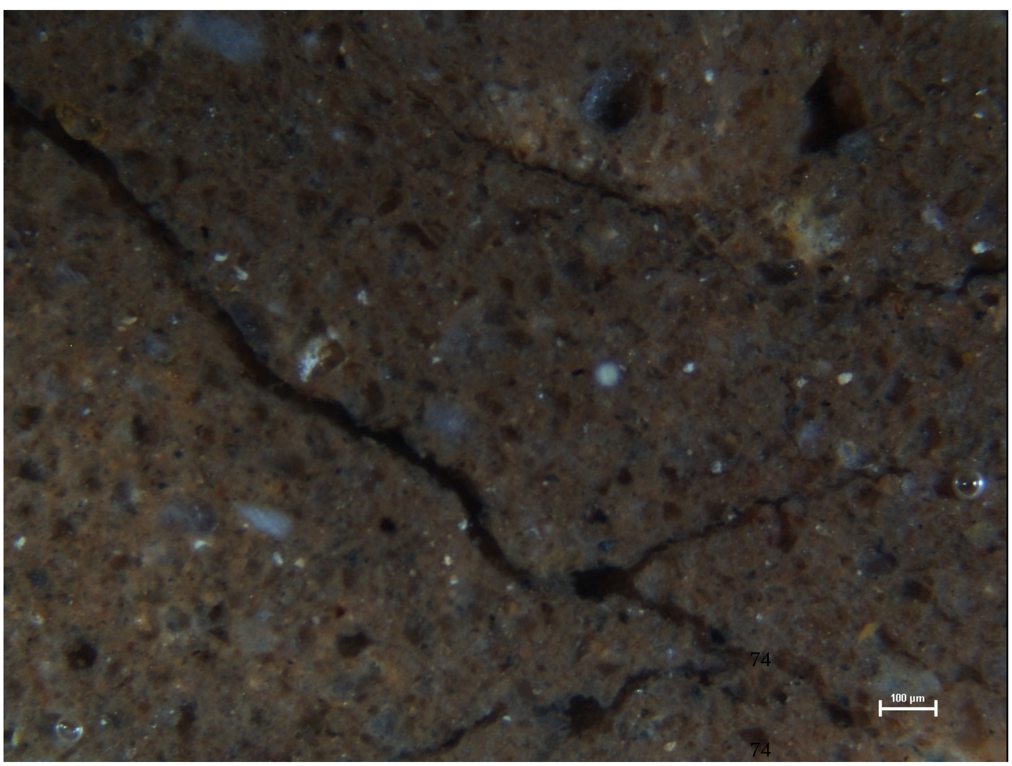


EMBEDDING METHOD

Soaked for 1 week in bioplast before undergoing vacuum

PHOTOMICROGRAPH:
Reverse Side
6.3x Magnification

PHOTOMICROGRAPH



T4B

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

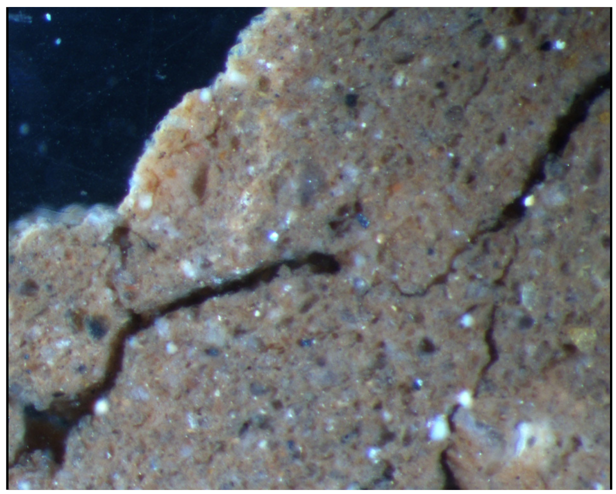
MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

Micro-cracks more severe than other samples. Wide interconnected cracks that bisect the sample.

LOCATION

Plaster Substrate from Detached Plaster Sample

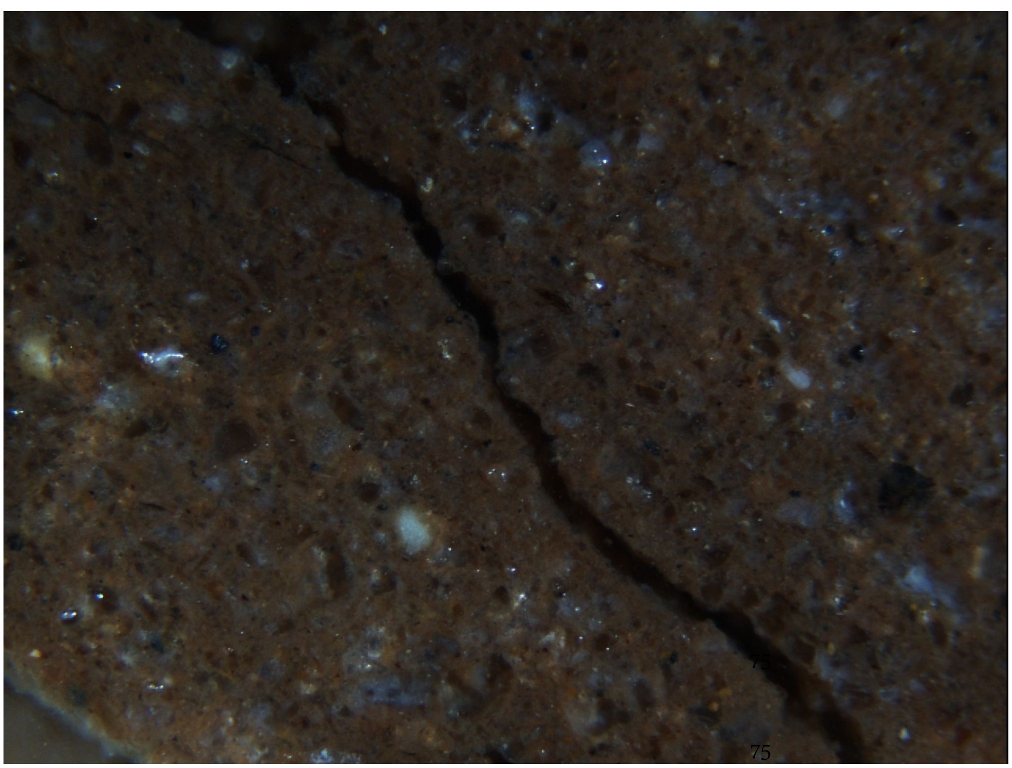


PHOTOMICROGRAPH:
Reverse Side
6.3x Magnification

EMBEDDING METHOD

Soaked for 1 week in bioplast before undergoing vacuum

PHOTOMICROGRAPH



T4C

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

No cracking and no plucking. Full bioplast penetration. Shows the best results.

LOCATION

Plaster Substrate from Detached Plaster Sample

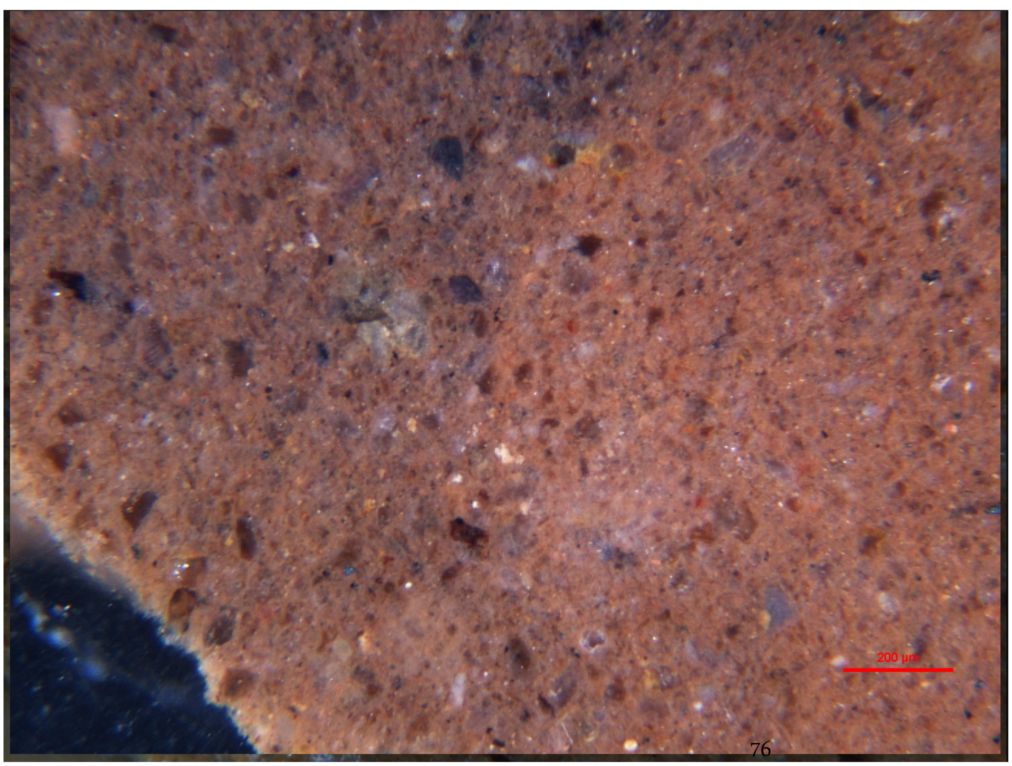
Not Available

EMBEDDING METHOD

Soaked in bioplast for 1 week before undergoing hand-cracknk vacuum pump

PHOTOMICROGRAPH: Reverse Side
6.3x Magnification

PHOTOMICROGRAPH



T5A

Fire Temple: Mesa Verde National Park
Embedding Under Vacuum Trial Samples

FEATURE:	LOCATION:	DATE ANALYZED:
Earthen Substrate Sample	North Wall, Kiva A	22 August 2012

MICROSCOPE:	MAGNIFICATION:	ILLUMINATION:	CAMERA:	ANALYZED BY:
Olympus CX31	4x	Raking Light	Nikon Digital Sight DS-Fi1	Daniel S. Castele

REMARKS:

No cracking and no plucking. Full bioplast penetration. Shows the best results.

LOCATION

Plaster Substrate from Detached Plaster Sample

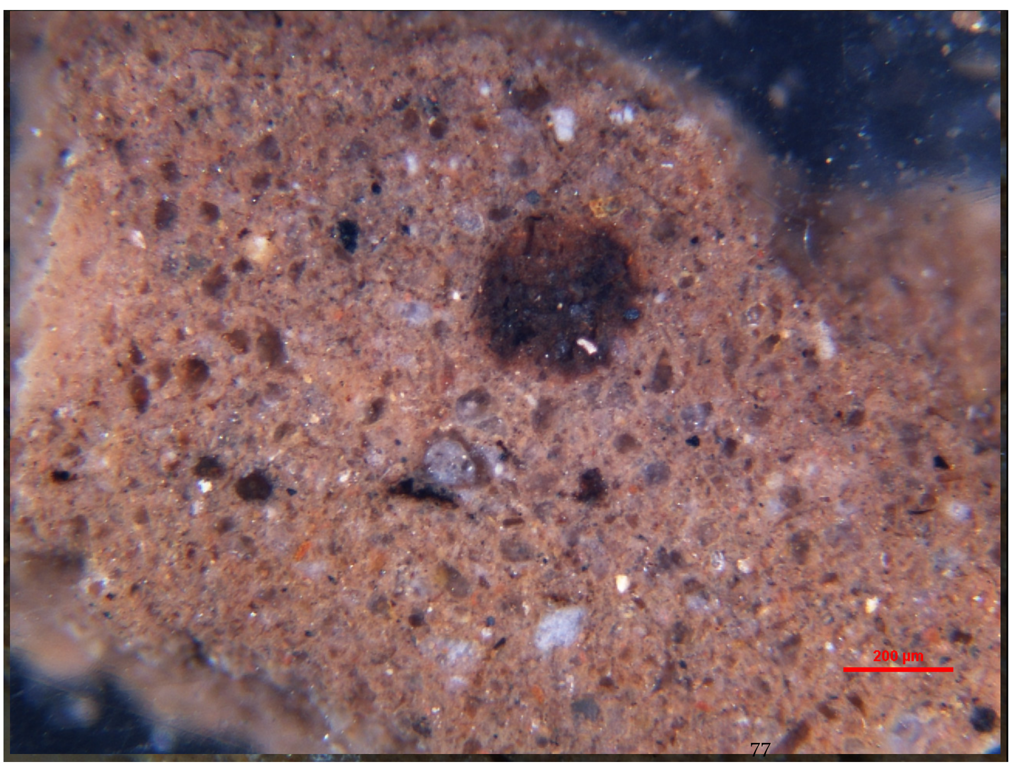
Not Available

EMBEDDING METHOD

Soaked in bioplast for 1 week before undergoing hand-cracknk vacuum pump

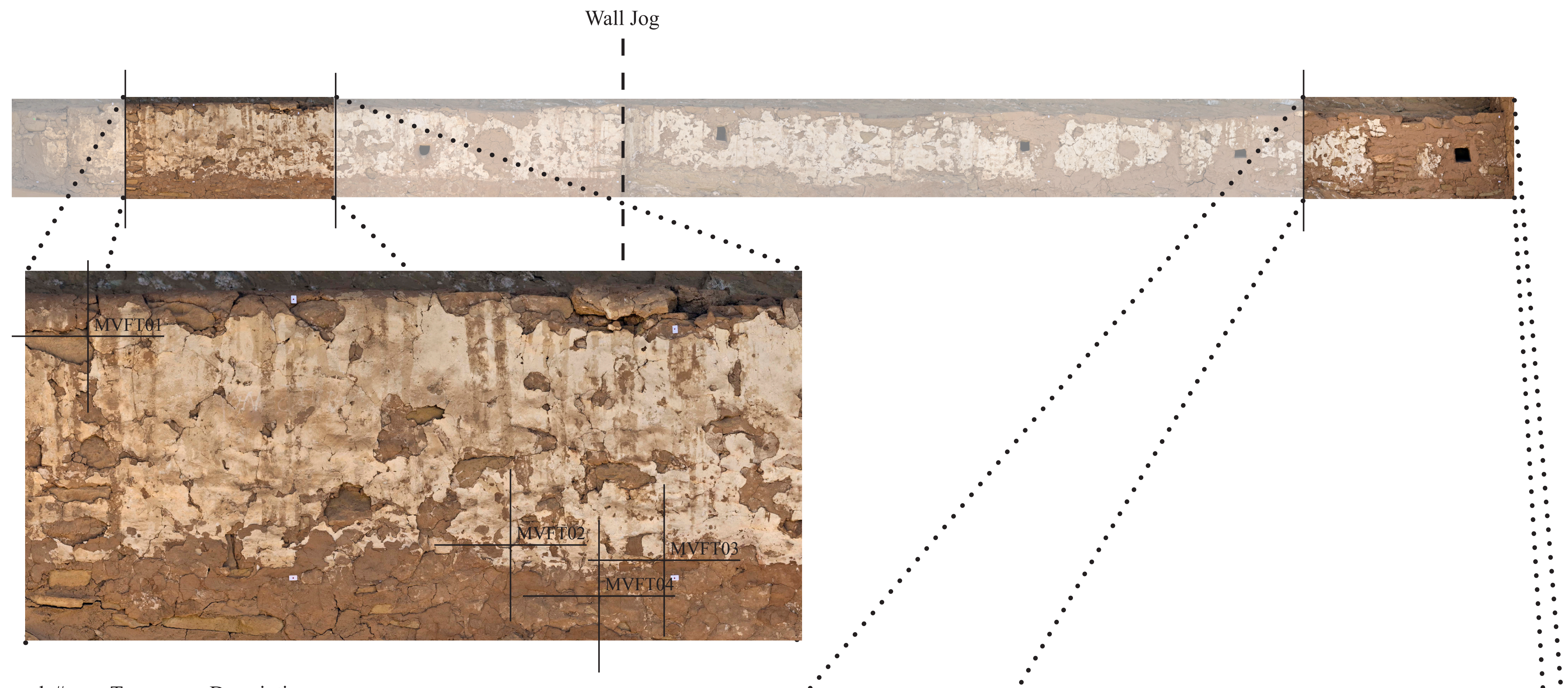
PHOTOMICROGRAPH: Reverse Side
6.3x Magnification

PHOTOMICROGRAPH



T6A

APPENDIX C:
FIRE TEMPLE SAMPLES



Sample#	Type	Description
MVFT01	Finish	Upper field, west end; finish and substrate
MVFT02	Finish	Lower field, west end; zigzag embellishment
MVFT03	Finish	First set of triangles with dado overlap, west end
MVFT04	Finish	Red dado on martar; west end
MVFT05	Finish	Yellow embellishment with mortar substrate; east end; between two easternmost niches
MVFT06	Finish	Final white over red zigzag, on mortar; east end; between two easternmost niches
MVFT07	Finish	White field on stone; jog of wall
MVFT08	Finish	Dado and plaster; jog of wall

* Sample locations for MVFT07 and MVFT08 are not represented because of their location on the jog of the wall

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Fire Temple [Mesa Verde National Park]

NORTH WALL

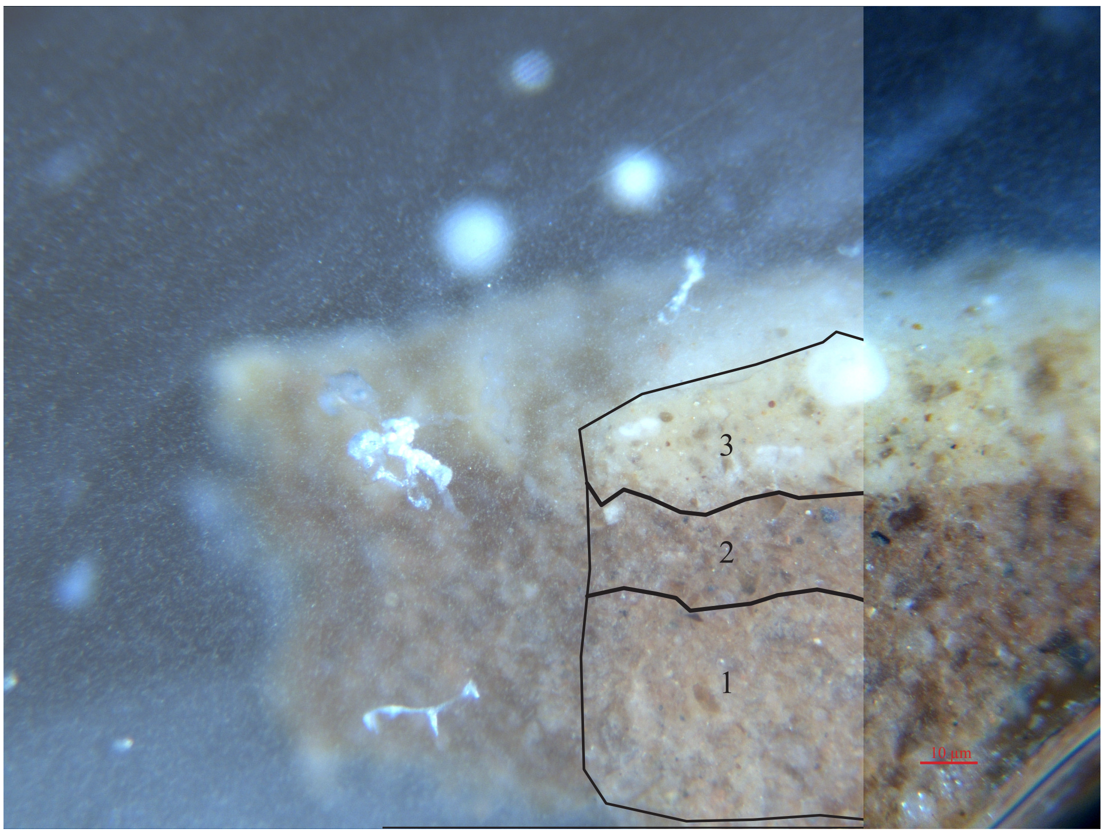
Sample Locations, 2011

DANIEL S. CASTELE

SHEET NUMBER:

5.1

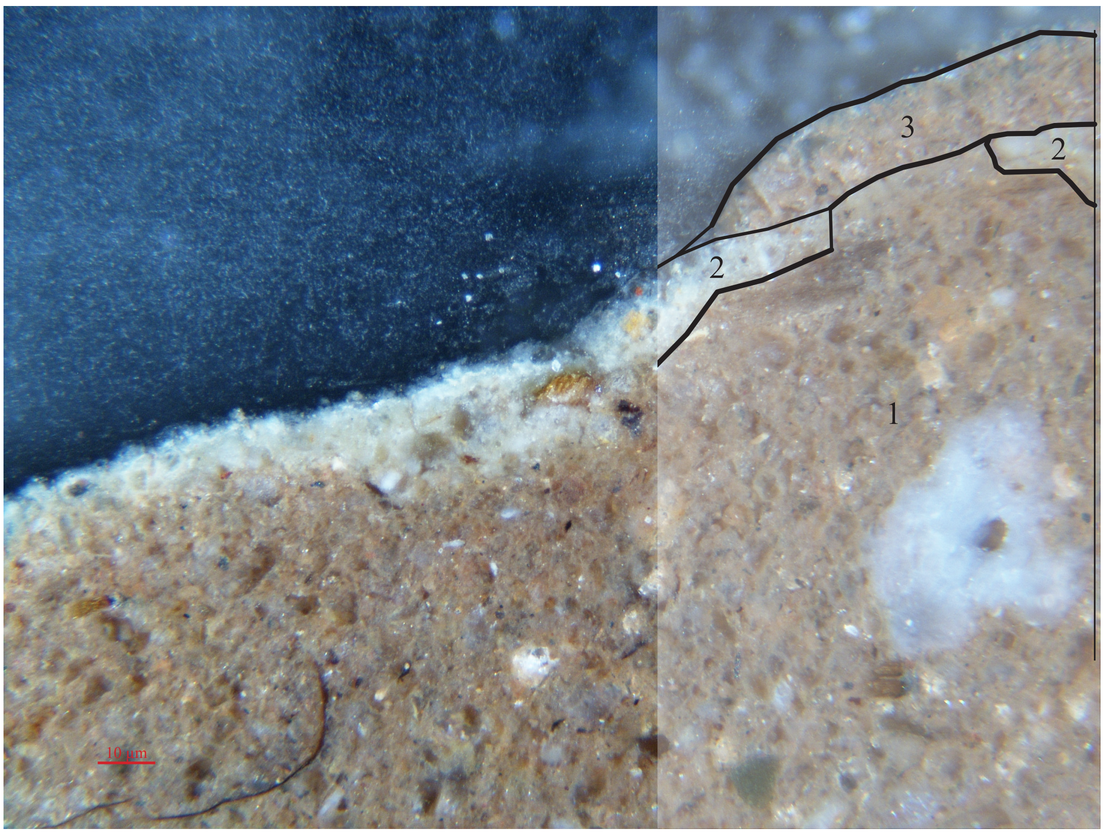
Sample No: MVFT01	
Site: Fire Temple, Mesa Verde National Park	
Location: North Wall, Kiva A	
Description: Earthen Substrate Sample	
Date Sampled/Analyzed: 29 November 2012	Illumination: Raking Light
Microscope: Olympus CX31	Magnification: 4x
Camera: Nikon Digital Sight DS’Fi1	Software: NIS Elements BR



Layer	Color	Thickness	Description/Remarks
3		-	Off-White Wash
2		-	Reddish Brown Wash
1		+	Reddish Brown Plaster

Key: + plaster, - wash, / layer of soot, ^ fracture

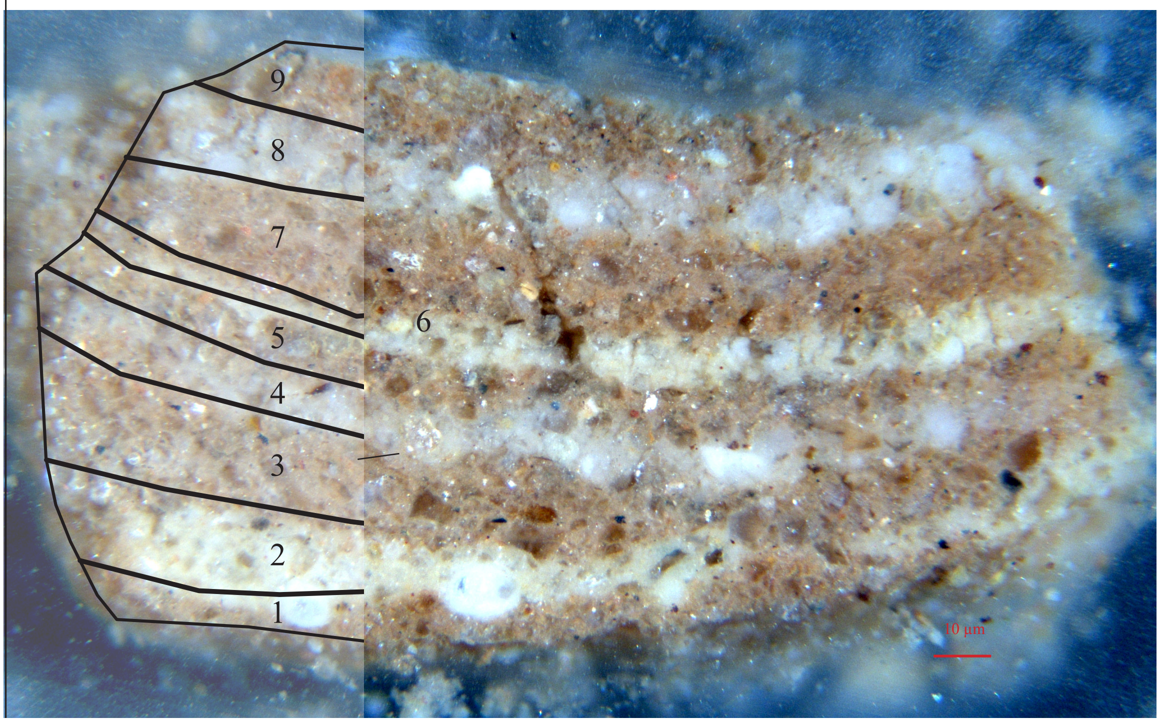
Sample No: MVFT02	
Site: Fire Temple, Mesa Verde National Park	
Location: North Wall, Kiva A	
Description: Earthen Substrate Sample	
Date Sampled/Analyzed: 29 November 2012	Illumination: Raking Light
Microscope: Olympus CX31	Magnification: 4x
Camera: Nikon Digital Sight DS'Fi1	Software: NIS Elements BR



Layer	Color	Thickness	Description/Remarks
3		-	Reddish Brown Wash
2		-	Off-White Wash
1		+	Reddish Brown Plaster

Key: + plaster, - wash, / layer of soot, ^ fracture

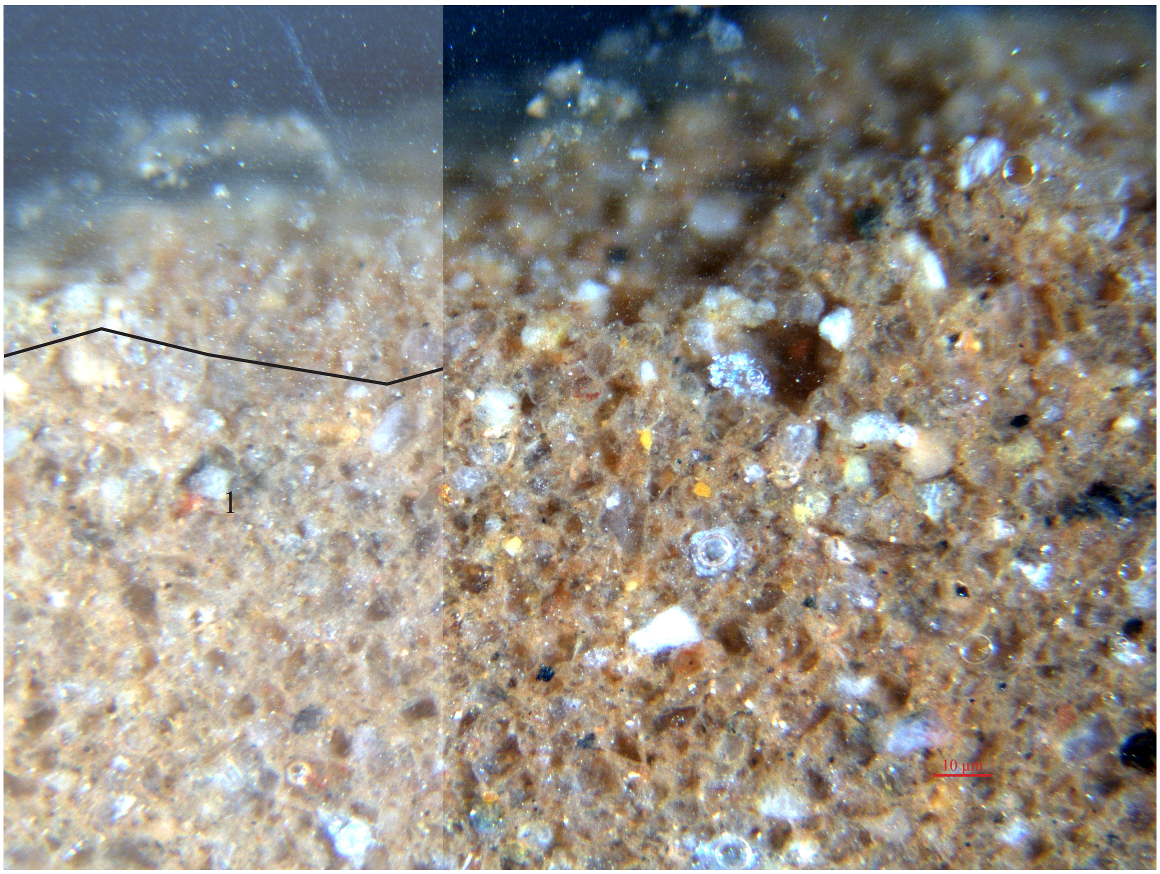
Sample No: MVFT03	
Site: Fire Temple, Mesa Verde National Park	
Location: North Wall, Kiva A	
Description: Earthen Substrate Sample	
Date Sampled/Analyzed: 29 November 2012	Illumination: Raking Light
Microscope: Olympus CX31	Magnification: 4x
Camera: Nikon Digital Sight DS'Fi1	Software: NIS Elements BR



Layer	Color	Thickness	Description/Remarks
9		-	Reddish Brown Wash
8		-	Bright White Wash
7		-	Reddish Brown Wash
6		-	Off-White Wash
5		+	Reddish Brown Wash
4		-	Bright White Wash
3		-	Reddish Brown Wash
2		-	Off-White Wash
1		+	Reddish Brown Layer

Key: + plaster, - wash, / layer of soot, ^ fracture

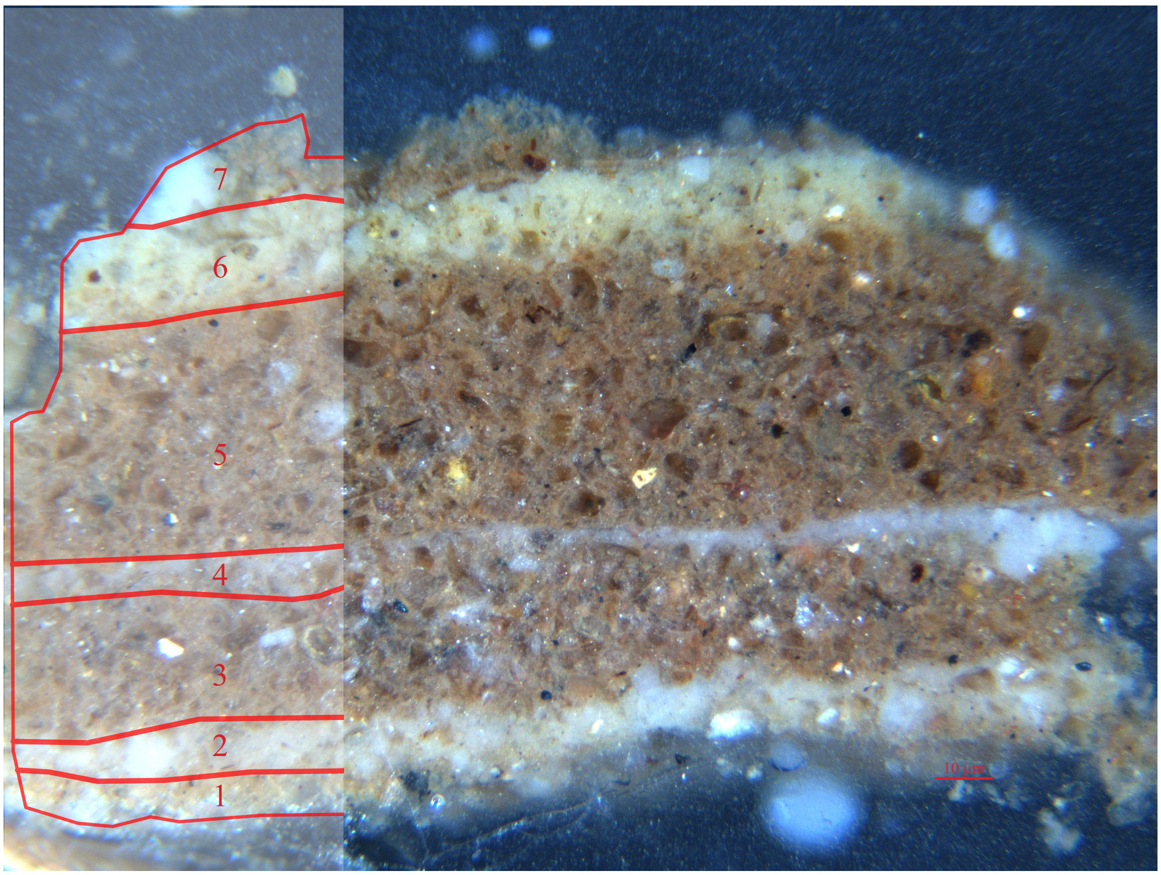
Sample No: MVFT04	
Site: Fire Temple, Mesa Verde National Park	
Location: North Wall, Kiva A	
Description: Earthen Substrate Sample	
Date Sampled/Analyzed: 29 November 2012	Illumination: Raking Light
Microscope: Olympus CX31	Magnification: 4x
Camera: Nikon Digital Sight DS'Fi1	Software: NIS Elements BR



Layer	Color	Thickness	Description/Remarks
1		+	Plaster

Key: + plaster, - wash, / layer of soot, ^ fracture

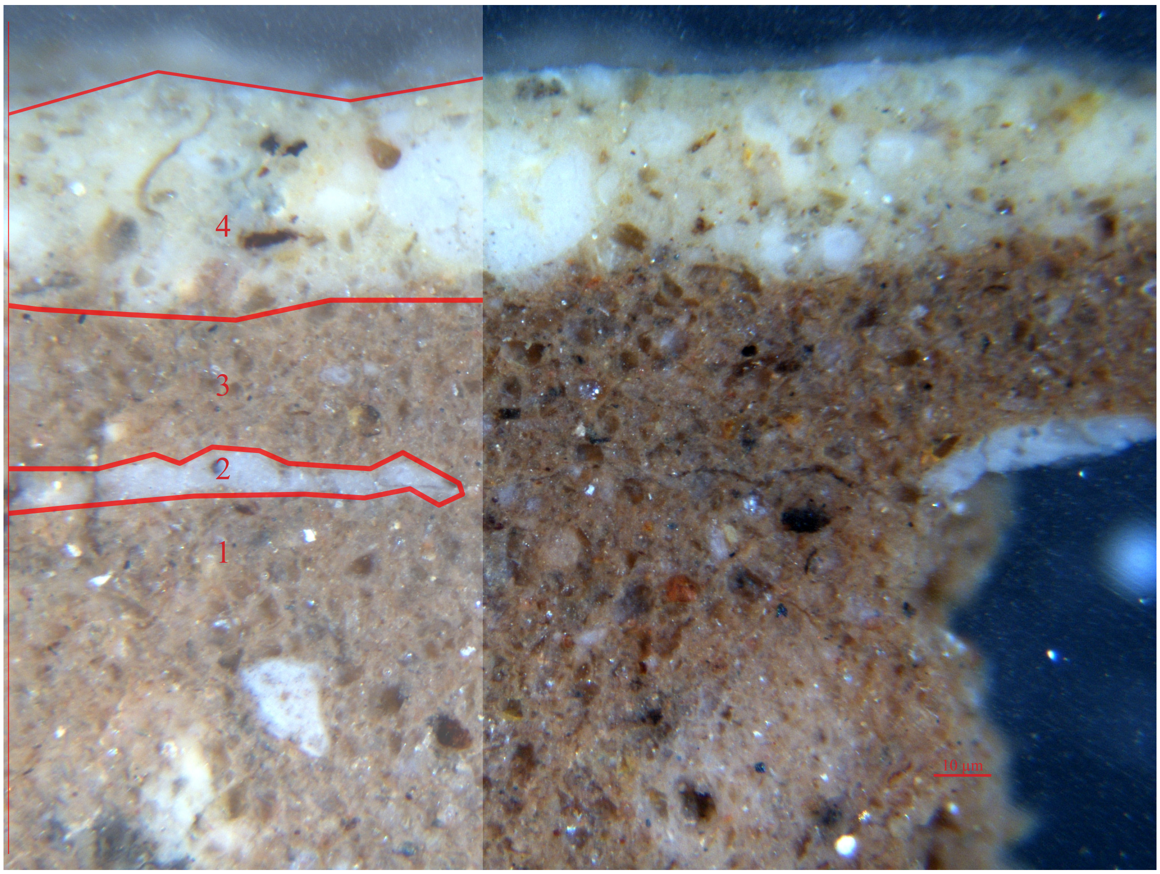
Sample No: MVFT06	
Site: Fire Temple, Mesa Verde National Park	
Location: North Wall, Kiva A	
Description: Earthen Substrate Sample	
Date Sampled/Analyzed: 29 November 2012	Illumination: Raking Light
Microscope: Olympus CX31	Magnification: 4x
Camera: Nikon Digital Sight DS'Fi1	Software: NIS Elements BR



Layer	Color	Thickness	Description/Remarks
7		-	Reddish Brown Wash
6		-	Off-White Wash
5		+	Reddish Brown Plaster
4		-	Bright White Wash
3		-	Reddish Brown Wash
2		-	Pale White Wash
1		+	Reddish Brown Wash or Plaster

Key: + plaster, - wash, / layer of soot, ^ fracture

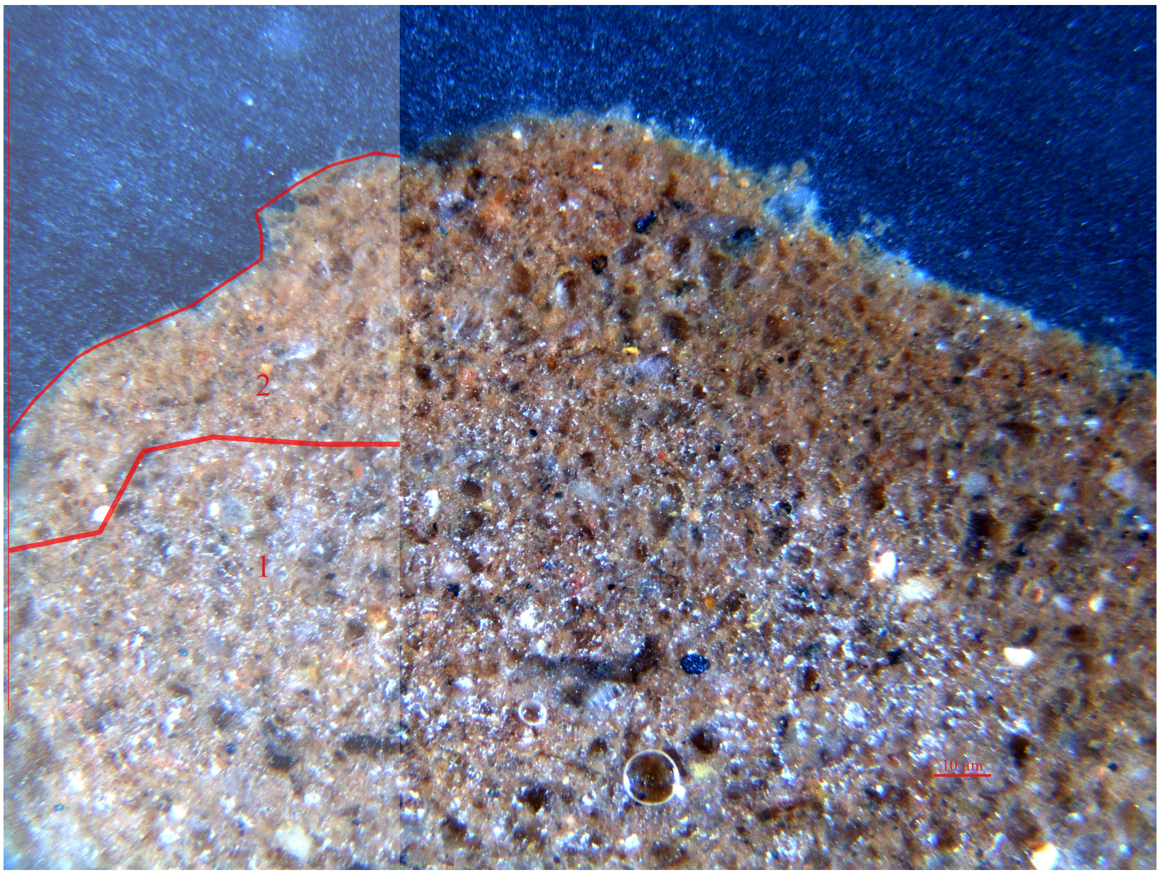
Sample No: MVFT07	
Site: Fire Temple, Mesa Verde National Park	
Location: North Wall, Kiva A	
Description: Earthen Substrate Sample	
Date Sampled/Analyzed: 29 November 2012	Illumination: Raking Light
Microscope: Olympus CX31	Magnification: 4x
Camera: Nikon Digital Sight DS’Fi1	Software: NIS Elements BR



Layer	Color	Thickness	Description/Remarks
3		-	Off-White Wash
2		-	Reddish Brown Wash
1		-	Off-White Wash
		+	Plaster

Key: + plaster, - wash, / layer of soot, ^ fracture

Sample No: MVFT08	
Site: Fire Temple, Mesa Verde National Park	
Location: North Wall, Kiva A	
Description: Earthen Substrate Sample	
Date Sampled/Analyzed: 29 November 2012	Illumination: Raking Light
Microscope: Olympus CX31	Magnification: 4x
Camera: Nikon Digital Sight DS'Fi1	Software: NIS Elements BR

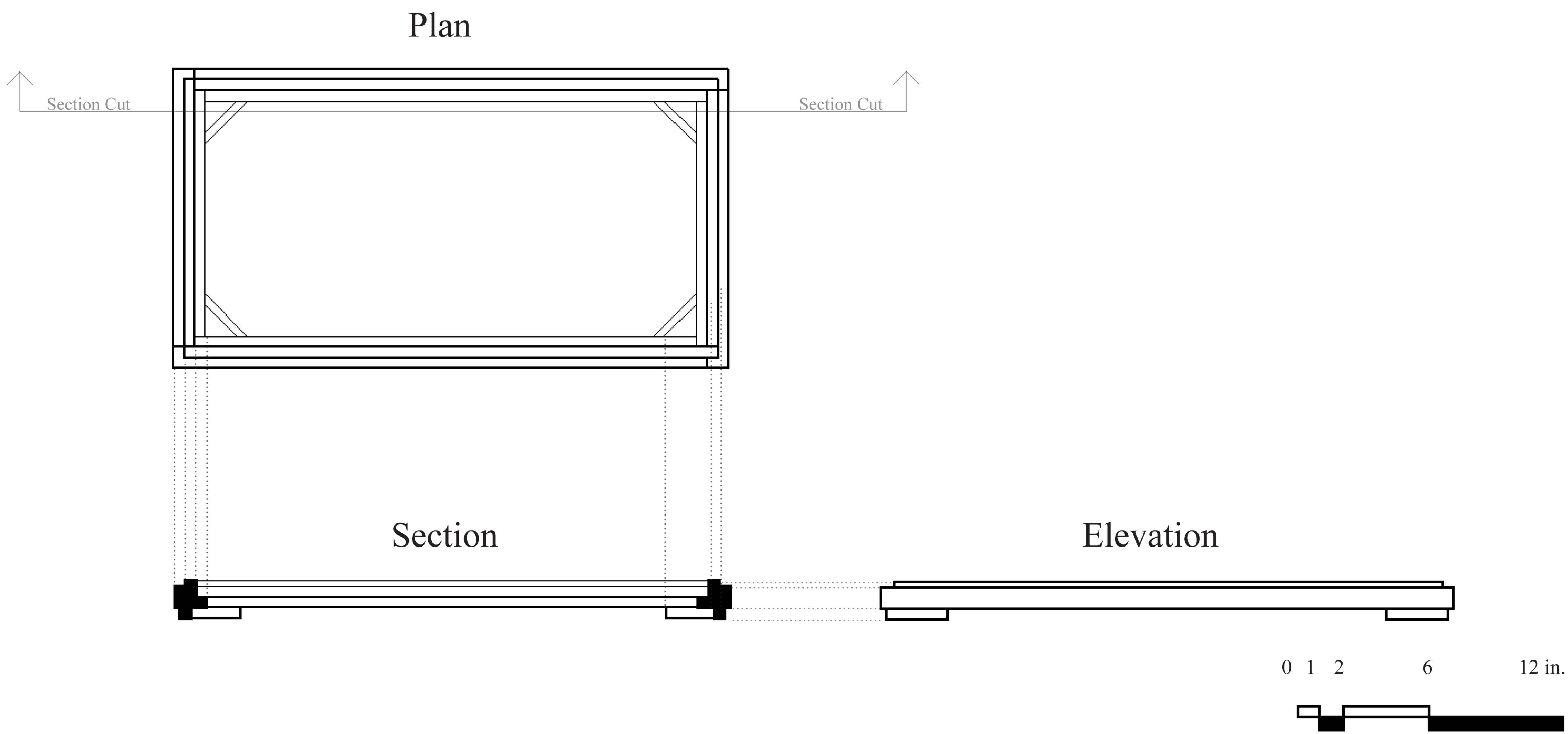


Layer	Color	Thickness	Description/Remarks
2		-	Reddish Brown Wash
1		+	Reddish Brown Plaster

Key: + plaster, - wash, / layer of soot, ^ fracture

APPENDIX D:

FACSIMILE FRAME DRAWINGS



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Fire Temple [Mesa Verde National Park]

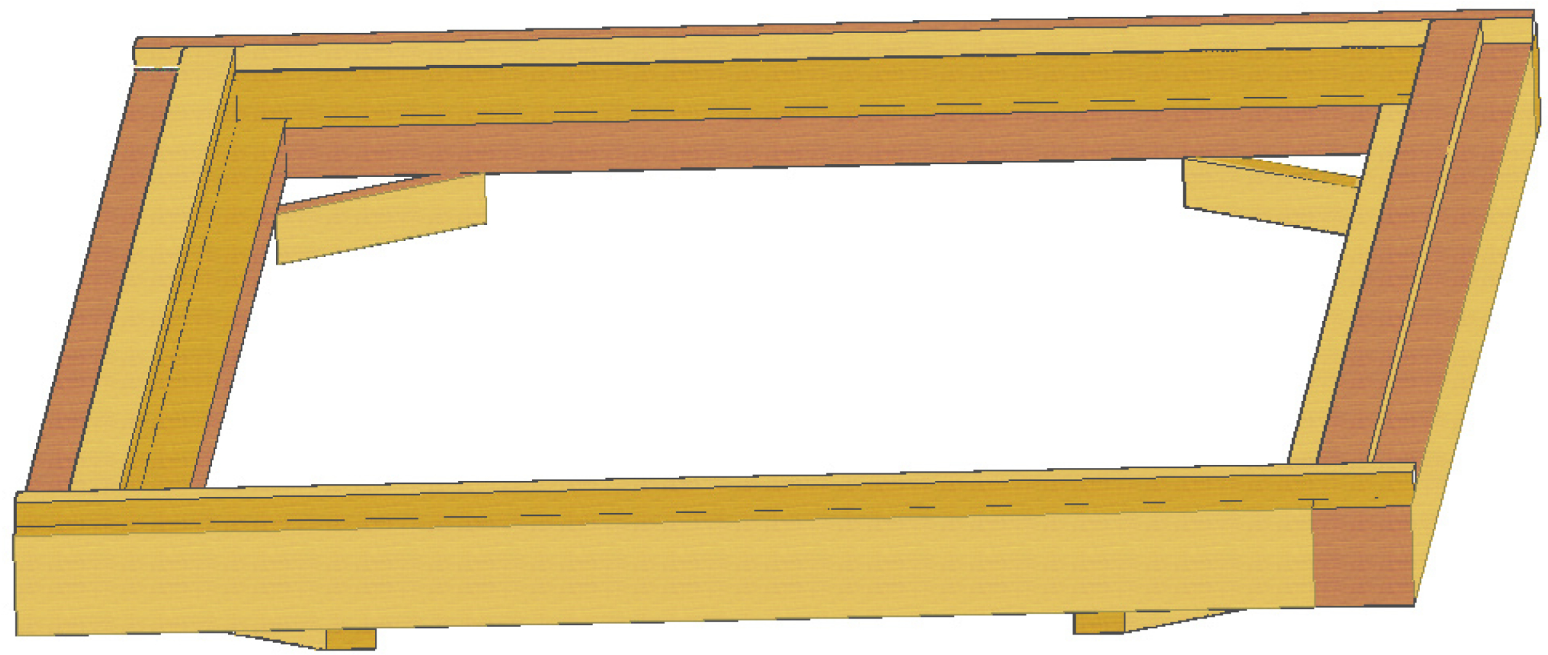
FACSIMILES

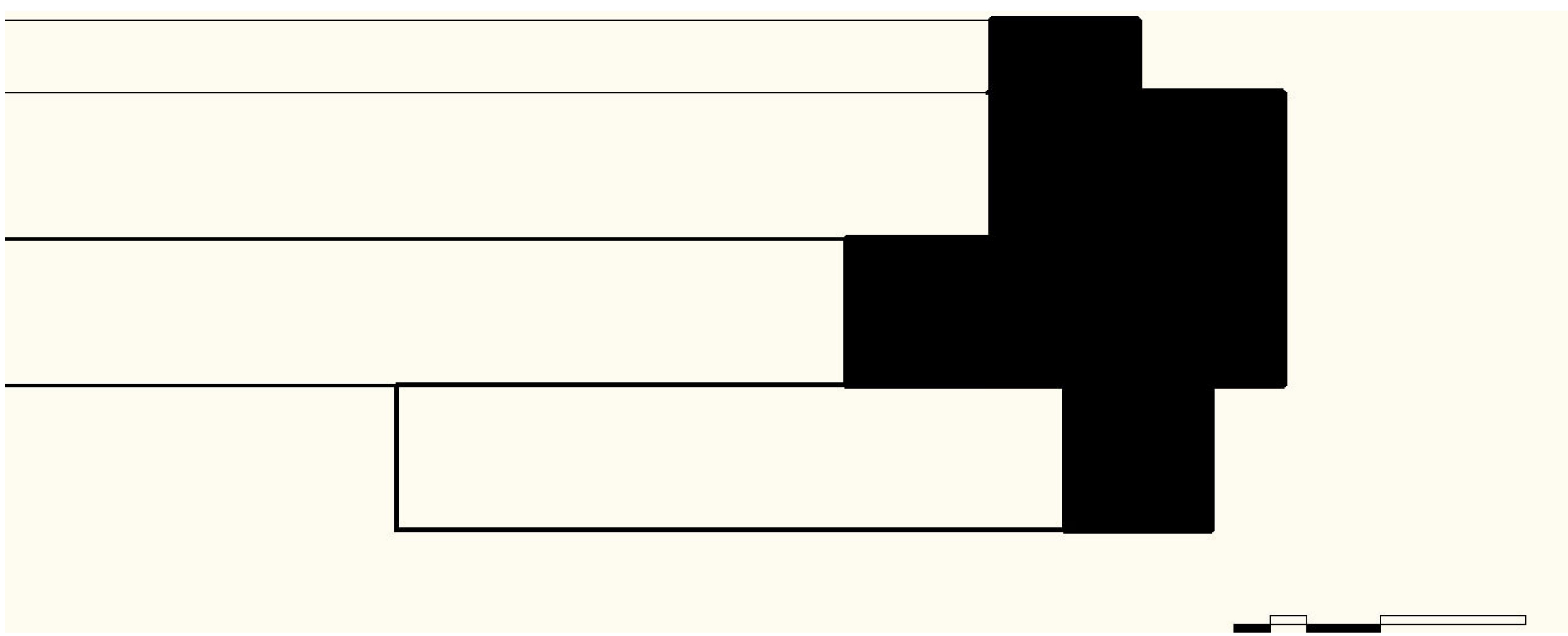
Frame Design

DANIEL S. CASTELE

SHEET NUMBER:

5.2





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Fire Temple [Mesa Verde National Park]

86
89

FACSIMILES

Frame Design

DANIEL S. CASTELE

SHEET NUMBER:

5.3

APPENDIX E:
ASTM STANDARDS

Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[1]

This standard is issued under the fixed designation D421; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice covers the dry preparation of soil samples as received from the field for particle-size analysis and the determination of the soil constants.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D2217 Practice for Wet Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

3. Significance and Use

3.1 This practice can be used to prepare samples for particle-size and plasticity tests where it is desired to determine test values on air-dried samples, or where it is known that air drying does not have an effect on test results relative to samples prepared in accordance with Practice D2217.

4. Apparatus

4.1 *Balance*, sensitive to 0.1 g.

4.2 *Mortar and Rubber-Covered Pestle*, suitable for breaking up the aggregations of soil particles.

4.3 *Sieves*—A series of sieves, of square mesh woven wire cloth, conforming to Specification E11. The sieves required are as follows:

No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 40 (425-μm)

4.4 *Sampler*—A riffle sampler or sample splitter, for quartering the samples.

5. Sampling

5.1 Expose the soil sample as received from the field to the air at room temperature until dried thoroughly. Break up the aggregations thoroughly in the mortar with a rubber-covered pestle. Select a representative sample of the amount required to perform the desired tests by the method of quartering or by the use of a sampler. The amounts of material required to perform the individual tests are as follows:

5.1.1 *Particle-Size Analysis*—For the particle-size analysis, material passing a No. 10 (2.00-mm) sieve is required in amounts equal to 115 g of sandy soils and 65 g of either silt or clay soils.

5.1.2 *Tests for Soil Constants*—For the tests for soil constants, material passing the No. 40 (425-μm) sieve is required in total amount of 220 g, allocated as follows:

Test	Grams
Liquid limit	100
Plastic limit	15
Centrifuge moisture equivalent	10
Volumetric shrinkage	30
Check tests	65

6. Preparation of Test Sample

6.1 Select that portion of the air-dried sample selected for purpose of tests and record the mass as the mass of the total test sample uncorrected for hygroscopic moisture. Separate the test sample by sieving with a No. 10 (2.00-mm) sieve. Grind that fraction retained on the No. 10 sieve in a mortar with a rubber-covered pestle until the aggregations of soil particles are broken up into the separate grains. Then separate the ground soil into two fractions by sieving with a No. 10 sieve.

[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved Sept. 1, 2007. Published September 2007. Originally approved in 1935. Last previous edition approved in 2002 as D421 – 85 (2002). DOI: 10.1520/D0421-85R07.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

6.2 Wash that fraction retained after the second sieving free of all fine material, dry, and weigh. Record this mass as the mass of coarse material. Sieve the coarse material, after being washed and dried, on the No. 4 (4.75-mm) sieve and record the mass retained on the No. 4 sieve.

7. Test Sample for Particle-Size Analysis

7.1 Thoroughly mix together the fractions passing the No. 10 (2.00-mm) sieve in both sieving operations, and by the method of quartering or the use of a sampler, select a portion weighing approximately 115 g for sandy soils and approximately 65 g for silt and clay soil for particle-size analysis.

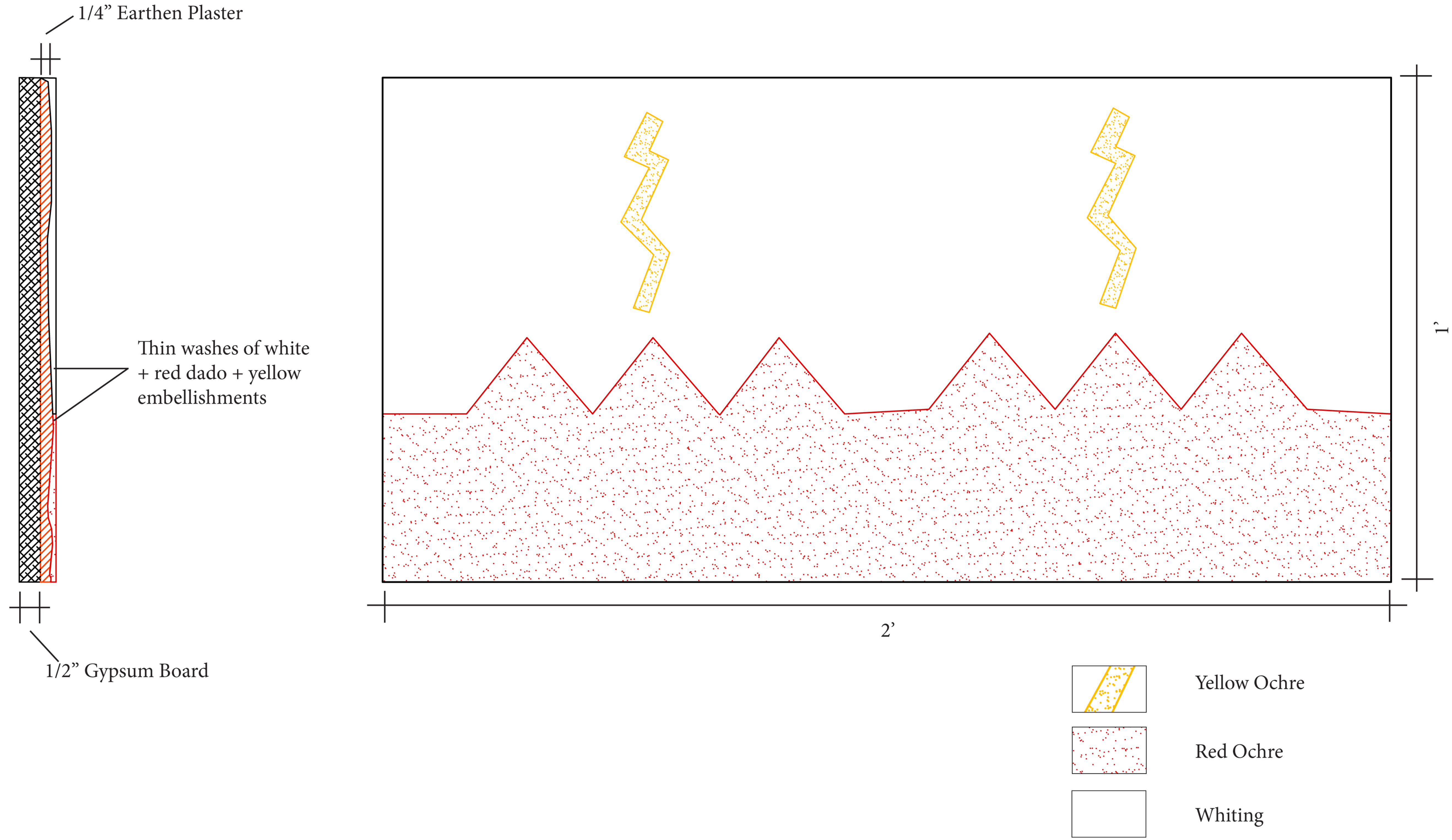
8. Test Sample for Soil Constants

8.1 Separate the remaining portion of the material passing the No. 10 (2.00-mm) sieve into two parts by means of a No. 40 (425-μm) sieve. Discard the fraction retained on the No. 40 sieve. Use the fraction passing the No. 40 sieve for the determination of the soil constants.

9. Keywords

9.1 dry preparation; particle-size analysis; soil

APPENDIX F:
FACSIMILE SCHEMES



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Fire Temple [Mesa Verde National Park]

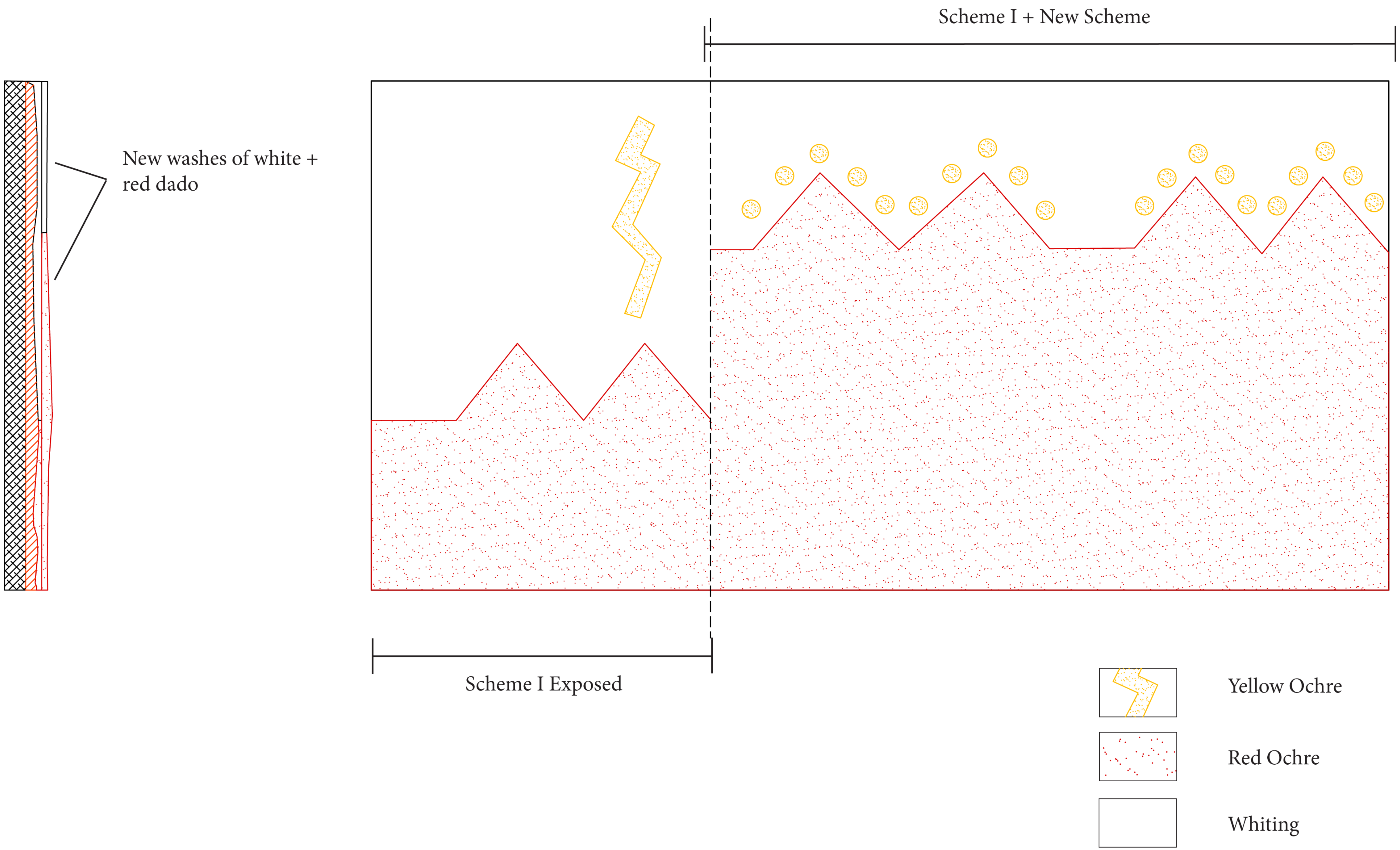
FACSIMILES

SCHEME I

DANIEL S. CASTELE

SHEET NUMBER:

5.4



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Fire Temple [Mesa Verde National Park]

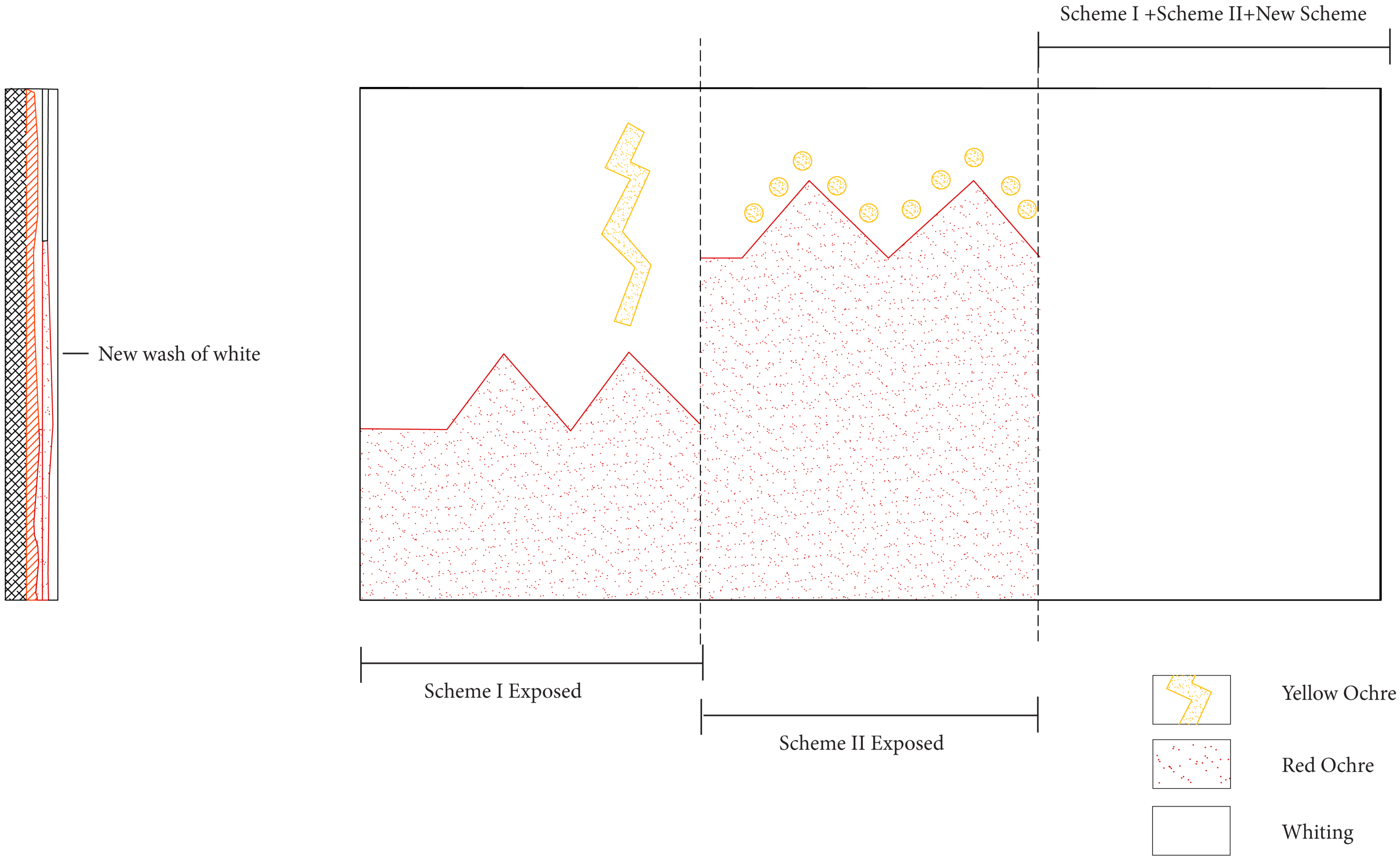
FACSIMILES

SCEME II

DANIEL S. CASTELE

SHEET NUMBER:

5.5



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Fire Temple [Mesa Verde National Park]

FACSIMILES

SCEME III

DANIEL S. CASTELE

SHEET NUMBER:

5.6

APPENDIX G:
DIGITIZATION DRAWINGS

20

Feet

Statistics

Area = 26,560 in^2

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Fire Temple [Mesa Verde National Park]

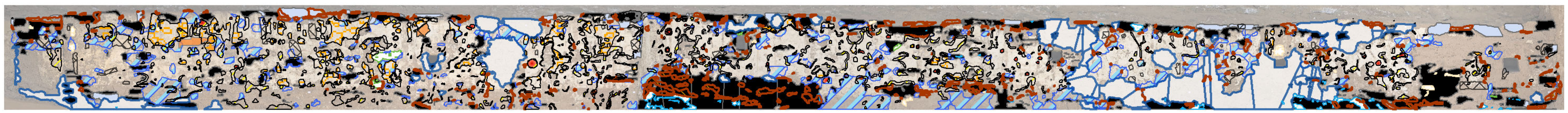
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

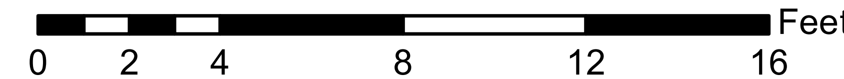
SHEET NUMBER:

5.7



Legend

Soil Deposits	Delamination	Graffiti
Disaggregation	Stone-Mortar Decay	Detachment
	Salt Surface Deposits	Carbon Surface Deposits
	Repair	Blistering
	Mechanical Damage	Biological Growth
	Map Cracking	Animal Surface Deposits
	Loose Mortar	Total Loss



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Fire Temple [Mesa Verde National Park]

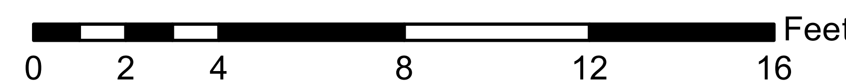
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.8



Legend

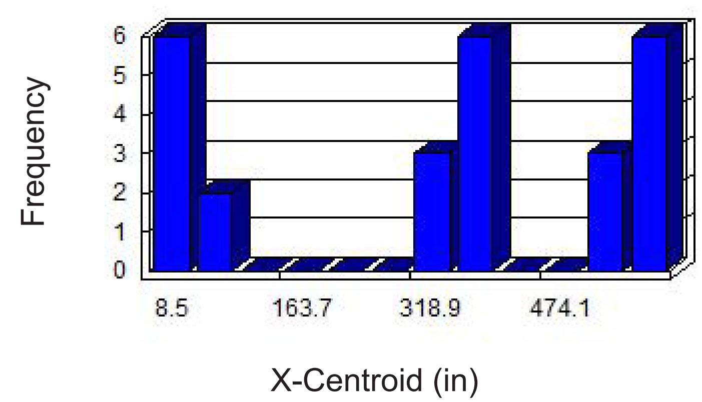
Disaggregation

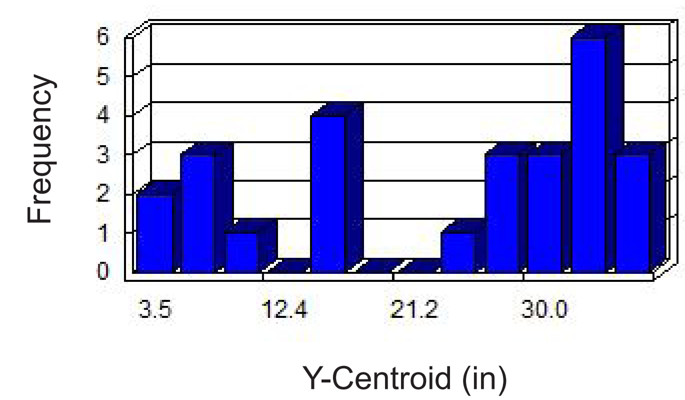
Statistics

Area:
Disaggregation- 58.078263 in^2

Percent of Surface Exhibiting Condition:
Disaggregation-.218%

Number of Occurrences:
Disaggregation-26





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Fire Temple [Mesa Verde National Park]

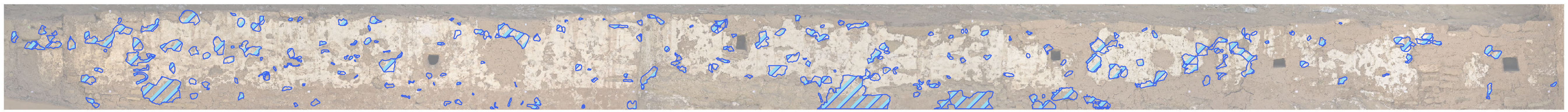
NORTH WALL

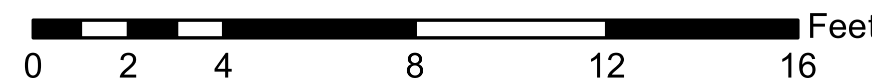
ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.9





Legend

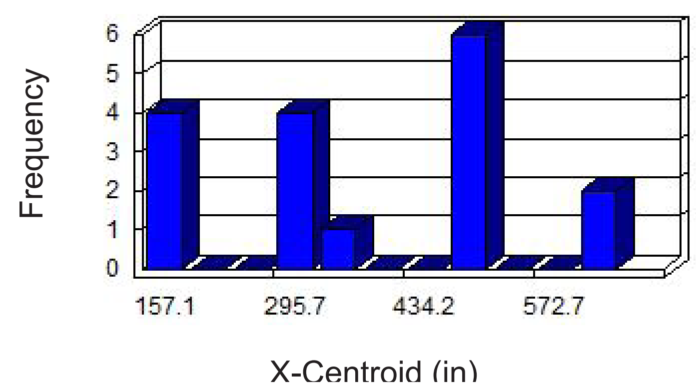
Detachment

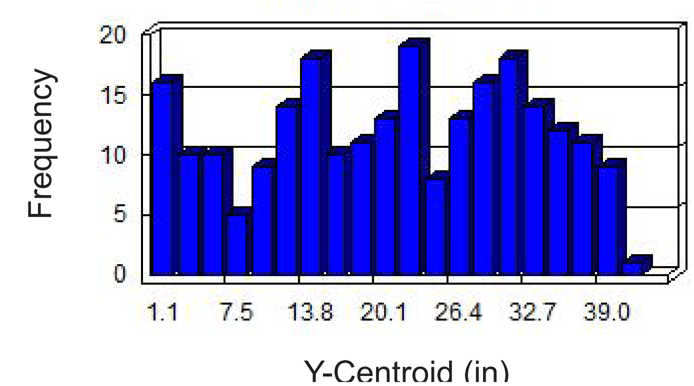
Statistics

Area:
Detachment-2328.438133 in^2

Percent of Surface Exhibiting Condition:
Detachment-8.766%

Number of Occurrences:
Detachment-239





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Fire Temple [Mesa Verde National Park]

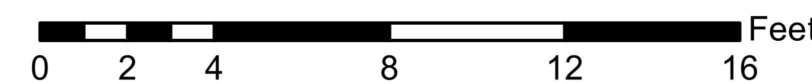
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.10



Legend

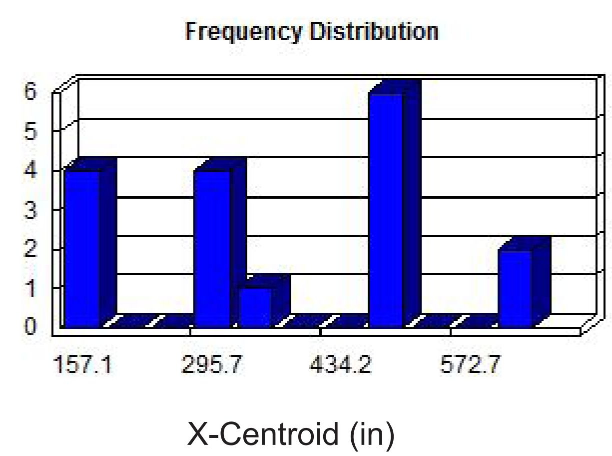
Biological Growth

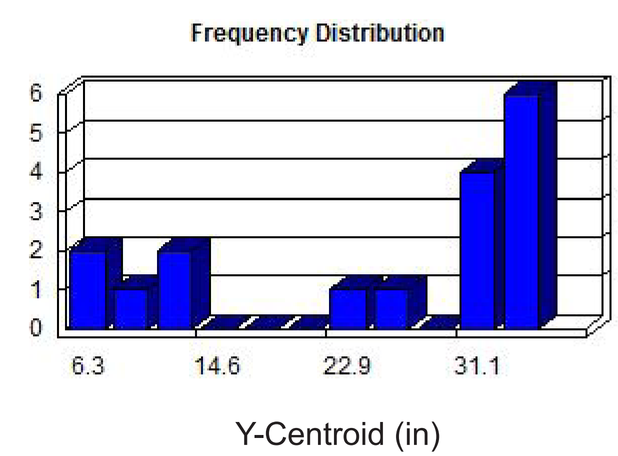
Statistics

Area:
Biological Growth-59.659578 in^2

Percent of Surface Exhibiting Condition:
Biological Growth-.224%

Number of Occurrences:
Biological Growth-17





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Fire Temple [Mesa Verde National Park]

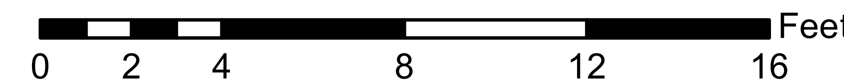
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.11



Legend

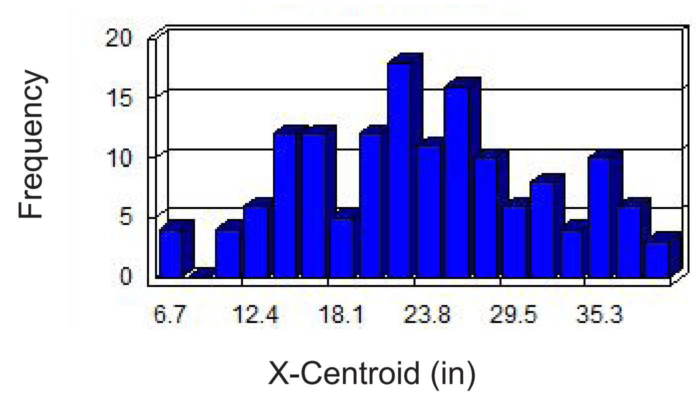
Blistering

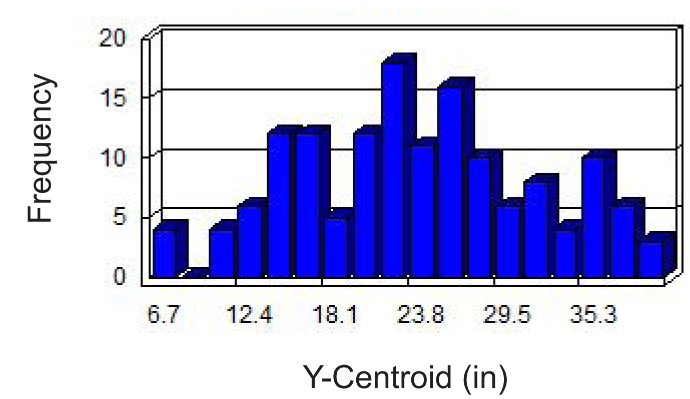
Statistics

Area:
Blistering-183 in^2

Percent of Surface Exhibiting Condition:
Blistering-.689%

Number of Occurrences:
Total Loss-147





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Fire Temple [Mesa Verde National Park]

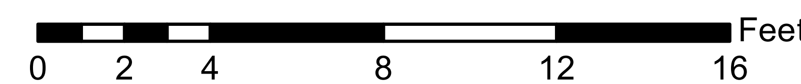
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.12



Legend

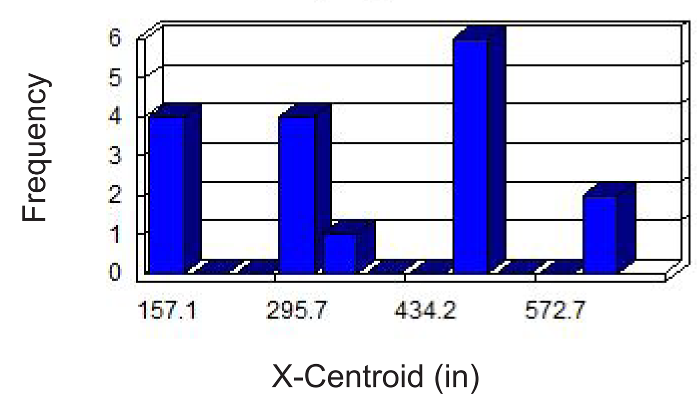
Carbon Surface Deposits

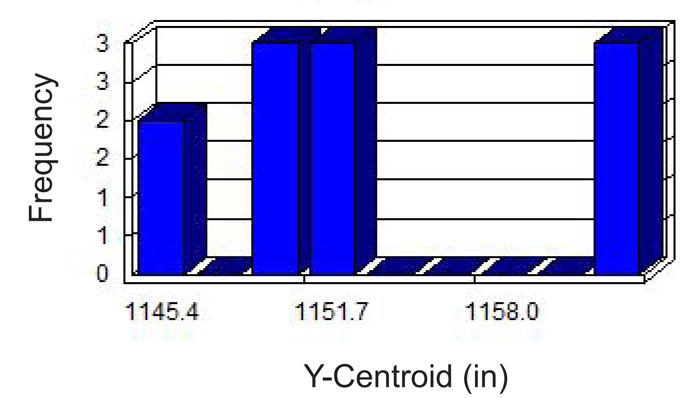
Statistics

Area:
Carbon Surface Deposits-58.09273 in²

Percent of Surface Exhibiting Condition:
Carbon Surface Deposits-.281%

Number of Occurrences:
Carbon Surface Deposits-11





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Fire Temple [Mesa Verde National Park]

NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.13

Feet
0 2 4 8 12 16

Legend

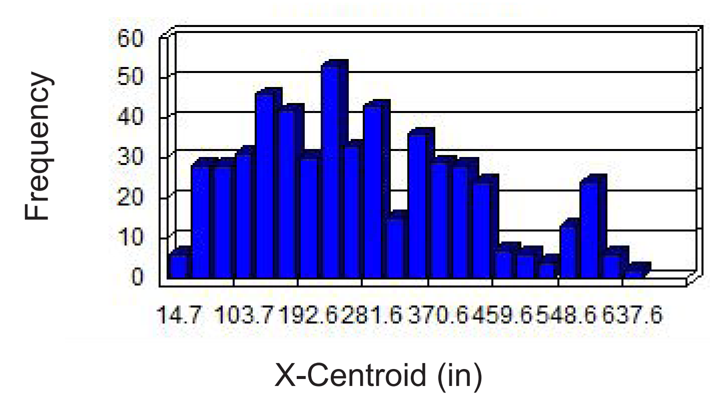
Delamination

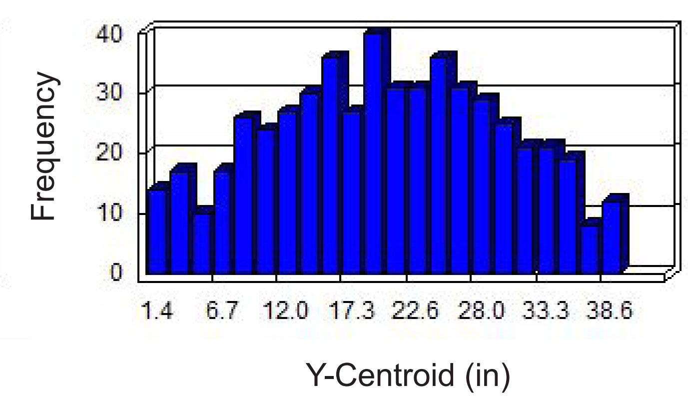
Statistics

Area:
Delamination-1453.679372 in^2

Percent of Surface Exhibiting Condition:
Delamination-5.470%

Number of Occurrences:
Delamination-535





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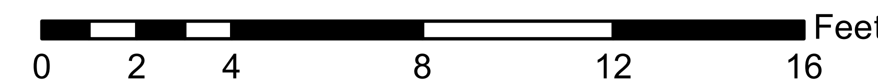
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.14



Legend

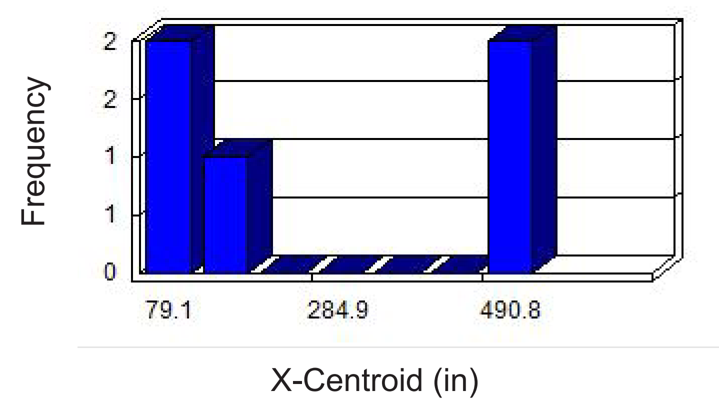
Graffiti

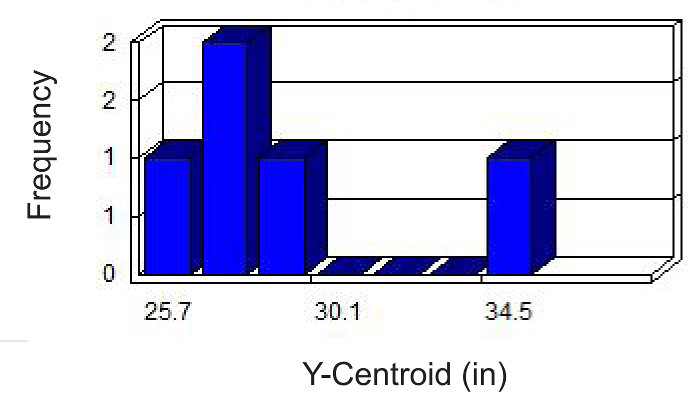
Statistics

Area:
Graffiti-70.611816 in²

Percent of Surface Exhibiting Condition:
Graffiti-.265%

Number of Occurrences:
Graffiti-5





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Fire Temple [Mesa Verde National Park]

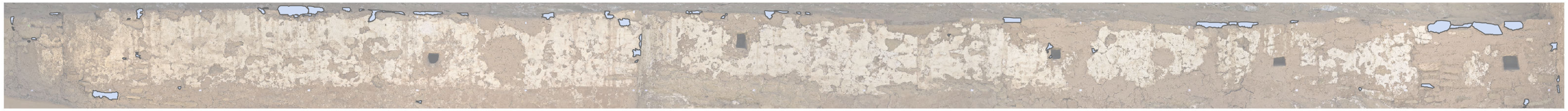
NORTH WALL

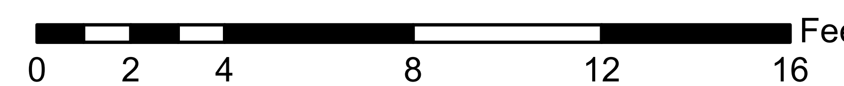
ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.15





Legend

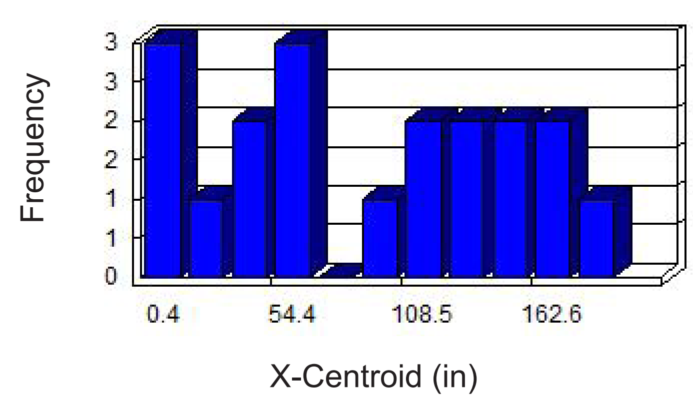
Loose Mortar

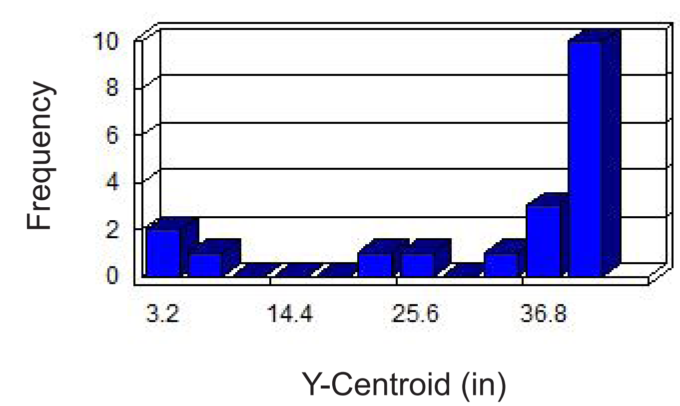
Statistics

Area:
Loose Mortar-474.466838 in^2

Percent of Surface Exhibiting Condition:
Loose Mortart-1.786%

Number of Occurrences:
Loose Mortar-61





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Fire Temple [Mesa Verde National Park]

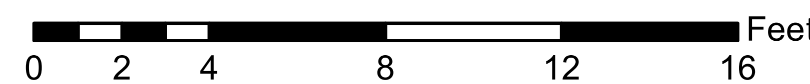
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.16



Legend

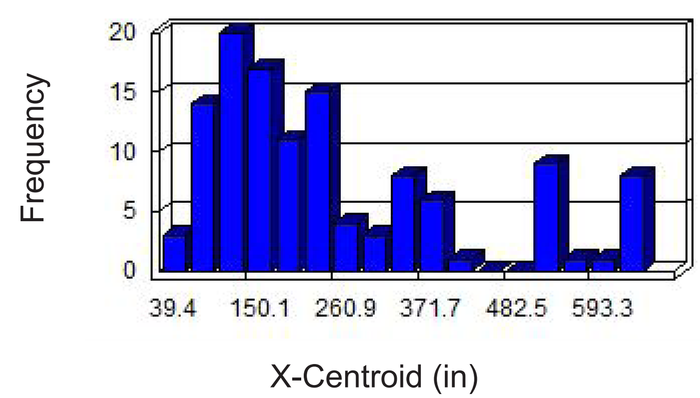
Map Cracking

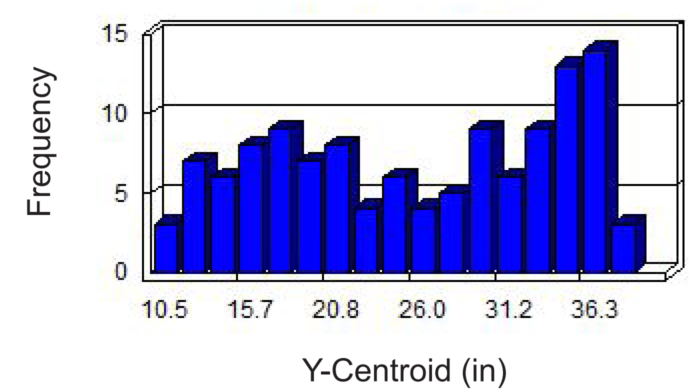
Statistics

Area:
Map Cracking 1227.710131 in^2

Percent of Surface Exhibiting Condition:
Map Cracking-4.622%

Number of Occurrences:
Map Cracking-123





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Fire Temple [Mesa Verde National Park]

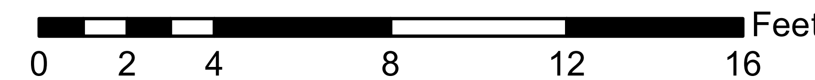
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.17



Legend

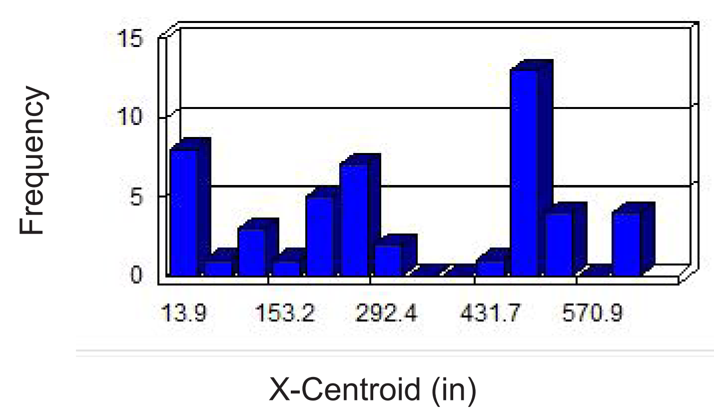
Mechanical Damage

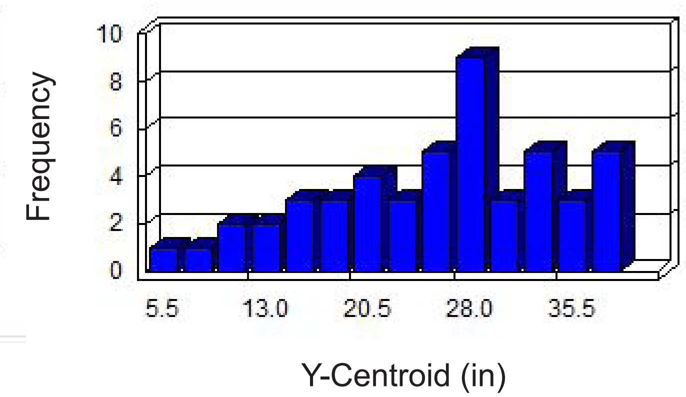
Statistics

Area:
Mechanical Damage-394.11872 in^2

Percent of Surface Exhibiting Condition:
Mechanical Damage-1.483%

Number of Occurrences:
Mechanical Damage-49





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Fire Temple [Mesa Verde National Park]

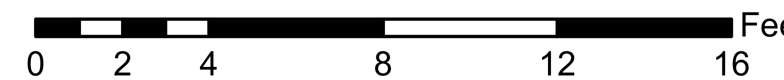
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.18



Legend

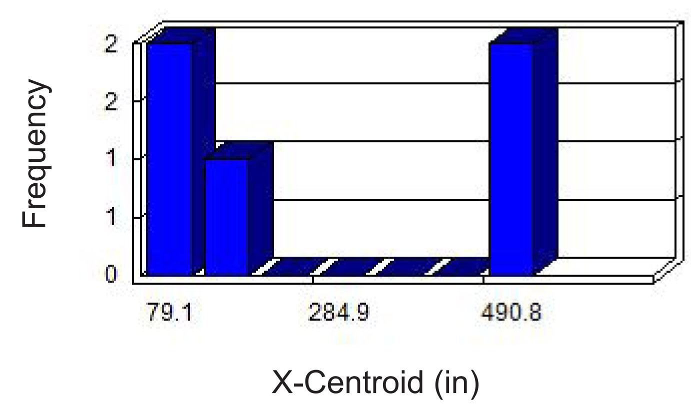
Repair

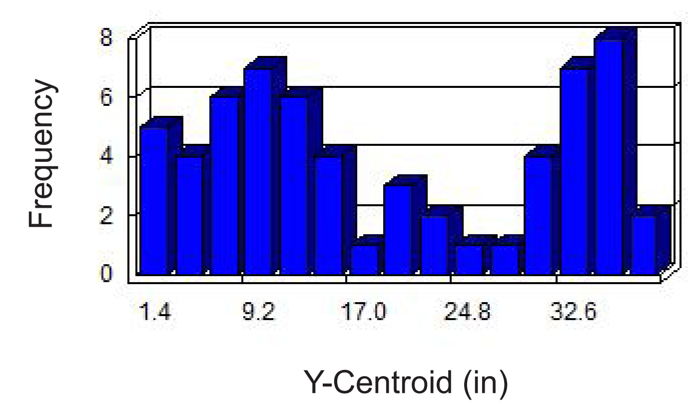
Statistics

Area:
Repair-3,018.006335 in^2

Percent of Surface Exhibiting Condition:
Repair-11.362%

Number of Occurrences:
Repair-61





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Fire Temple [Mesa Verde National Park]

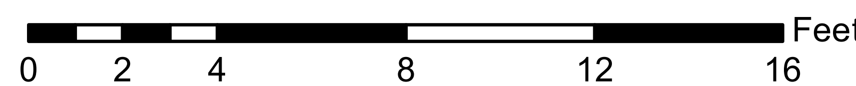
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.19



Legend

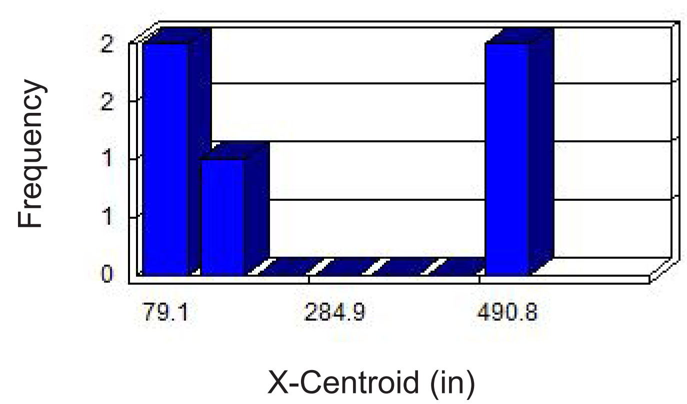
Salt Surface Deposits

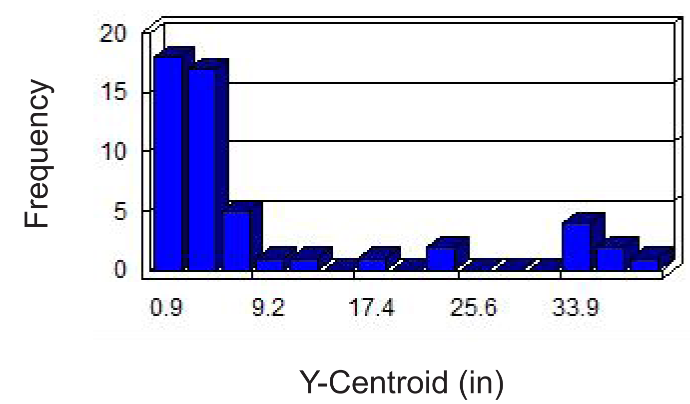
Statistics

Area:
Salt Surface Deposits-131.996913 in^2

Percent of Surface Exhibiting Condition:
Salt Surface Deposits-4.969%

Number of Occurrences:
Salt Surface Deposits-52





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Fire Temple [Mesa Verde National Park]

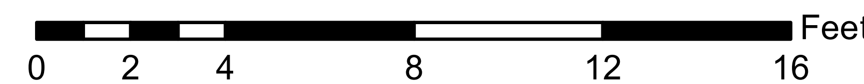
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.20



Legend

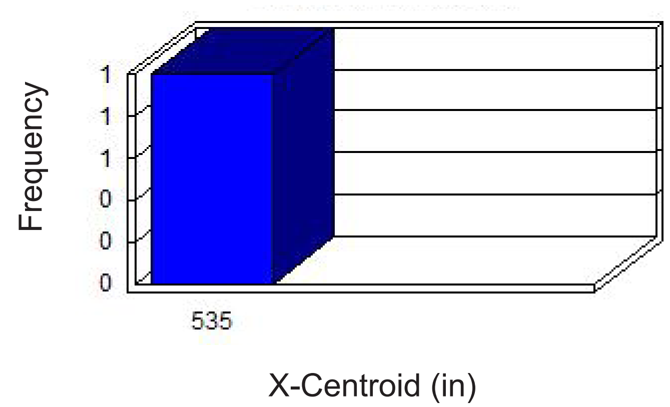
Soil Deposits

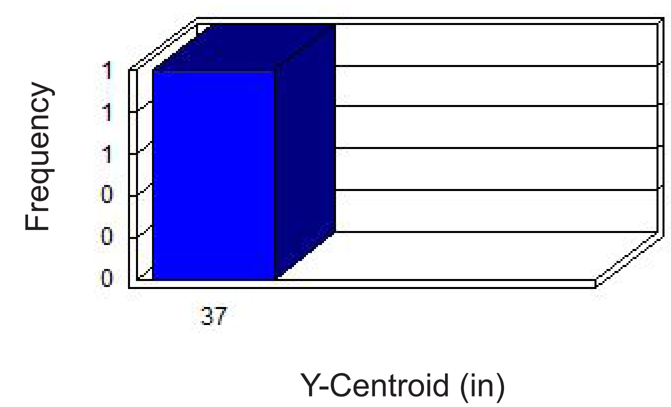
Statistics

Area:
Soil Deposits-.064188 in^2

Percent of Surface Exhibiting Condition:
Delamination-0%

Number of Applications:
Soil Deposits-1





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Fire Temple [Mesa Verde National Park]

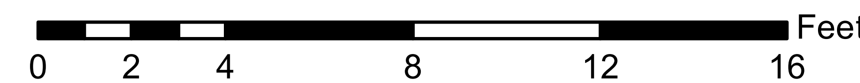
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.21



Legend

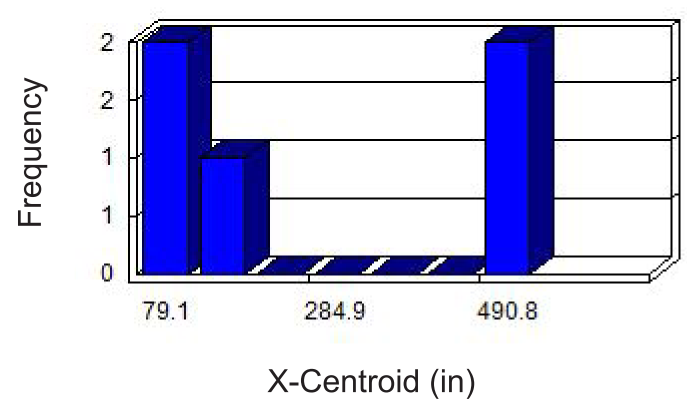
Stone-Mortar Decay

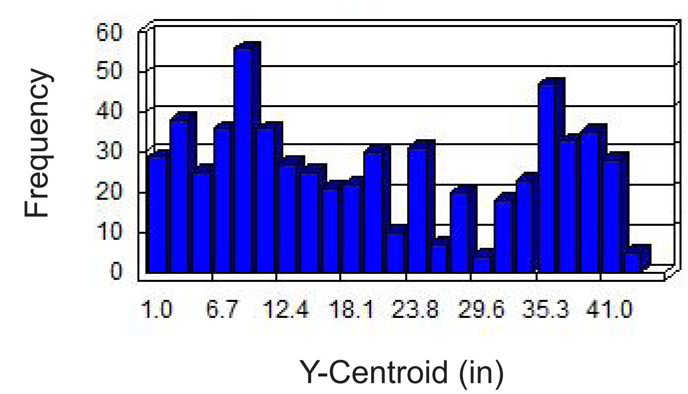
Statistics

Area:
Stone or Mortar Decay-1168.597735 in^2

Percent of Surface Exhibiting Condition:
Stone or Mortar Decay-4.399%

Number of Occurrences:
Stone or Mortar Decay- 607





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Fire Temple [Mesa Verde National Park]

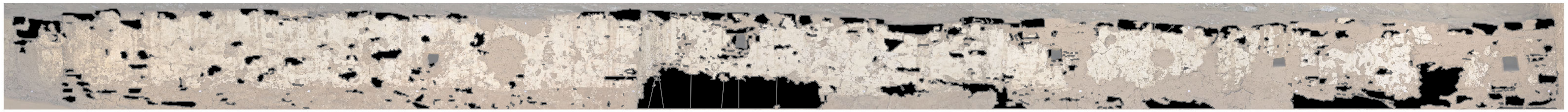
NORTH WALL

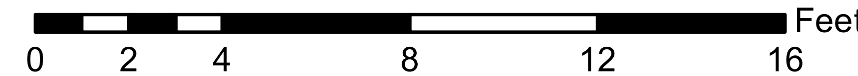
ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.22





Legend

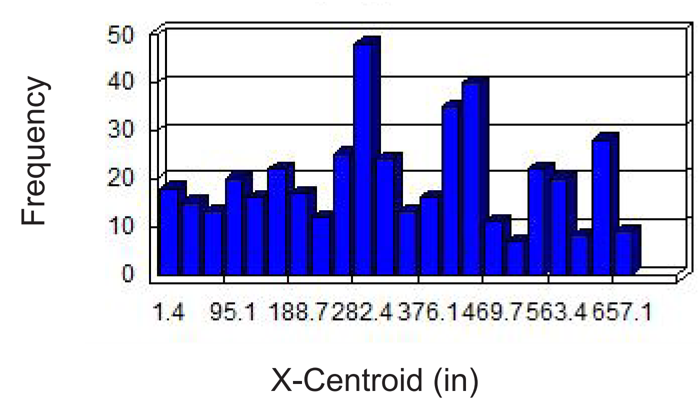
■ Total Loss

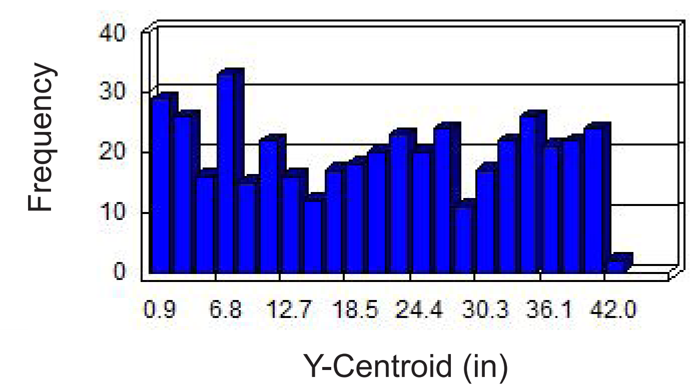
Statistics

Area:
Total Loss-3827.19278 in^2

Percent of Surface Exhibiting Condition:
Total Loss-14.409%

Number of Occurrences:
Total Loss-439





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Fire Temple [Mesa Verde National Park]

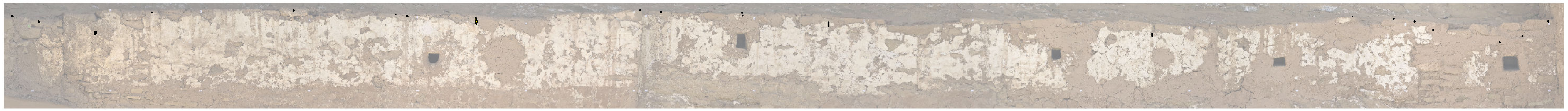
NORTH WALL

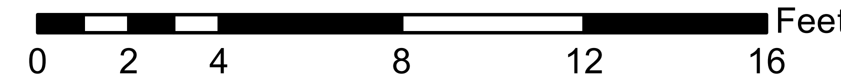
ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.23





Legend

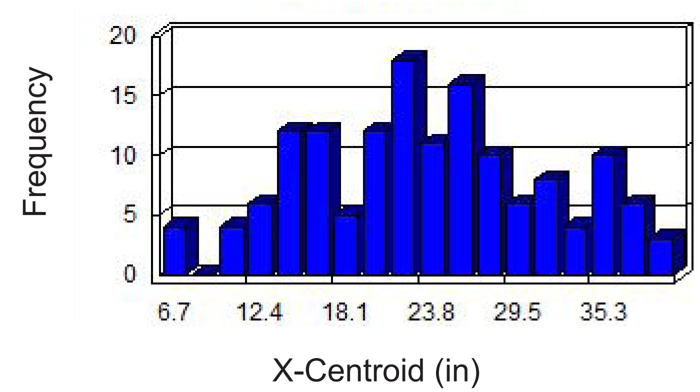
Animal Surface Deposits

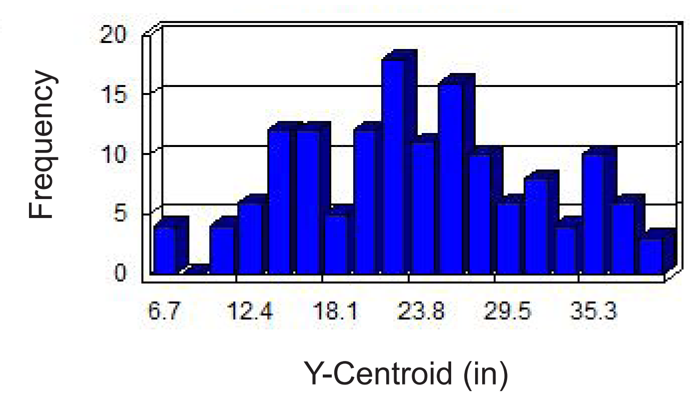
Statistics

Area:
Blistering-183 in^2

Percent of Surface Exhibiting Condition:
Blistering-.689%

Number of Occurrences:
Total Loss-147





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Fire Temple [Mesa Verde National Park]

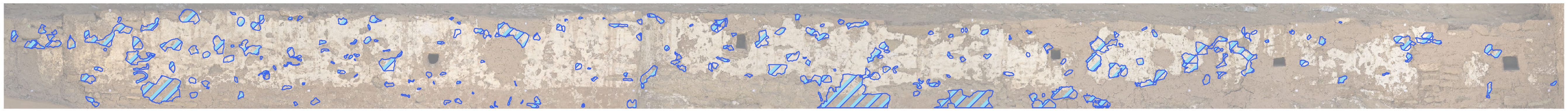
NORTH WALL

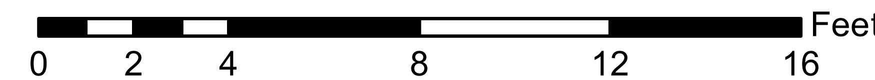
ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.24





Legend

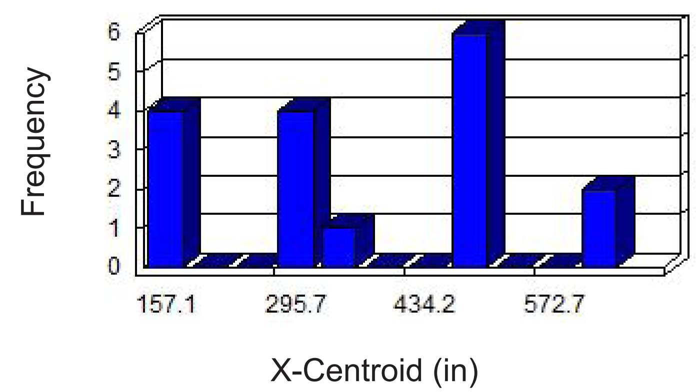
Detachment

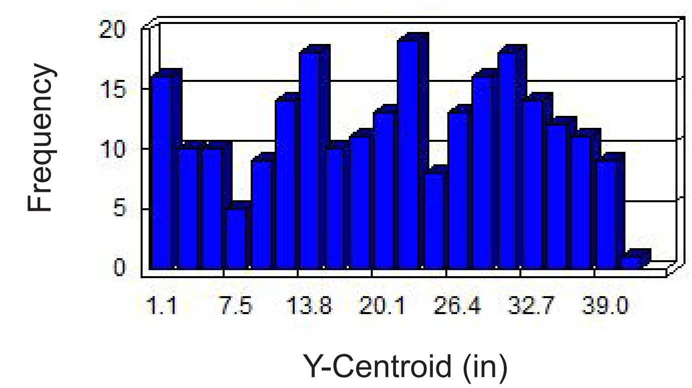
Statistics

Area:
Detachment-2328.438133 in^2

Percent of Surface Exhibiting Condition:
Detachment-8.766%

Number of Occurrences:
Detachment-239





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Fire Temple [Mesa Verde National Park]

NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.25

Legend

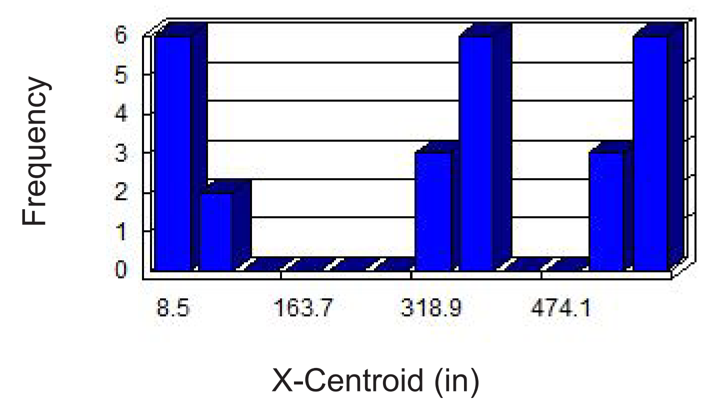
Disaggregation

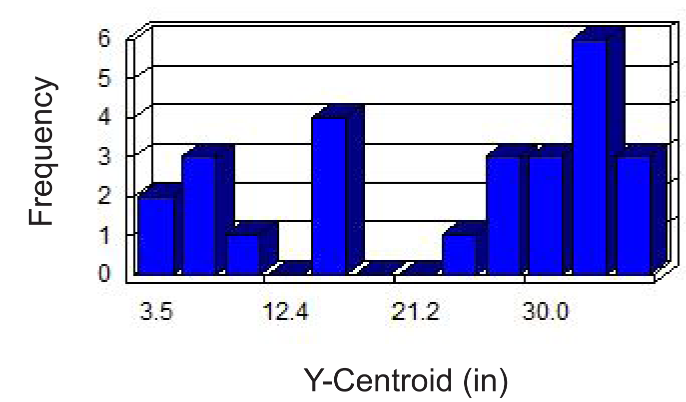
Statistics

Area:
Disaggregation- 58.078263 in^2

Percent of Surface Exhibiting Condition:
Disaggregation-.218%

Number of Occurrences:
Disaggregation-26





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Fire Temple [Mesa Verde National Park]

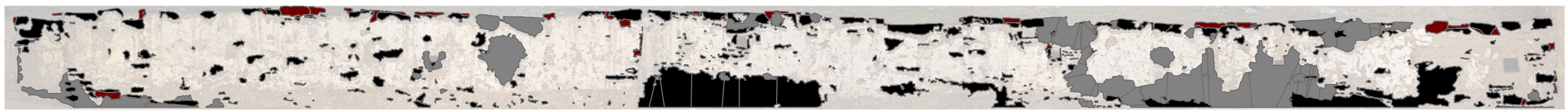
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.26



Legend

Total Loss | Repair | Loose Mortar

20 Feet

Statistics

Area:
Repair-3018.0063335 sq inches
Total Loss-3809 sq inches
Loose Mortar-474.466838 sq inches

Total Mural Lost =
7301.473173 sq inches
27.5%

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Fire Temple [Mesa Verde National Park]

NORTH WALL

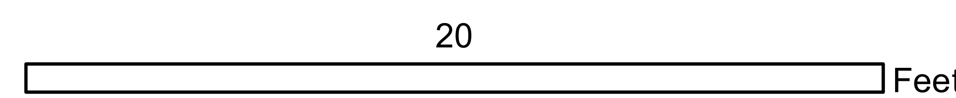
ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER: 5.27

Statistics

Total Remaning Area of Original Mural =
19,258.52687 in^2
72.5%



Fire Temple [Mesa Verde National Park]

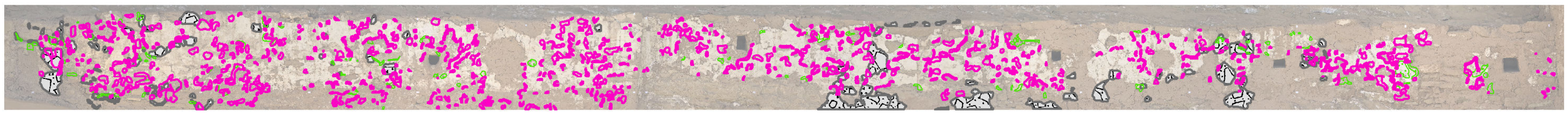
NORTH WALL

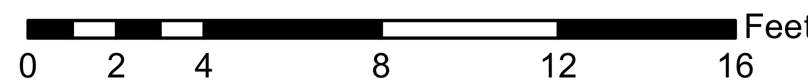
ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.28





Legend

5% Gelatin Treatment

10% Gelatin Treatment

Grout Treatment

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Fire Temple [Mesa Verde National Park]

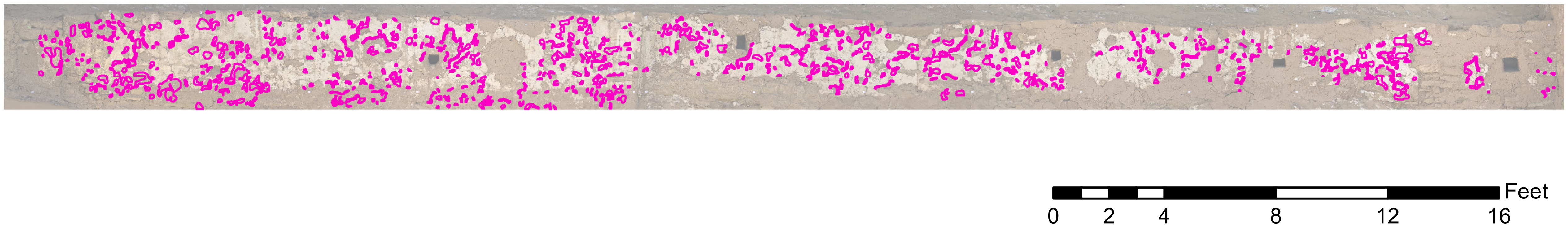
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.29



Legend

5% Gelatin Treatment

Statistics

Area:
5% Gelatin Treatment- 1694.676699 in^2

Number of Applications:
5% Gelatin Treatment-749

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Fire Temple [Mesa Verde National Park]

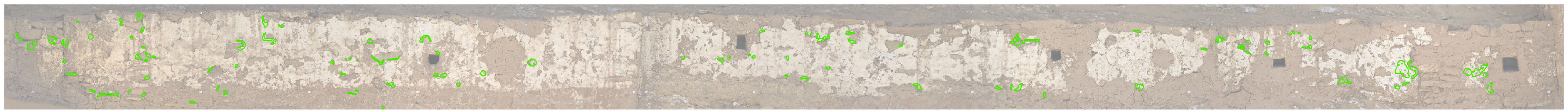
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.30



Feet
0 2 4 8 12 16

Legend

10% Gelatin Treatment

Statistics

Area:
10% Gelatin Treatment- in^2

Number of Applications:
10% Gelatin Treatment-105

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Fire Temple [Mesa Verde National Park]

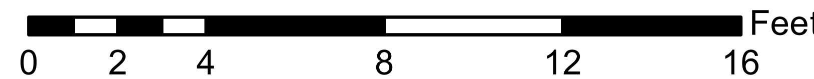
NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.31



Legend

Grout Treatment

Statistics

Area:
Grout Treatment-1330.780916 in^2

Number of Applications:
Grout Treatment-116

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Fire Temple [Mesa Verde National Park]

NORTH WALL

ArcGIS Digitization and Quantification

DANIEL S. CASTELE

SHEET NUMBER:

5.32

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