Laser Imaging of El Morro Inscriptions, El Morro National Monument, New Mexico

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Abstract

Archaeology Southwest and its subcontractors Statistical Research Inc and Mimic Studios Inc, recorded three-dimensional LIDAR scans of 10 panels of historic carved stone inscriptions at El Morro National Monument in 2006, 2007 and 2010. Despite a number of technical complications, comparisons of these yearly scans indicate that 2 panels are suffering serious problems with erosion, while the remained of the panels documented appear to be relatively stable.

Management Summary

In 2005 Archaeology Southwest (formerly the Center for Desert Archaeology), under the Cooperative Ecosystems Study Unit, was asked to develop a program of research to evaluate the use of close range LIDAR Scanning on 9 inscription panels at El Morro National Monument.

To complete this research, all of the inscription panels needed to be mapped in three dimensions, conforming to the UTM coordinate system for documentation. Our first step was to establish geodetic controls for a series of six datum points that would allow the locations of the inscription panels to documented in three-dimensional space. Each inscription panel was bound by the placement of 6 to 14 paper micro-targets, which were then assigned coordinates by our team's surveyor.

The scanning of the inscription panels took place in 4 steps. In 2006, all of the inscription panels were scanned at a resolution of .2mm with a Minolta VIVID 910 Non Contact 3D Digitizer. During this time, it was decided that inscription panel #9 actually represented 2 panels, and so the total count of inscription panels was changed to 10. At the same time, the North-East point of Inscription Rock, which includes panel #7 was scanned in its entirety with a Leica ScanStation 2 scanner for the purpose of creating a 2 cm contour map of this surface for incorporation with existing research on processes of erosion and deposition on this part of Inscription Rock. In 2007, the Minolta scanner was utilized to repeat the 2006 scans.

In 2008 a serious deficit in our scanning strategy was revealed when it became obvious that the software used for analyzing the scan data was generating false results. Relying upon an algorithm designed to match surfaces, the analysis package used to "stitch" the scan data into models of the entire inscription panel was not able to detect some obvious features that had changed in the year between the scans. Archaeology Southwest's subcontractor declined to participate further in this study, and a new subcontractor was selected based upon their proven ability to use the data that had been collected to date. At this point it was decided to delay the third year of scanning until 2010, so that we could develop a better estimate of potential changes to the inscription surface geometry through time.

The scanning project in 2010 again used the Minolta VIVID 910 scanner, but this time the scans were more focused upon actual inscription features, and the data collected was augmented with the use of a large format area scanner called a Surphaser HSX SR. The data collected by the Surphaser allowed an index geometry to be created that allowed alignment and analysis of all three years' worth of scan data.

The resulting analysis revealed more problems with our research methodology, indicating that the accuracy of the scan data is problematic in a variety of ways, - that the Minolta VIVID 910 scanner could not provide .2 mm accuracy in field scanning conditions. Despite this finding, the comparisons of each year's scanning data indicate that erosional processes near the rainwater pool and northeast point of Inscription Rock require immediate attention, while the remainder of panels scanned show little change over the past 4 years.

Introduction

The ancient and historic glyphs that have been carved into Inscription Rock at El Morro National Monument represent a heritage resource of global significance. The inscriptions chronicle ancient life in the American Southwest, the initial contact of Puebloan peoples with Spanish conquistadores and missionaries, as well as the Nineteenth century expansion of the American frontier. The messages carved into the soft Zuni Sandstone of the El Morro formation have lasted for centuries, but are currently threatened by what appears to be accelerating processes of erosion.

Under the Cooperative Ecosystems Study Unit program, Archaeology Southwest (formerly the Center for Desert Archaeology) was asked to employ close range LIDAR scanning to digitize the surface topography of 9 key historic inscription panels over 3 successive years to determine if LIDAR scanning was an effective means of documenting carved inscriptions, and to determine if baseline data on rates of erosion or deposition could be calculated via the comparison of scanned inscription data through time. In addition, a detailed scan of the northeastern point of Inscription Rock was also requested, as this portion of the monument is currently suffering the most obvious effects of erosion.

Previous Research on El Morro's Inscriptions

The most detailed and relevant research on potential problems with erosion and the inscriptions at El Morro was conducted by Christina Burris, who's 2007 Masters Thesis focused upon sandstone deterioration of the Northeast point of Inscription Rock. The thesis is available via the University of Pennsylvania's website at http://repository.upenn.edu/hp_theses/65. Burris' summary provides some examples of previous studies on potential threats to the inscriptions at El Morro, including Lichens and air pollution, which were found to be negligible (St Clair, 2001), and impacts from road and trail vibration, which were also found to be negligible (King et al 2003). Burris goes on to summarize the various attempts to chemically consolidate the friable and decomposing Zuni Sandstone beginning with attempts by Evon Vogt to use clear paraffin in the 1920's through to the use of modern consolidants in the early 21st century. Of particular important ace to this study, the work of rock art conservator Antoinette Padgett is cited as identifying the key factors contributing to the erosion at El Morro. These factors were found to include "salt, insect activity, clay/water wash, the presence of biogrowth,

graffiti, and graffiti removal, moisture, unknown accretions, and loss" (Burris, 2007, Oliver and Padgette, 2005). Buris then goes on to explain the variety of factors causing erosion through differential layers of moisture penetration, freeze-thaw cycles, thermal expansion, air pollution, salt crystal florescence, and wind abrasion. Citing the research of Snethlage and Wendler (1997) She goes on to argue that factors relating to moisture are leading to a process of granular disintegration where areas of the stone remain relatively wet, and contour scaling in areas where the stone can dry quickly after initial exposure to water. Another damaging form of erosion consists of problems relating to clay wash, where clay deposits accumulate upon the sandstone surface and then spall off of this surface, removing aggregate materials in the process.

Methods and Results

Geodetic Mapping

Fieldwork for the first year of research was conducted on October 26-30, 2006. This document is meant to accompany a wide range of digital resources that are provided on a DVD-ROM as an appendix to this report.

The first set of tasks to be conducted in regards to the El Morro inscription scanning project was the establishment of a set of mapping control points that would be used to establish the bounds and physical dimensions of the inscription panels to be studied.

Horizontal and vertical geodetic control was established by the use of survey grade Global Positioning System (GPS) receivers, providing the most accurate location data possible. Wilson & Associates, Inc., Albuquerque, NM, was contracted by Statistical Research to establish a GPS control network at the monument. Six points consisting of rebar with aluminum caps (CP1-6) were set along the eastern aspect of Inscription Rock (Figure 1, Coordinates listed in Table 1). CP1 and CP6 coordinates are OPUS solutions computed using rapid ephemeredes from approximately three hours of static GPS observations at each monument. GPS measurements were made with a Trimble 5800 L1/L2 integrated receiver/antenna on 25 October 2006 (CP1) and 30 October 2006 (CP6). CP1 and CP6 positions have an overall RMS of .016 m and .013 m. CP2-5 were measured using L1/L2 RTK GPS relative to CP1. All project area geodetics are metric coordinates UTM Zone 12, NAD83(CORS96:2002), NAVD88(Geoid03).

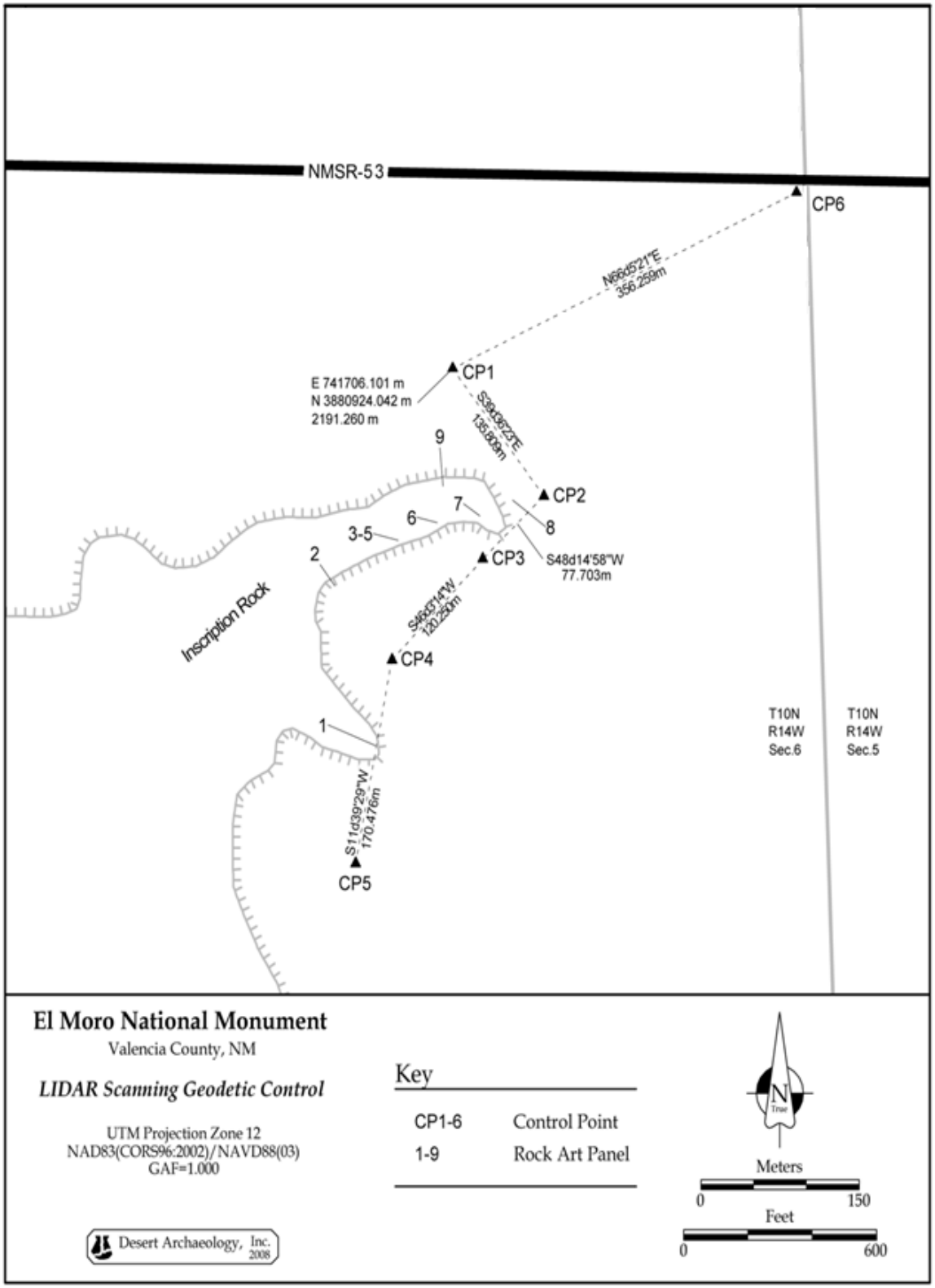


Figure 1 - Geodetic Control and Inscription Scan Panel locations

El Morro Ground Control: UTM Zone 12 North
NAD 83, NAVD 88, All Data Recorded in Meters
Combined Ground-to-Grid Factor = 0.99997714

DAT	North	East	Elevation	Description
1	3880924.039	741706.094	2191.260	CP 1 (Rebar with Alum. Cap)
2	3880819.507	741792.610	2197.021	CP 2 (Rebar with Alum. Cap)
3	3880767.898	741734.785	2202.678	CP 3 (Rebar with Alum. Cap)
4	3880684.717	741648.492	2212.377	CP 4 (Rebar with Alum. Cap)
5	3880517.805	741614.043	2216.217	CP 5 (Rebar with Alum. Cap)
6	3881068.435	742031.787	2189.147	CP 6 (Rebar with Alum. Cap)

Table 1 - Control Point UTM Coordinates

As requested in the scope of work agreement, geodetic data has been provided in a variety of digital formats. On Disk 1, in the folder entitled "Geodetics", the following cad and shape files are ready for use in a variety of Geographic Information Systems.

GIS Formats
elmo control_pts.dbf
elmo control_pts.prj
elmo control_pts.sbn
elmo control_pts.sbx
elmo control_pts.shp
elmo control_pts.shx

Autocad Formats:
el morro geodetics- acad 2007.dwg
el morro geodetics- acad 2000.dwg
el morro geodetics- acad 2007.dxf
el morro geodetics- acad 2000.dxf

Raw Data:
wilson_associates_survey_info.pdf

Graphical Format:
el_morro_survey_control.tif

Please note that the data provided in Autocad format has been corrected by Year 2 Survey efforts.

Once the survey control datums were established our research strategy dictated that the panels to be scanned would be defined by the application of a set of Micro-targets that would

bound the area to be scanned, and provide spatial control on a year to year basis. The scanning targets consist of 2 mm pieces of paper, with a crosshair consisting of 2 filled triangles within a circle. The targets were affixed to the inscription panels with a b-42 parasol adhesive, by NPS conservator Gretchen Voeks. (See Figures 2, and 3).

Figure 2 - Affixing a Scan Target

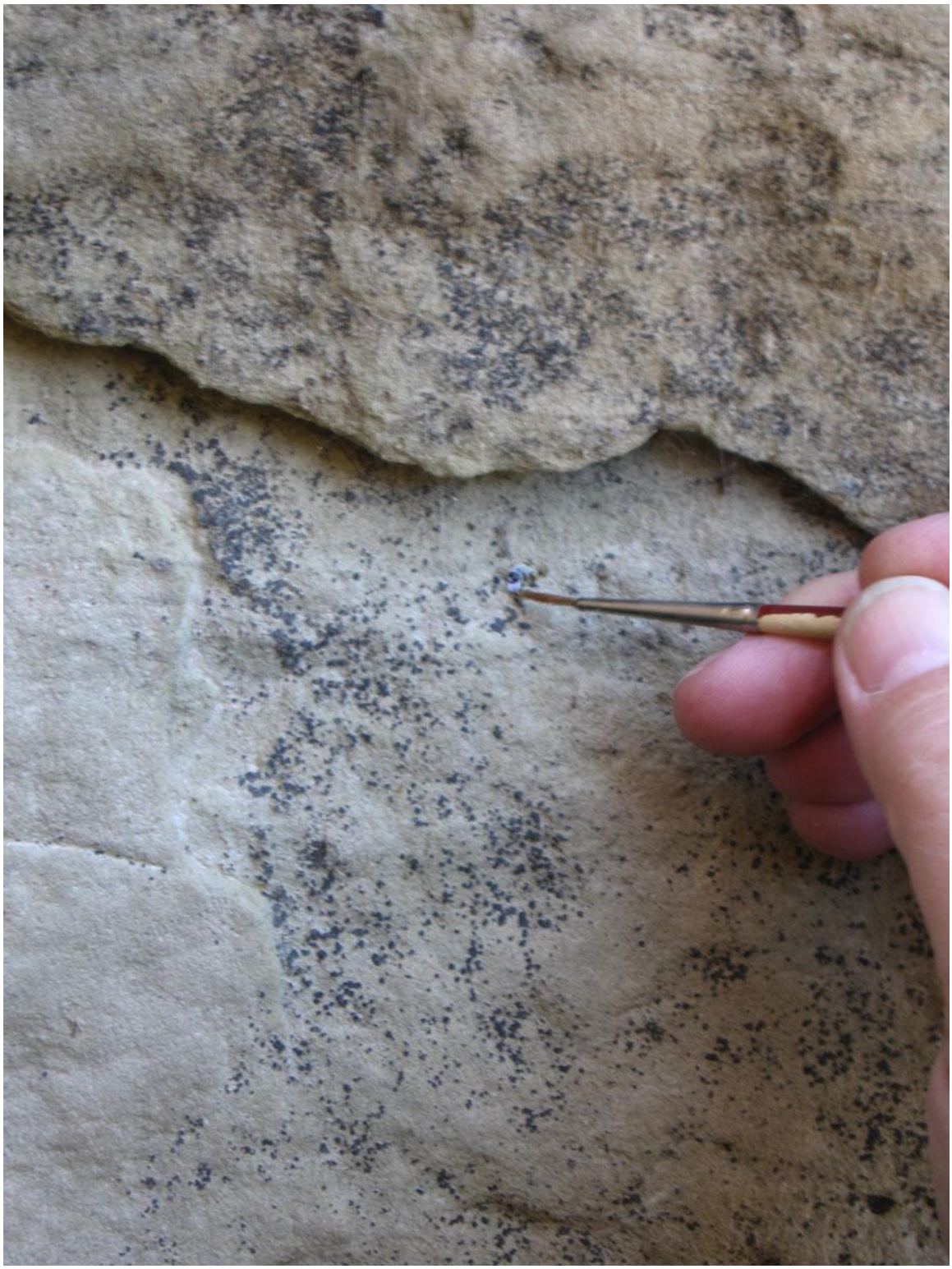


Figure 3 - Detail View of Scan Target

The geodetic control for these points was provided by Mike Brack, an archaeological surveyor for Desert Archaeology Inc. Desert Archaeology was tasked with tying the LIDAR scanning to the GPS control network. After all six GPS control points were recovered and measured optically, the GPS network was traversed, and scanning reference points were tied to local control at nine individual inscription panels. Work was completed 3-5 December 2007 using a Sokkia SRX 1-second reflectorless total station correcting for temperature, pressure, humidity, earth curvature, and refraction. All control measurements were made with standard infrared EDM and -30 mm offset prisms. Reflectorless measurements were used for individual scanning reference points, which consist of 3 mm diameter paper targets affixed to the exposed rock. CP1 was used as the basis of control for optical mapping. The inverse of CP1 to CP6 defines the basis of bearing. CP2-5 were traversed, and optical measurements were adjusted to the GPS network with the least squares method using CP1-5 as constrained horizontal control points. CP1 is also the basis of elevation in the project area with an OPUS-derived orthometric height of 2,191.26 m. The ground-measured combined scale factor for the control network is .9999711467 (GAF=1.000028854). GPS and least squares-adjusted coordinates for CP1-6 are shown in Appendix I, along with the RMS error from the ground-to-grid adjustment.

Once again, on Disk 1, in the folder "geodetics" the following files provide spatial and coordinate data for the micro scanning targets. Visual Plots of scan target locations are provided in Figures 4-13

Autocad Formats:
el morro geodetics- acad 2007.dwg
el morro geodetics- acad 2000.dwg
el morro geodetics- acad 2007.dxf
el morro geodetics- acad 2000.dxf

Microsoft Excel Format:
scan target co-ordinates.xls

Raster Graphics (JPG) Format:
Panel 1 Markers & Targets.jpg
Panel 2 Markers & Targets.jpg
Panel 3 Markers & Targets.jpg
Panel 4 Markers & Targets.jpg
Panel 5 Markers & Targets.jpg
Panel 6 Markers & Targets.jpg

Panel 7 Markers & Targets.jpg
Panel 8 Markers & Targets.jpg
Panel 9a Markers & Targets.jpg
Panel 9b Markers & Targets.jpg

Year One LIDAR Mapping: Northeastern Point of Inscription Rock

As part of the inscription scanning and modeling process, Tucson based registered surveyors Darling and Associates Ltd. conducted a wide area LIDAR scan of the Northeast point of Inscription rock. This scan data is intended to augment existing studies of clay wash and other depositional processes that may be effecting the dense collection of historic inscriptions on this portion of the sandstone surface. According to the Scope of Work agreement, his scan was supposed to be at a resolution of 3 cm of accuracy, but Darling and Associates were able to provide a scan at a resolution of 5 mm. The resulting scan data, presented as a simplified Autocad drawing can be seen in Figure 14. This data was converted into a digital mesh, and rendered with a photographic texture map in Figure 15.

Notes on Three Dimensional File Formats and Delivery:

Part of the Scope of Work agreement defines that Archaeology Southwest, whenever possible, shall provide 3D data in formats that can be utilized for both GIS analysis and 3D modeling. To these ends, data will be provided in multiple formats.

One such 3D modeling format that will be used extensively for the delivery of 3D data formats is the Virtual Reality Mark Up language, known as VRML (pronounced as "vermil"). 3D models provided in the current VRML 2.0 Standard will carry the file format suffix ".wrl" Numerous free, open source programs can import VRML files directly into web browser programs such as Internet Explorer and Mozilla Firefox. . One such program, the Octaga Player, is available in the "3D applications" folder on disk 1. Once installed, the Octaga player will allow the opening .wrl files directly from your web browsing software's "file/open" menu item. Alternatively, the Octaga Player program can be run as a stand-alone application which can then be used to open .wrl files directly.

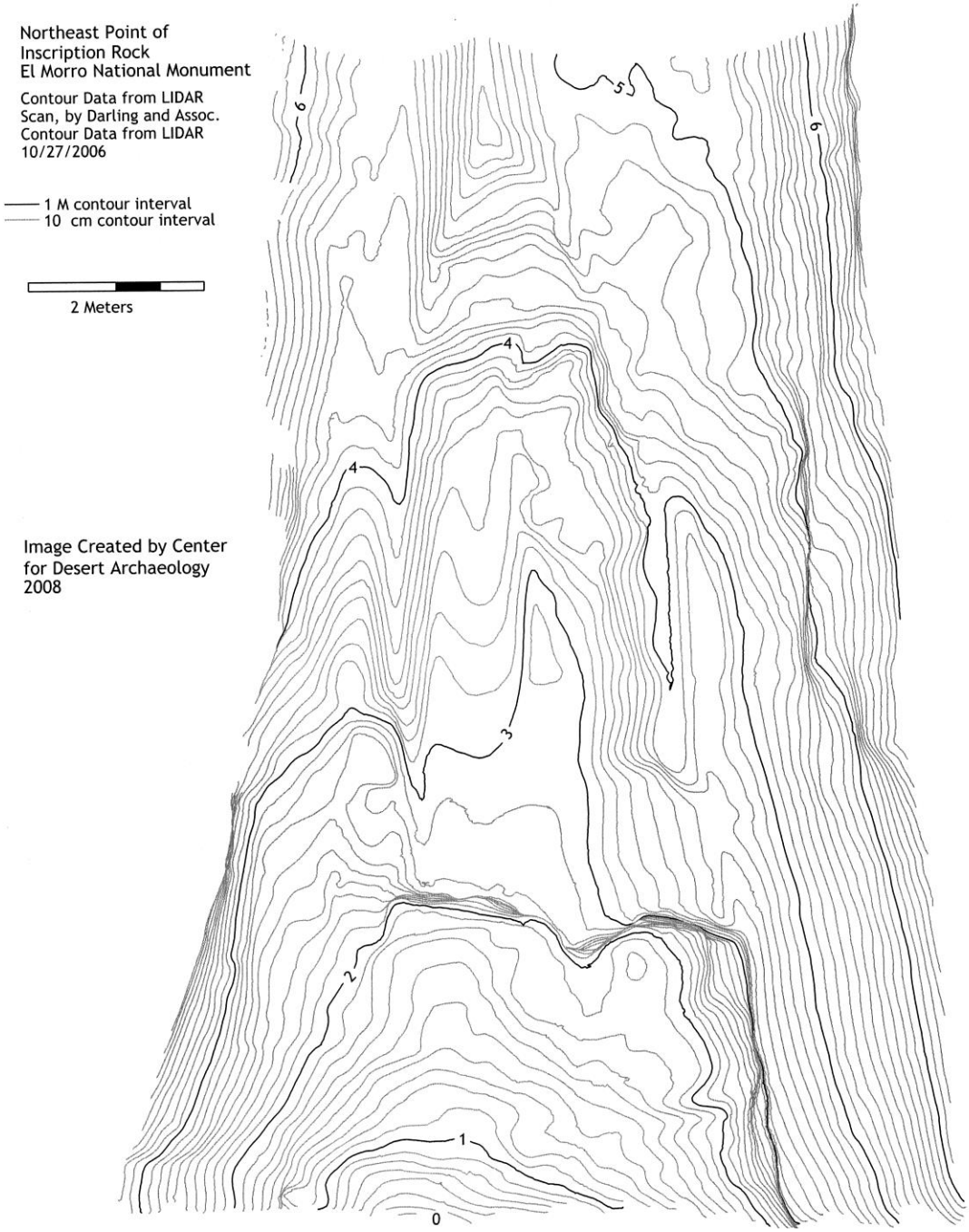


Figure 4 - Cad Plot of 10 Cm Contours of Northeastern Point of Inscription Rock

Another common industry standard way of examining 3D modeling data is with the .3Ds file format. There is some confusion about this file format, as it is commonly called the "3D studio" file format, but it is not the file format used by the industry standard program "3D Studio Max," rather it is an older file format from the DOS version of 3D Studio. As such, this file format is quite limited. The file can only handle 64,000 polygon vertexes, while scan data files

can easily contain 15,000,000 vertices or more. In addition, all data files and supporting data files such as texture maps are limited to the old DOS file naming standard of 8 characters with a three character suffix. Despite these limitations the ".3Ds" file format is a very robust, error free means, commonly used for sharing 3D data. Please remember that any data delivered in .3Ds format is for display purposes only, as the data density has been heavily reduced by resampling algorithms to allow for display on desktop personal computers. A free open source program called "Meshlab" has been provided in the "3D applications" folder to allow opening this, and several other 3D file formats.

Figure 5 - Northeastern point of Inscription Rock, Rendered 3D Model of Scan Data

Finally, for very large 3D mesh files, a unique file browser that allows for the display of dense polygon data is provided by Rapidform. This file format requires mesh data be displayed within Internet Explorer (unfortunately, the rapidform viewer will not function in any other

internet browser) . This file format displays the 3D data within I.E. as long as the host computer has an active Internet connection.

Digital Files for Northeastern Point of Inscription Rock

Raster graphics, Cad and 3D Geometry files of all of the data collected for this scanning project are provided on Disk 1. These files are contained in the folder **Northeast Point**:

Subfolder 3D data:

JPG files: NE point Contour Texture.jpg (Texture map for 3D Models)
North Face Contour Map 1.jpg
North Face Contour Map 2.jpg
North Face Texture.jpg (Texture map for 3D Models)
ELMO NOR.jog (texture map for .3Ds Format)

3D Modeling Files:

NE point.wrl - Mesh file in VRML 2.0 format
NePoint.3Ds - (3Ds format, Data density reduced by 90%)
Northeast Point.max (3D Studio Max Format)
Northeast Point.stl (Stereo Lithography format)
Northeast Point.dxf (Autodesk Drawing Exchange format - data density reduced by 50%)

Subfolder Cad Data:

North point, el morro display.dwg - Autocad 2007, 10 cm contour map
North point, el morro raw data.dwg - Autocad 2007, 5 mm raw data.
North point, el morro raw data.dxf - Autodesk Drawing Exchange file.
elmo north point.jpg - Raster Plot of el morro display.dwg

Subfolder Scan Data:

el morro north face.xyz - raw data plot from LIDAR scan.

Analytical Methods and Results for 3D Modeling

With the spatial controls established, work focused upon collecting the actual LIDAR scans of the inscription panels. The panels to be scanned were selected upon the basis of previous work in documenting and in some cases, treating historic inscriptions to gauge and deter deleterious effects upon the stone carvings. As part of the scanning effort, these assessments and treatments were digitized by Archaeology Southwest, so that these areas could receive specialized attention once the analysis of the comparisons of multi-year scans of the

historic inscriptions began. These data are stored upon disk 1 the folder "IRMS_Panel_Treatments."

Digitized Treatment Data Files:

Subfolder Digitized Data:

panel 2 assessment.dwg & dxf - Autocad, & Autodesk Drawing Exchange Format
panel 2 treatment.dwg - (dxf) Autocad & Autodesk Drawing Exchange Format
panel 3 assessment.dwg - Autocad & Autodesk Drawing Exchange Format
panel 4 assessment.dwg - Autocad & Autodesk Drawing Exchange Format
panel 5 assessment.dwg - Autocad & Autodesk Drawing Exchange Format
panel 6 assessment.dwg - Autocad & Autodesk Drawing Exchange Format
panel 7 assessment.dwg - Autocad & Autodesk Drawing Exchange Format
panel 7b assessment.dwg - Autocad & Autodesk Drawing Exchange Format
panel 9a assessment.dwg - Autocad & Autodesk Drawing Exchange Format

Scanning of the selected inscription panels took place over 5 years, with the first scans recorded on October 26-30, 2006, the second scans acquired on October 28 and 29, 2007 and the final scans collected on October 12 and 13 of 2010. For all of these days, the weather could be defined as bright and sunny, which caused some measure of difficulty for the scanner operators, as the sunlight tended to overpower the LIDAR's infrared laser return signal. However, this issue was negligible for the scans of Panels 9a and 9b, as these areas remained in shadow for each of the day's observations.

The scanning process was constrained by the relatively small area that the Minolta Vivid 910 scanner could digitize in a single operation. The roughly 10 by 15 cm scan area required the scanner to digitize enough overlapping areas to allow the analysis and modeling software the ability to "stitch" each individual scan into a single linked file that modeled the true size of the inscription panel. An average inscription panel would require somewhere between 40 and 60 scans to create a composite digital model, referred to as a "scan world" of the entire panel.

After the second set of scans was acquired we discovered a significant problem with our data collection methodology. After the data was assembled into 3D scan worlds within a program called Rapidform, a set of test comparisons were generated with scans from interpretive panel #8 (on the north-east point of Inscription Rock). This panel was chosen because it showed evidence for an obvious episode of macro-scale spalling, and we wanted to be certain that the Rapidform software could detect the erosion. To our dismay, not only was the spalling episode invisible, but the scan worlds from 2006 and 2007 showed a small area in the center of the

inscription panel as unchanged, and areas along the edges of the scan world as having as much as 4 cm of loss during the course of the year. It was obvious that the algorithm that analyzed overlapping portions of the scan world had allowed for errors to be introduced to the surface fitting procedure, causing the scanned data to "warp" inward, with spatial data becoming more inaccurate the further away they were from the geomentric centroid of the scan world.

At this point our subcontractor decided that the project was beyond the limits of their capacity, and we turned to Mimic Studios, who were providing technical support for our efforts to see what could be done with the data we had already collected. A decision was made to delay the year 3 scans by 2 years to provide a better baseline of potential erosion or deposition, and then the year 3 scans would focus more directly upon the inscription features, utilizing a larger area scanner to provide a model by which the two previous years of scan data could be successfully aligned for comparison with the third year of scans by an identical Minolta Vivid 910 digitizer.

Project Findings

Unfortunately our primary finding was that the Minolta Vivid 910 was a poor choice for this type of monitoring of ancient or historic stone inscriptions. The scanner was advertised as providing .2mm accuracy, but we suspect that this accuracy is only possible in controlled laboratory conditions, outside of direct or indirect sunlight. From our observations, the large area "Surpahser" scanner was just as accurate as the Vivid 910, providing roughly .5 mm accuracy 10 to 20 times faster than vivid scanner was able to operate.

In addition, even with the Surfaser data helping to rectify the spatial topologies of the three sets of scans, a small amount of error remains unavoidable in the compilation of this data, yielding a higher degree of error towards the edges of the scan world in comparison to the geometric centriod.

Panel 1 Scan Results

Panel 1 was selected for inclusion based upon the 1852 Sitgreaves inscription. This panel was not on the interpretive trail and for most of our scanning efforts the area was complicated by the mixture of lighting conditions with bright sunlight and strong shadows. An operator error in 2006 resulted in a pair of missing scans that prevented analysis of the Sitgreaves inscription from this year. The remainder of the panel, including dated inscriptions by Woodhouse and Henry Newman were included in this effort.

All panel 1 data is provided on Disk 1, in the subfolder Panel 1. Included within this folder are renderings of each year's scan, as well as the actual scan data in STL and VRML 97 (wrl) formats.

Scan alignment of the individual scans to each other and to previous years data was completed by Mimic Studios in December of 2011, using Polyworks IMAlign. IMAlign uses a least square best fit technique for creating the optimum alignment between scans and groups of scans. Comparison between scans was done using the Geomagic Studio analysis tool to show the deviation difference between two sets of scans which are presented as color maps in the following figures.

Figures 6 and 7 provide the loss / gain model analysis for Panel 1. The graphics illustrate differences in the model's surfaces on a scale of -2 to +2 millimeters with a standard deviation of .411 mm in the 2006 comparison, and .473 millimeters in 2007 comparison. Close examinations of these two figures reveals that there are problems with this analysis. The 2006 vs. 2010 scan data indicates a significant area of surface loss above and slightly to the right of the "U.S.A." text (indicated as the blue stripe) of the Sitgreaves inscription. In the 2007 vs. 2010 comparison this area shows very little inferred surface loss. If the data in these models were accurate, we would have to infer that this area lost a full millimeter of surface in 2006, which was then replaced by 2007. A more likely explanation for this finding is that the striping we see in the scan comparisons are due to areas of light and shadow interfering with the scanner function, and that this interference indicates that the scanner's precision in this setting is greater than 1 mm. Once again, this project was supposed to provide accurate scans at scale of .2 mm which our efforts have failed to achieve.

Despite these problems it does appear that the gain/loss models provide some details at a more coarse scale of analysis. In the case of Panel 1 there are a number of areas that show evidence for the accumulation of extra materials, including a slight amount of clay wash and areas of discrete accumulations of sands and clays captured by spider webs and wasp castings.

Panel 2 Scan Results

Panel 2, situated over the small pond and damn, and one of the first stops on the interpretive trail apparently did not suffer the same degree of striping and uneven lighting as Panel 1, but there are still signifigant problems with the precision of the measurements generated. The standard deviation for the 2006 vs. 2010 scans is 1.354 mm, and 1.020 mm for the 2007 vs. 2010 comparison, but the standard deviation value appears to be skewed by the analysis software including differences between areas on the edges of the scan world that did not match exactly between the annual scans. Given the degree of uncertainty associated with this value, the following findings should be evaluated critically, but it does appear that the

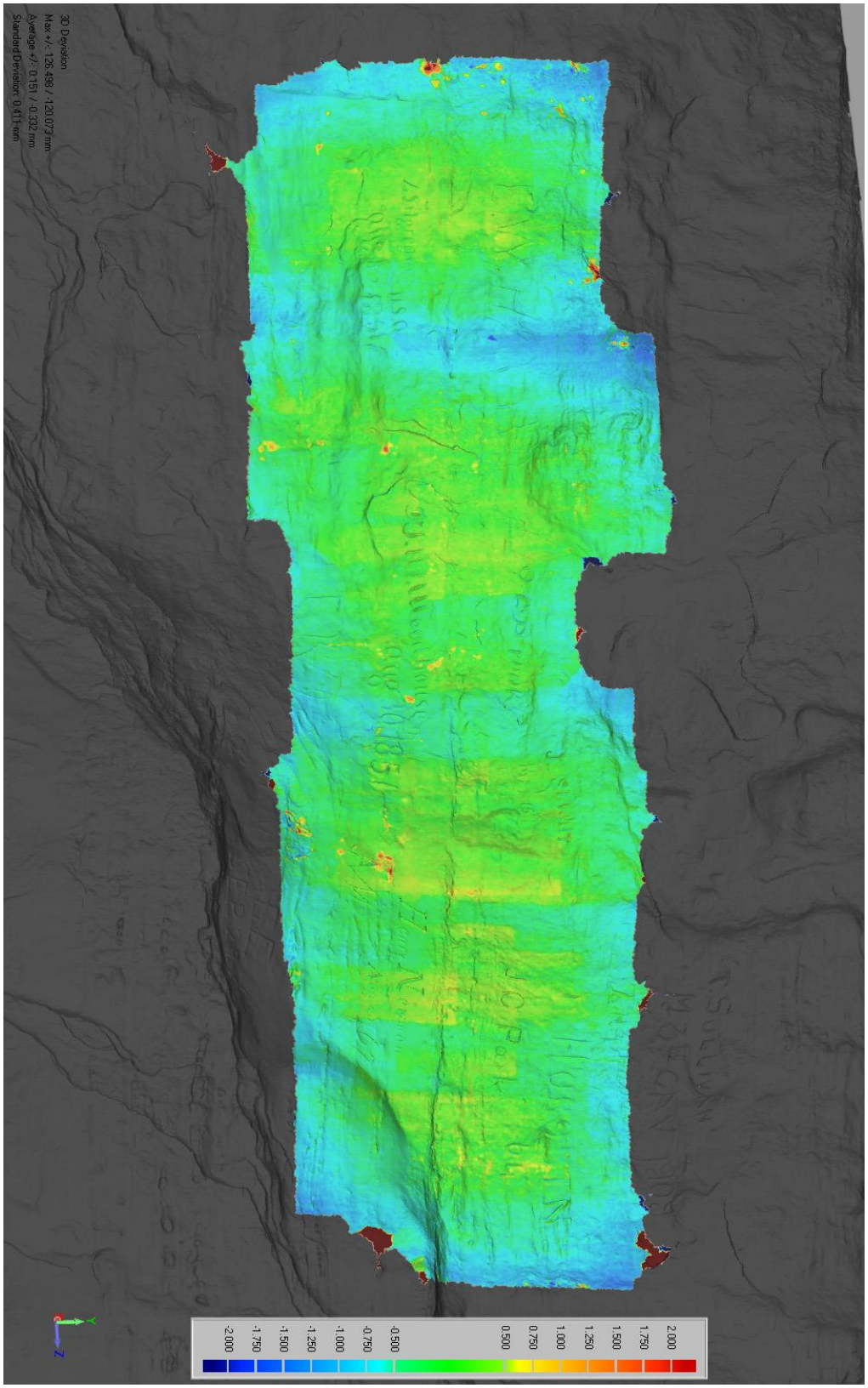


Figure 6 – Comparison Between 2006 and 2010 scan data on Panel 1

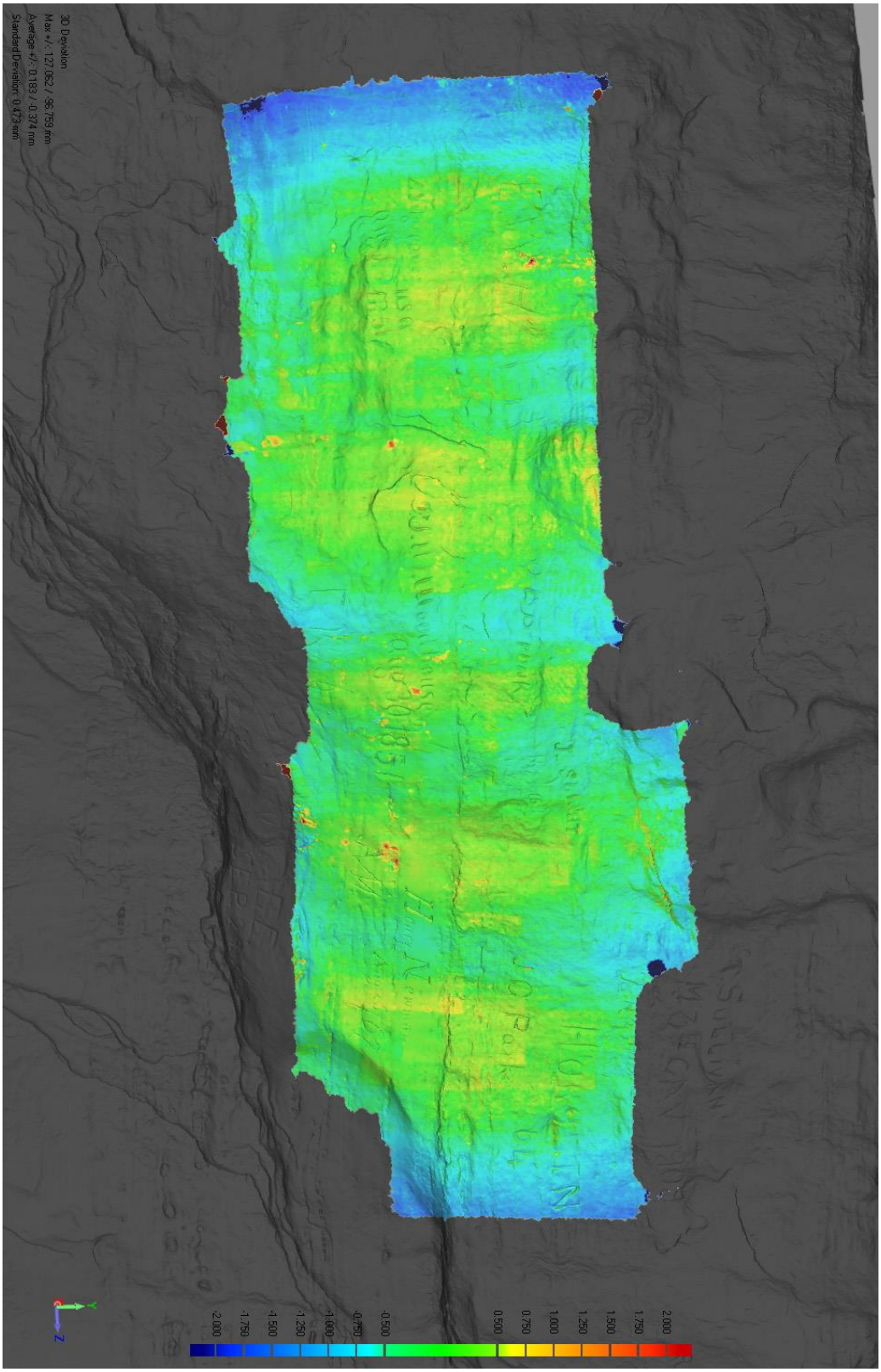


Figure 7 – Comparison Between 2007 and 2010 scan data on Panel 1

comparisons between scan worlds indicates that this panel is undergoing a high degree of activity in both loss and accretion of material, particularly immediately below the small stone ridges and at the bottom edge of the inscription panel. Much of the accretion is due to insect activity but there have also been some significant areas of spalling indicated by the scan world comparisons (see Figures 8 and 9).

All panel 2 data is provided on Disk 1, in the subfolder Panel 2. Included within this folder are renderings of each year's scan, as well as the actual scan data in STL and VRML 97 (wrl) formats.

Panel 3 Scan Results

The scanning results for Panel 3were much more encouraging. Again the standard deviation values range around .43 mm, but once again, this high value seems to have more to do with the edge matching problem than a wide range of possible gain or loss in the sandstone.

The comparison of scans from 2006 and 2007 to 2010 present a much more realistic case for the use of LIDAR in rock art documentation because the area to be scanned is much smaller, resulting less accumulation of error in the assemblage of individual scans, and because of the smaller size of the scan, the lighting conditions remained unchanged through the scanning process. Despite the unreliable value for standard deviation it seems fairly clear that the only process acting upon this inscription panel might be a slight amount of clay wash adding perhaps 1/10 of 1 mm of extra material to the stone surface, However, it seems more likely that this panel remained in a stable state for the 2006-2010 period.

All panel 3 data resides in on disk 2, in the panel 3 directory.

Panel 4 Scan Results

Like Panel 3, the results from the Panel 4 comparisons indicate a relatively stable inscription panel without serious episodes of erosion or deposition. The 2007 to 2010 comparion of scan world data does seem to indicate a slight amount of clay wash may be impacting this feature. Panel 4 data is presented in Figures 12 and 13, and resides on disk 2 in the panel 4 folder.

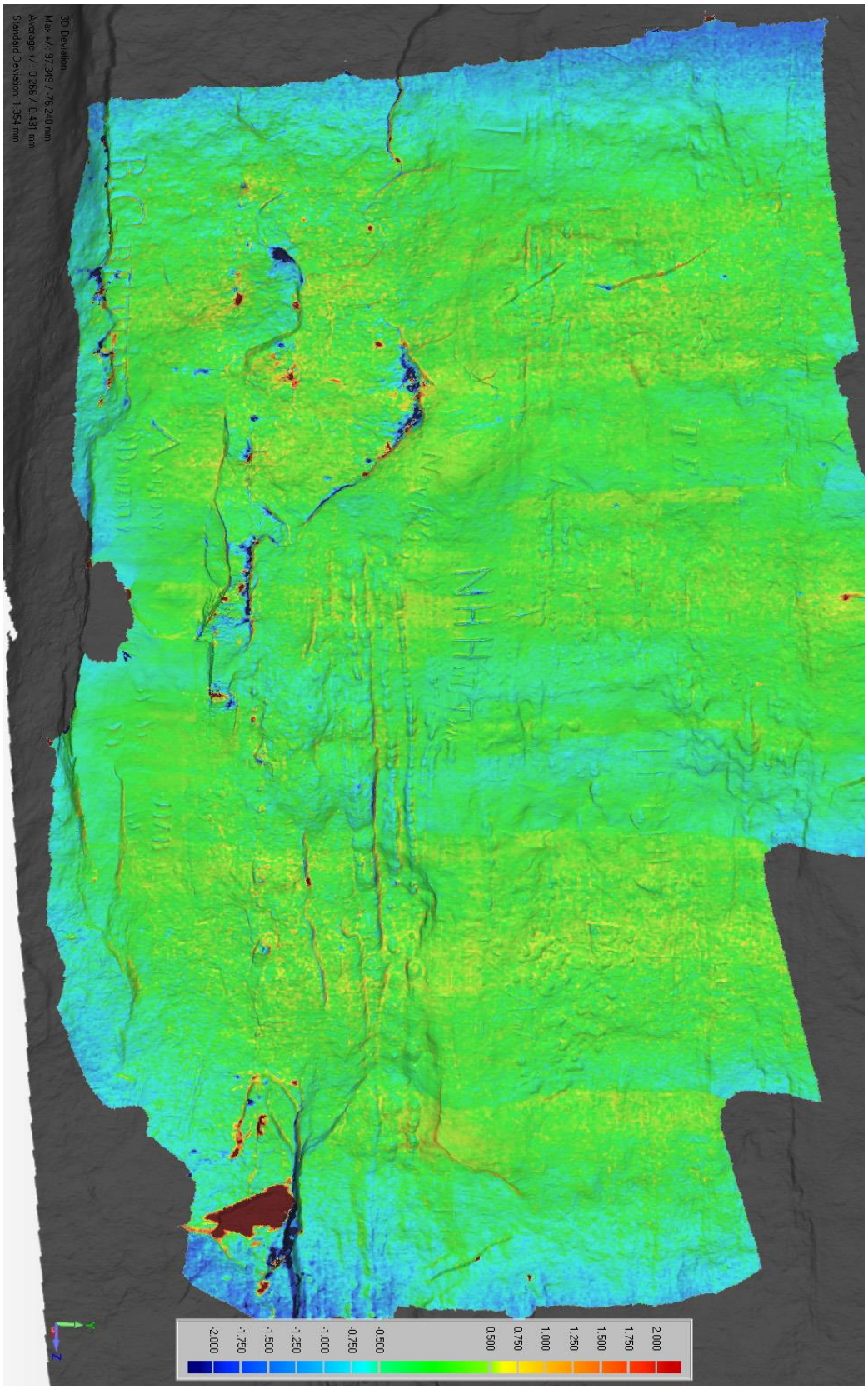


Figure 8 – Panel 2 Comparison of 2006 and 2010 Scan Data

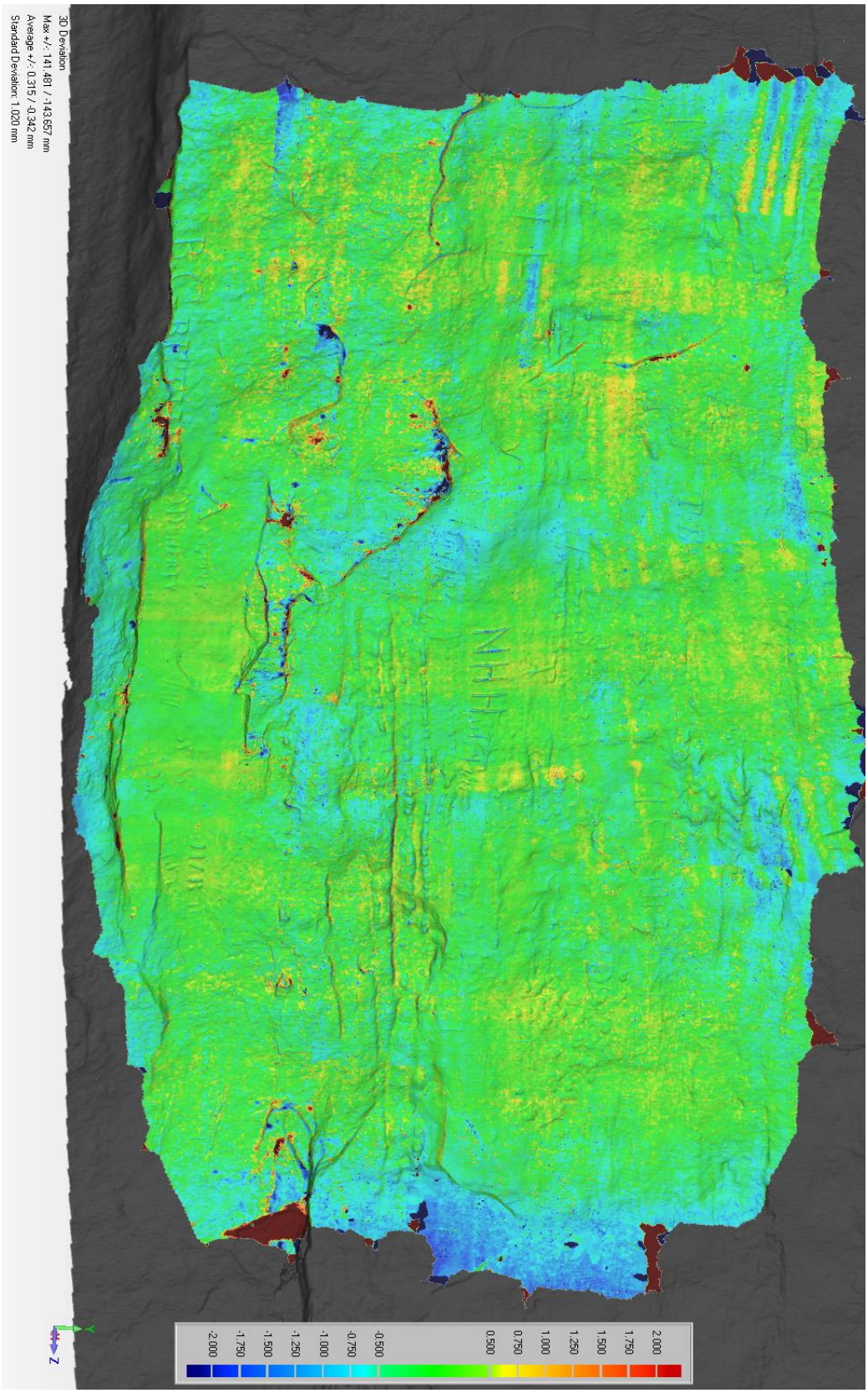


Figure 9 – Panel 2 Comparison of 2006 and 2010 Scan Data

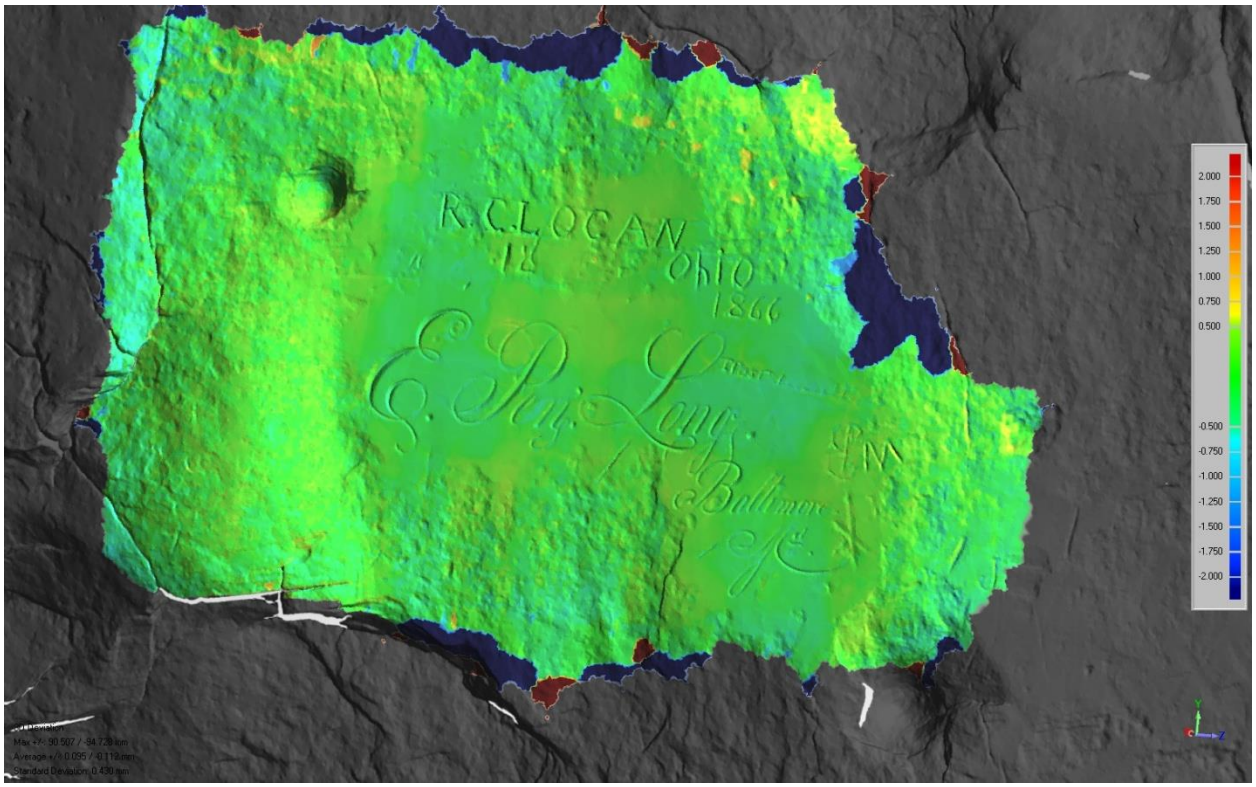


Figure 10 - Panel 3 Comparisons of 2006 and 2007 scan world data

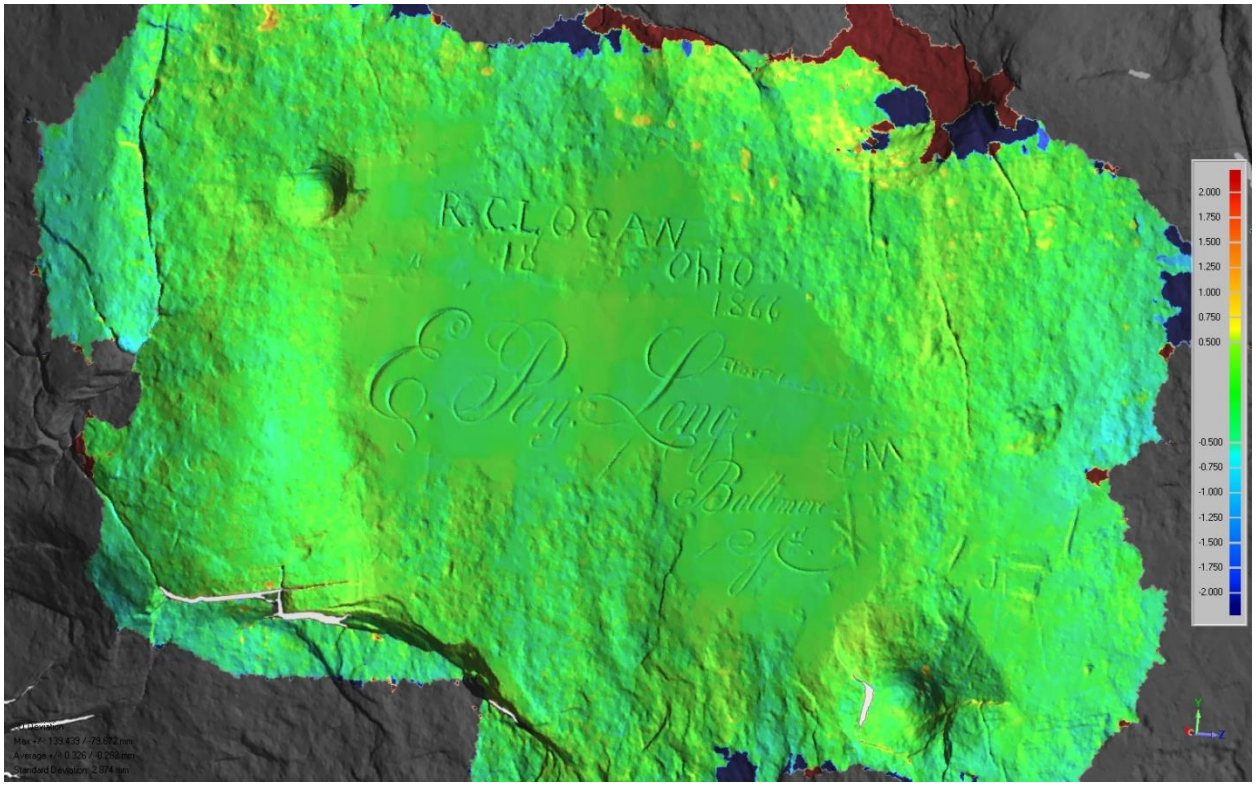


Figure 11- Panel 3 Comparisons of 2007 and 2010 scan world data

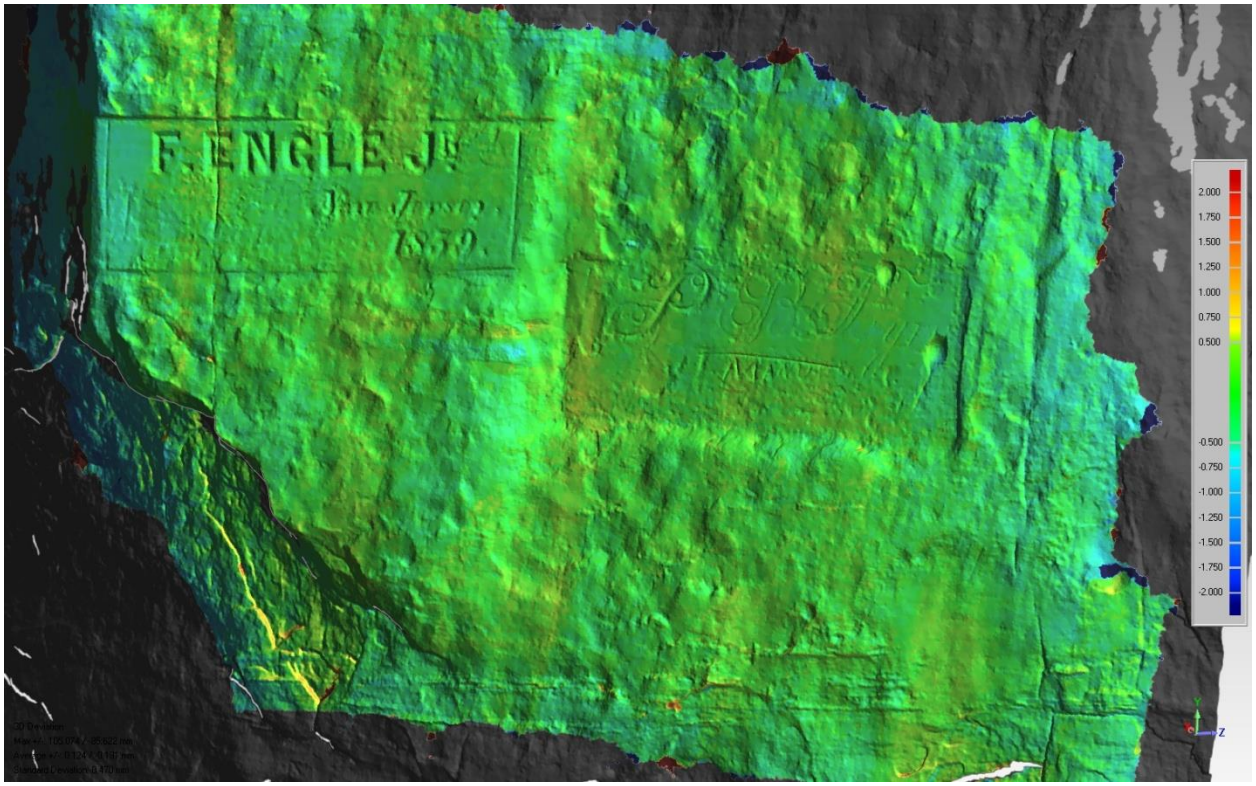


Figure 12 – Panel 4 Comparison of 2006 and 2010 scan worlds

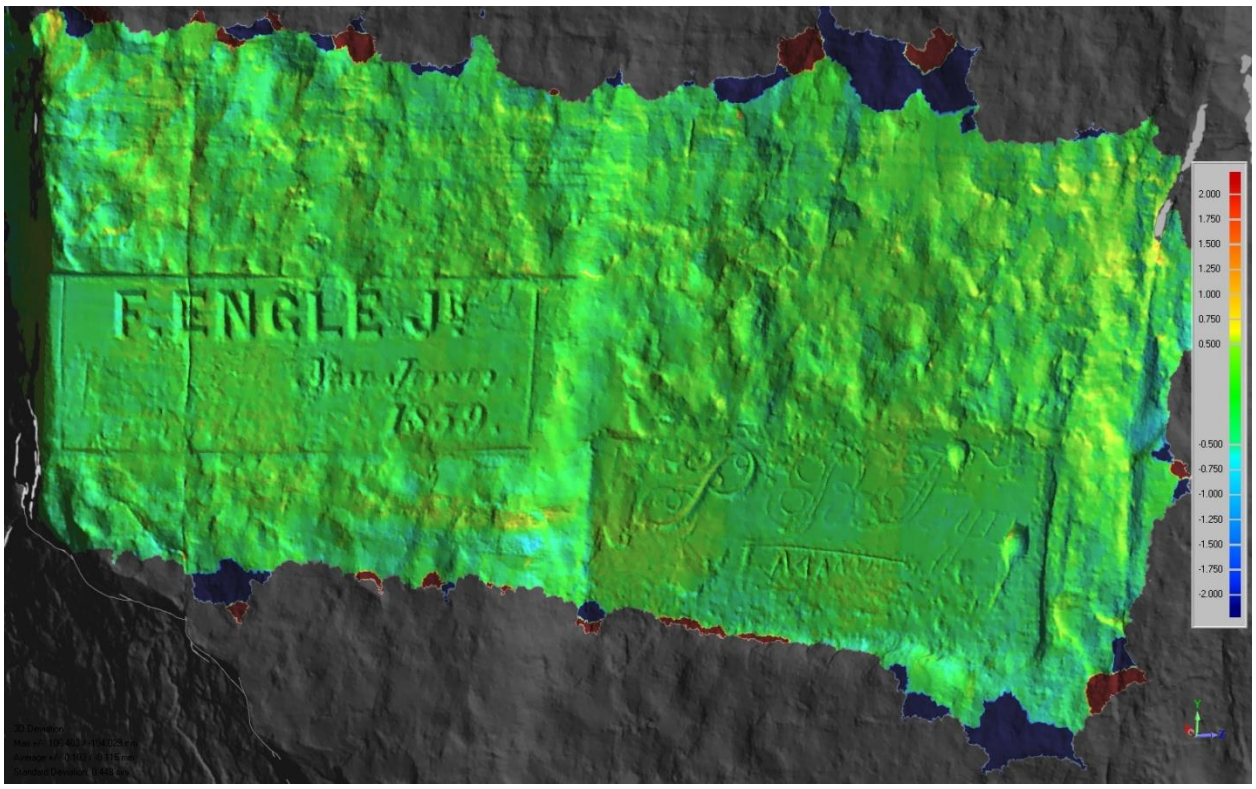


Figure 13 – Panel 4 Comparison of 2007 and 2010 scan worlds

Panel 5 Scan results

Panel 5, the inscription by Breckenridge appears to show the same basic results as panels 3 and 4, but there are some complications with this data. If one looks closely at the original scan data from 2006 and 2007 there are some obvious errors in the collection of this data. The raw scan data is presented in figures 14,15, and 16. In figure 14, above and to the right of the Breckenridge inscription there appears to be sets of many fine parallel lines. This represents statistical noise being generated by the scanner's sensor being overloaded by bright light during the scan. The problem is not as pronounced in the 2007 scan (compare figures 15 and 16) but the 2007 scan still presents more noise than is visible in the 2010 scan.

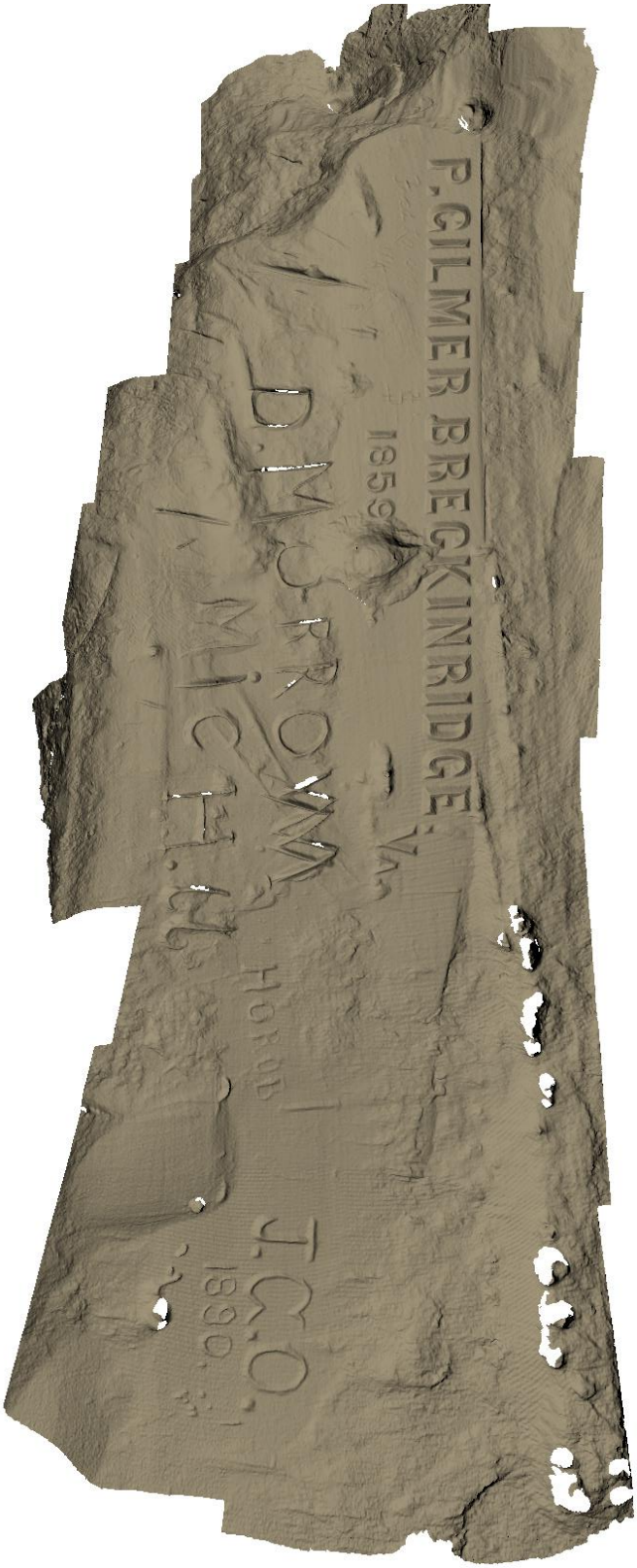
Evaluating the comparisons between the annual scans for panel 5 (Figures 17 and 18) is made more difficult by the presence of noise with these scans, but looking closely at the actual inscriptions, it seems safe to conclude that there might be a small amount of clay wash, particularly in the 2007 scan comparison (Figure 18) but otherwise this panel appears stable, much like panels 3 and 4. Panel 5 data is stored upon disk 2, in the Panel 5 folder.

Panel 6 Scanning Results

Panel 6 represents two unique and historically significant panels dating to the Spanish Colonial period. The upper panel contains the "Paso Por Aqui" inscription from Onaté in 1605, and the lower panel represents the inscription left by the Bishop of Duragno in 1730. This particular panel presented a number of challenges to the scanning crew. First off, the area is intermittently shaded by a Juniper tree that complicated the lighting levels, second, the Onaté inscription has been highlighted by graphite or lamp black which overwhelmed the scanning sensor in 2006. Another complicating factor was the relatively shallow nature of the Onaté inscription itself, which was easily the most shallow carving of any of the major inscriptions scanned on this project. Finally, the two inscription areas were scanned and treated as a single inscription panel, when obviously we would have achieved much more accurate results if the two panels had been treated as two separate panels for analysis.

Given the above complicating factors, the scan data comparisons for 2006 and 2007 should be considered inconclusive. The standard deviations recorded for these scans were quite low, with values of .206 for 2006 and .192 for 2007, but the 2007 scan comparison (Figure 19) shows obvious banding that is not reflected in the 2006 scan, indicating problems with light and shadow during the scanning effort, and this banding is not reflected in the 2006 scan.

Figure 14 - Panel 5 Scan Results for 2006 – Note the noise in the area above the JCO



inscription

Figure 15 – Panel 5 Scan Data with extra noise visible throughout scanned area

Figure 16 – Panel 5 Clean Scan data from 2010

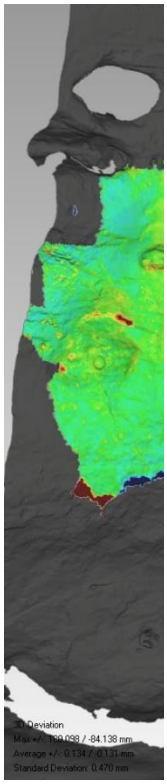
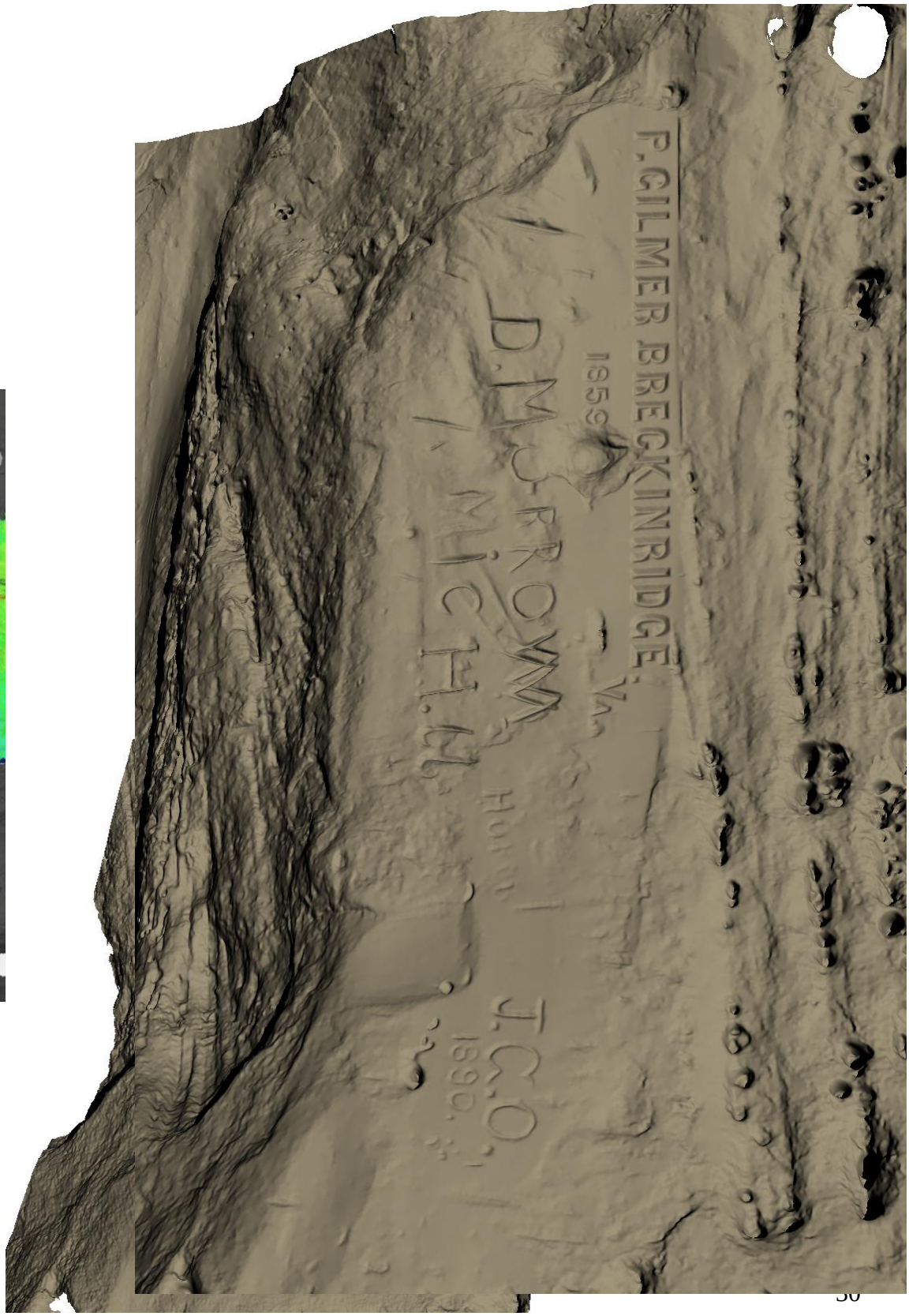


Figure 17 – Panel 5 Comparison of 2006 and 2007 scan data



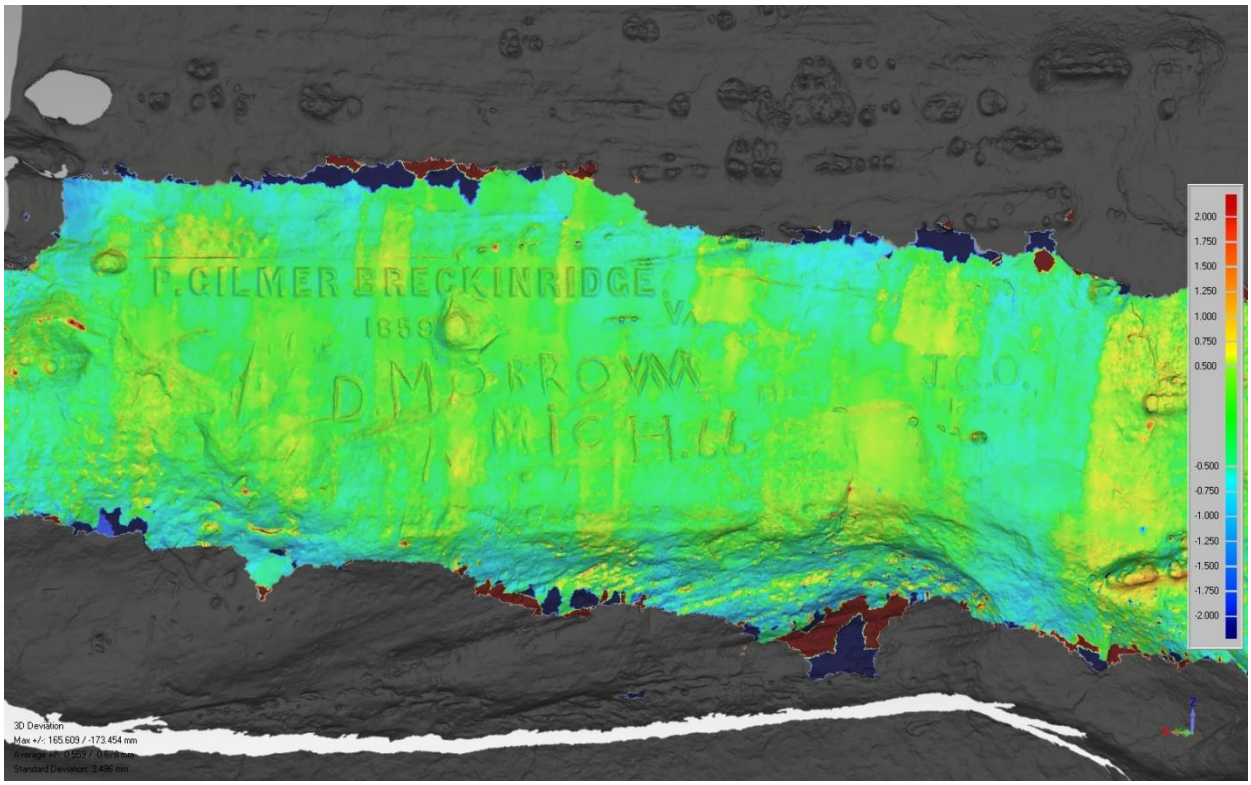


Figure 18 – Panel 5 Comparisons of 2007 and 2010 scan data

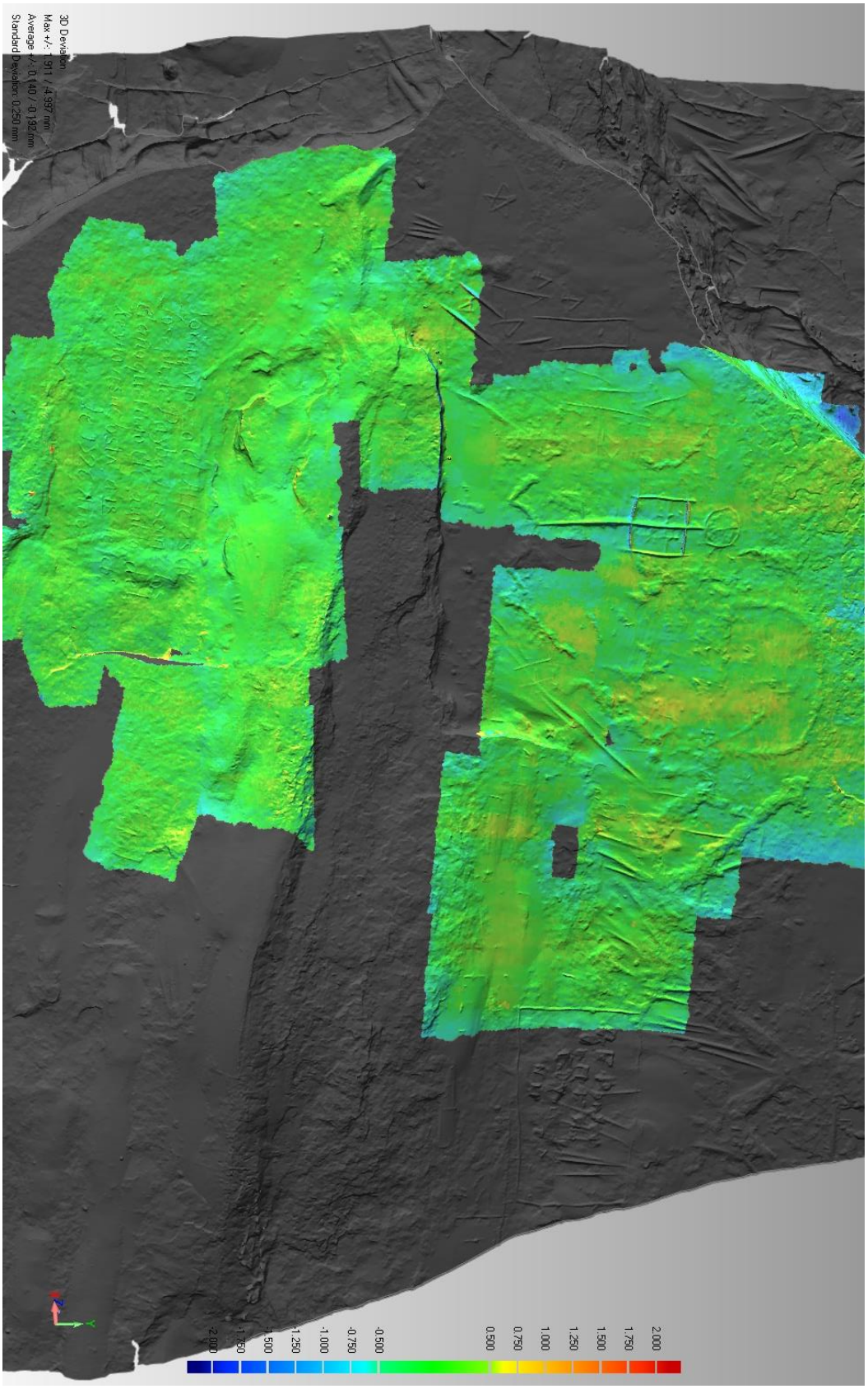

3D Deviation
Max +/-: 1.911 / -4.997 mm
Average +/-: 0.140 / -0.192 mm
Standard Deviation: 0.250 mm
2.000
1.750
1.500
1.250
1.000
0.750
0.500
-0.500
-0.750
-1.000
-1.250
-1.500
-1.750
-2.000

Figure 19 – Panel 6 Comparison of 2006 and 2010 scan worlds

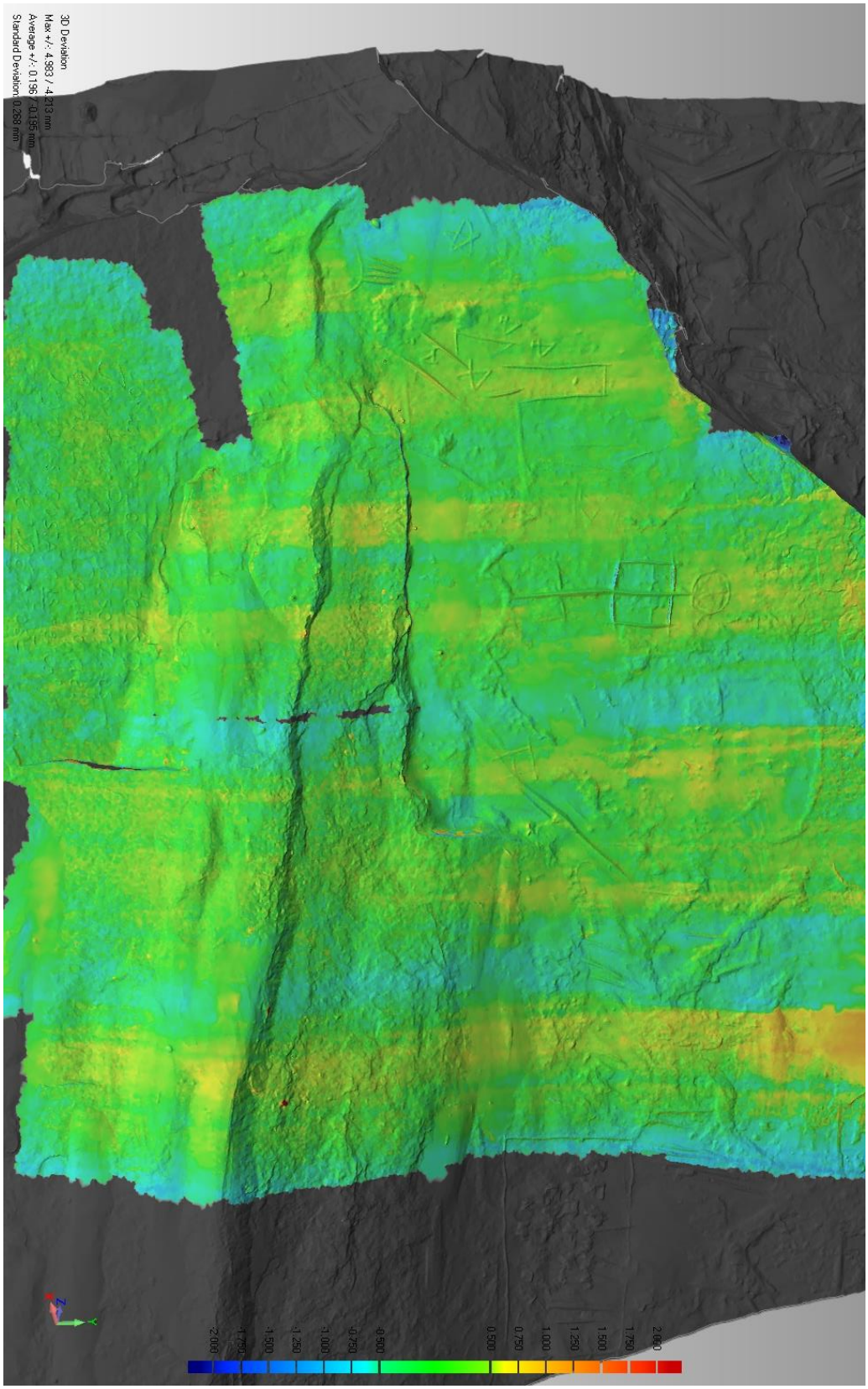

3D Deviation
Max +/-: 4.983 / -4.213 mm
Average +/-: 0.196 / -0.135 mm
Standard Deviation: 0.268 mm
-2.000
-1.750
-1.500
-1.250
-1.000
-0.750
-0.500
-0.500
0.750
1.000
1.250
1.500
1.750
2.000

Figure 20 – Panel 6 Comparison of 2007 and 2010 scan worlds

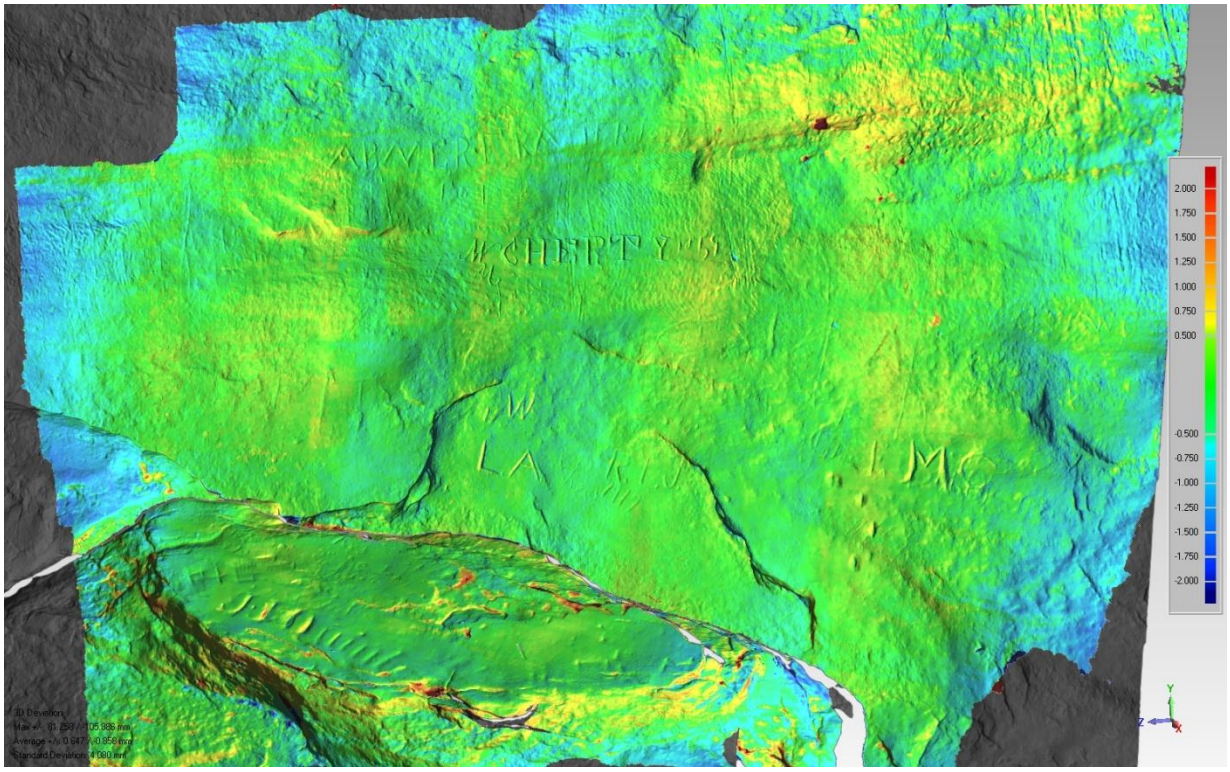


Figure 21 – Panel 7 Comparison of 2006 and 2007 scan worlds

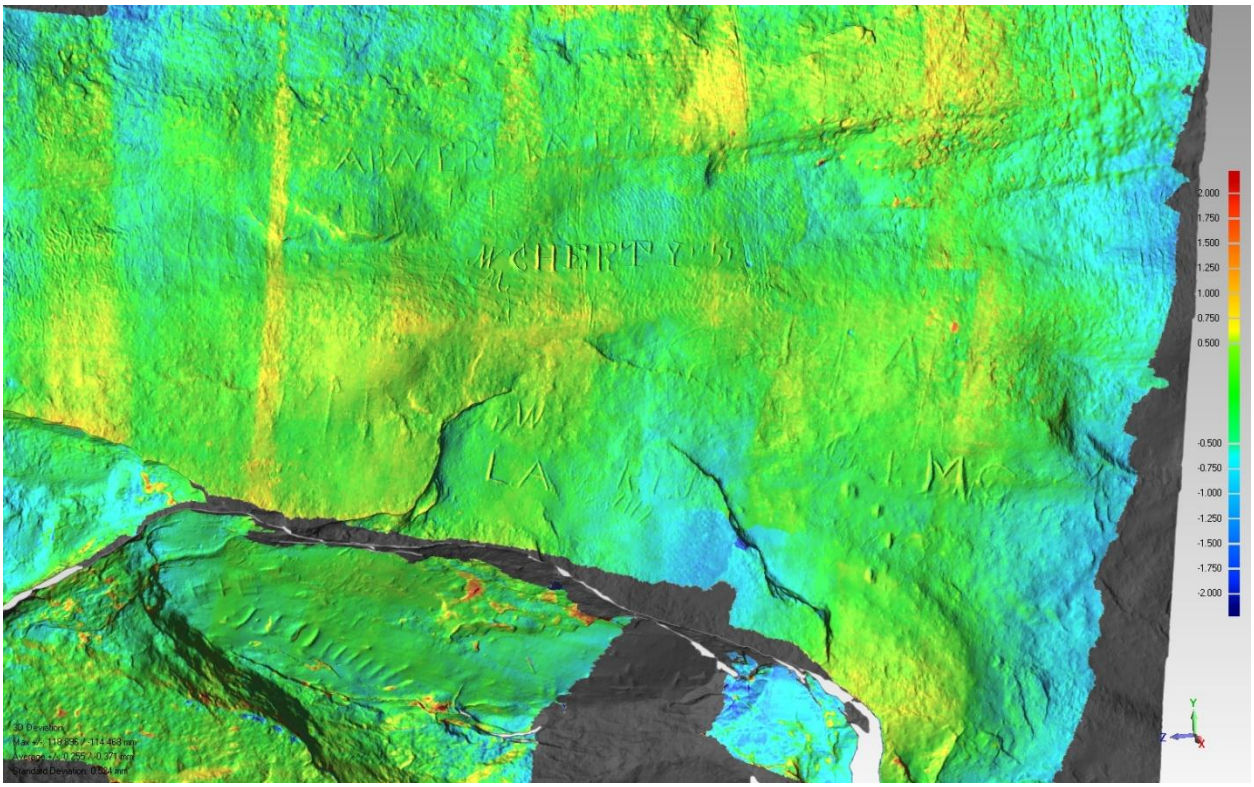
The 2007 scan, compared to the 2010 scan indicates that there has been very little change in the panel 6 surface during this time period (Figure 20). However, in the 2007 and 2010 scans, the Onaté inscription is barely visible, which calls the accuracy of both of these scans into question. If the 2007 – 2010 scan comparison is accurate, then the Onaté and Bishop of Durango inscriptions appear to remain stable.

All of the scan data for Panel 6 is located on Disk 2 in the Panel 6 subdirectory.

Panel 7 Scan Results

The scanning and analysis of Panel 7 appears to be problematic. This panel includes the "Cherty" inscription from 1859, as well as a separate panel of inscriptions that resides upon a rock outcrop angled roughly thirty degrees out from the plane of stone that contains the Cherty glyph. These two panels represent a topology with a number of folds and crevices that were not always recorded by the vivid scanner. Because each year's scan recorded different gaps in the scan worlds, the comparisons between

years reflect a high degree of both vertical banding and statistical noise. The standard deviation value for the 2006 to 2010 comparison was .5 mm, which is at least tolerable for comparison, but the deviation for



the 2007 to 2010 comparison was more than 4 mm, rendering the comparisons nearly meaningless. The two separate surfaces in panel 7 should have been scanned and analyzed separately if we were to expect significant results.

Figure 22 – Panel 7 Comparison of 2007 and 2010 scan worlds

If the 2006 and 2007 scans can be trusted (Figure 21 and 22), it would appear that there is a problem with clay wash deposition around the Cherty inscription. The apparent banding in these comparisons cannot be explained by the contrasting patterns of sunlight and shade that may have affected the scans on Panels 1 and 6. Both the 2007 and 2006 comparison indicate a new scratch just to the immediate left of the date on the Cherty panel that is due to vandalism.

All data for the Panel 7 is provided on disk 3, in the folder Panel 7.

Panel 8 Scan Results

On a statistical level, the scans of panel 8 (the northeast point of inscription rock) suffer the same problems with complex geometry as panel 7. There are at least 5 inscription panels that should have been analyzed separately to avoid the problems with differing gaps in scan coverage between the

individual scan worlds. The 2006 to 2010 comparison yielded a standard deviation of 2 mm, while the 2007 to 2010 analysis shows a standard deviation of more than 5 mm.

Despite the problem with statistical evaluation, the comparisons of scans from 2006 (Figure 23) and 2007 (Figure 24) indicate that Panel 8 is quickly disintegrating and in immediate need of some type of stabilization, or at a minimum, extremely high resolution digital scanning to preserve the inscriptions that are rapidly being destroyed.

When evaluating the comparisons of scan worlds from this area, one needs to ignore the areas in dark red along the margins of the scan world. These areas indicate gaps in scan data, rather than the +3 mm of deposition that the comparison's scale would indicate. With this factor in mind, it is clear that there is a mixture of process working to ablate the Northeast point of Inscription rock, as previously described by Burris in 2007. Both the 2006 and 2007 scans indicate areas of severe spalling, granular disintegration, and clay wash deposition that are actively working to obliterate the historic inscriptions on this portion of the sandstone surface.

All data for Panel 8 are provided on Disk 3, in folder Panel 8

Panel 9 Scan Result

Panel 9 originally consisted of two panels on the northern face of inscription rock, for this report, the easternmost of these panels, the Arrasain inscription of 1734, is now called Panel 9, and the western inscription by Elizacochea is now referred to as Panel 10. Both Panels 9 and 10 remained in shade during the scanning process for all three scanning years.

The scans of Panel 9 appear to indicate that this panel remains relatively stable and well preserved. The 2006 to 2010 comparison (Figure 25) shows a trace of banding that might be due to a slight layer of claywash, but is more likely to be statistical noise generated in the processing of the scan worlds. With a standard deviation of .125 mm, this may represent one of the more accurate scans collected.

The 2007 to 2010 comparison (Figure 26) shows areas of much more regular and blocky geometric patterns of "deposition" which is almost certainly due to processing errors. The standard deviation for this scan equaled .228 mm which might explain some measure of this error.

Source files and all other data for this panel are provided on disk 3 in the folder Panel 9.

Panel 10 Scan Results

Panel 10 shares the same general setting, context, and date as Panel 9, so it is not surprising that this area also appears to remain in a stable and well preserved state. This stability can be seen in Figure 27, where other than some possible light deposition on the far left side of the scan world, the panel does not display any significant changes between the 2006 and 2010 scans. Again following the pattern established on Panel 9, the 2007 to 2010 comparison (Figure 28) shows a much higher standard deviation

(.459 mm) and a consistent pattern of banding that appears too geometric to be anything other than statsistical noise. All Panel 10 data files reside on Disk 3 in the folder Panel 10.

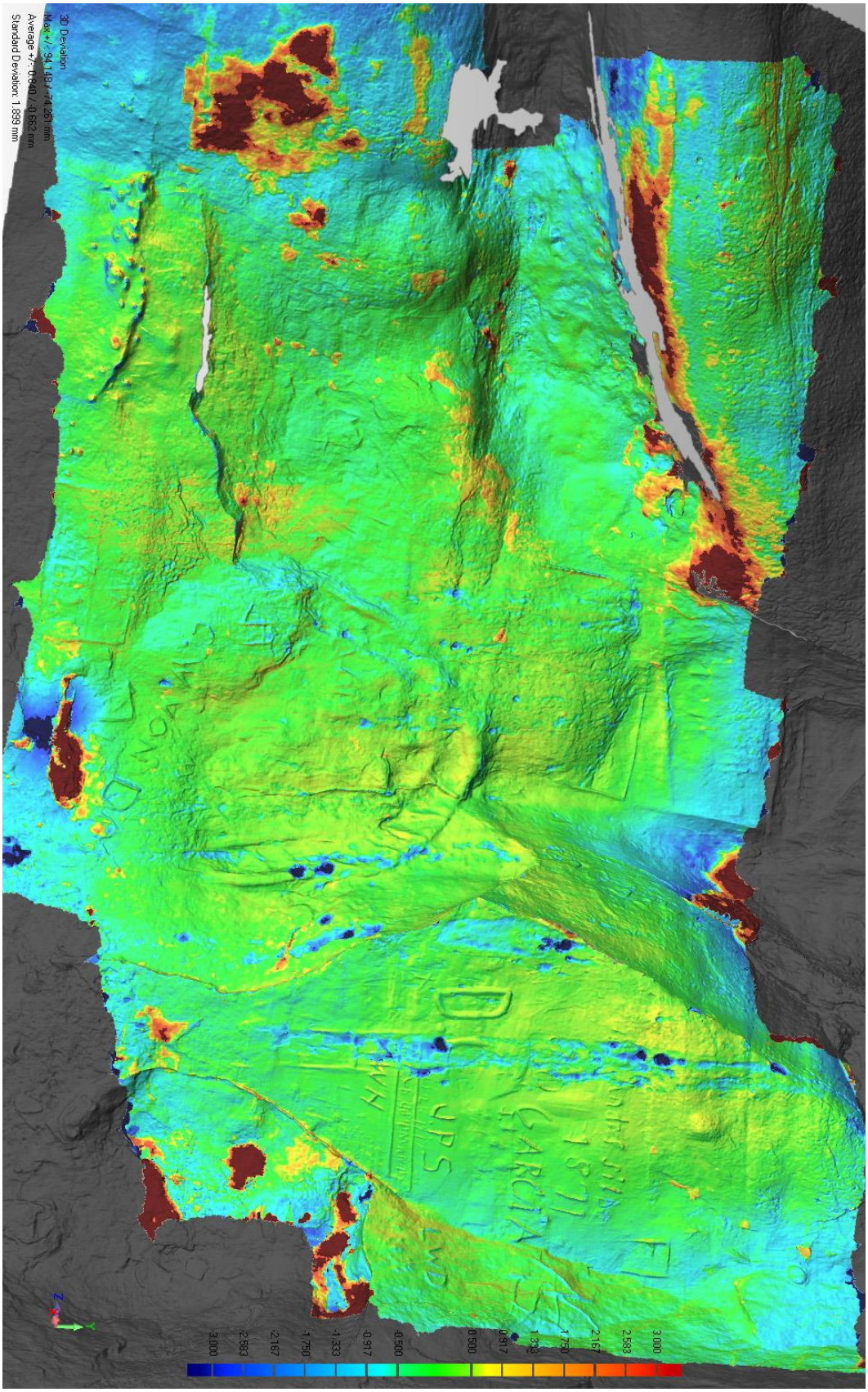


Figure 23 – Panel 8 (Northeast Point) comparison of 2006 and 2010 scan worlds

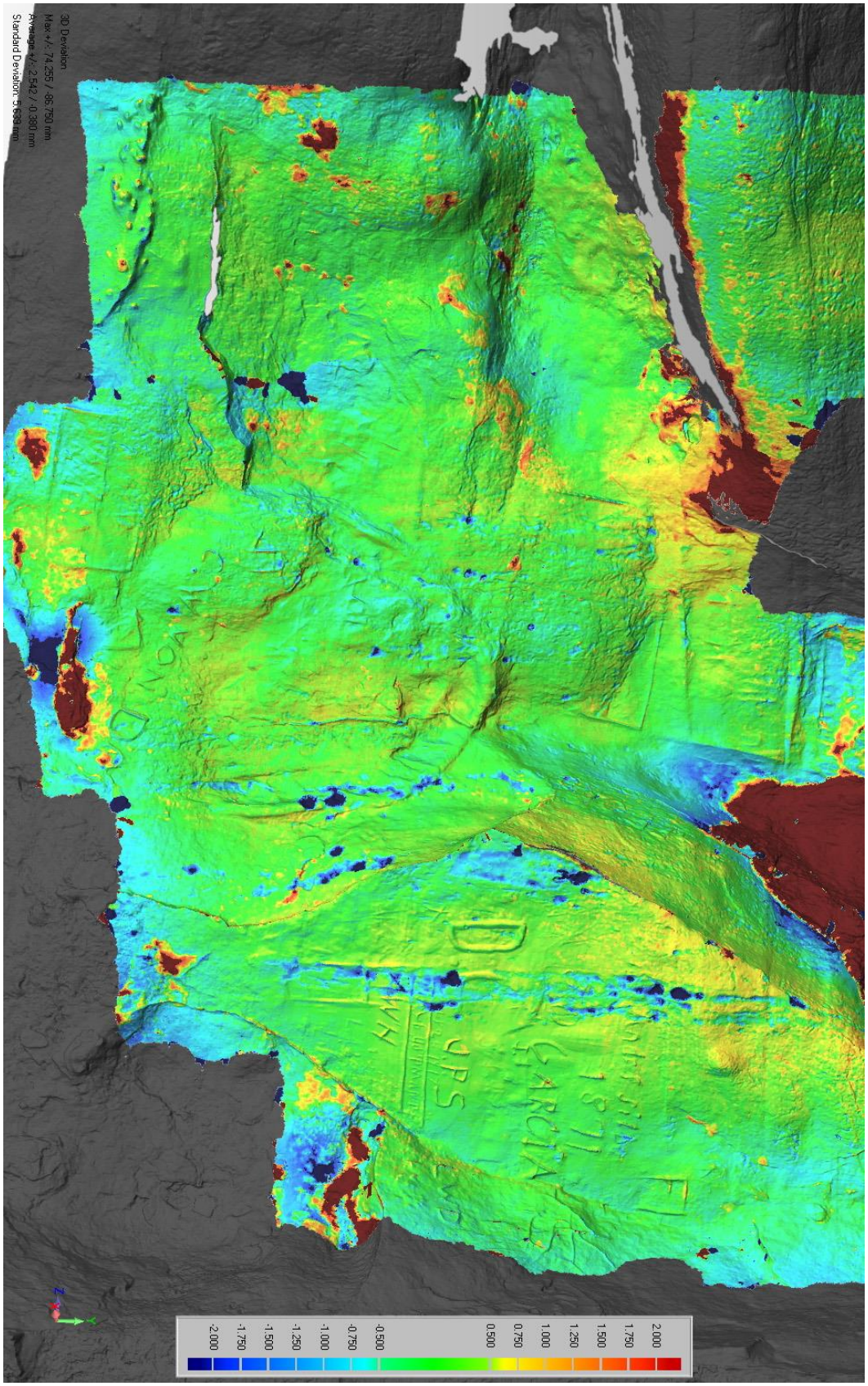


Figure 24 – Panel 8 (Northeast Point) comparison of 2007 and 2010 scan worlds

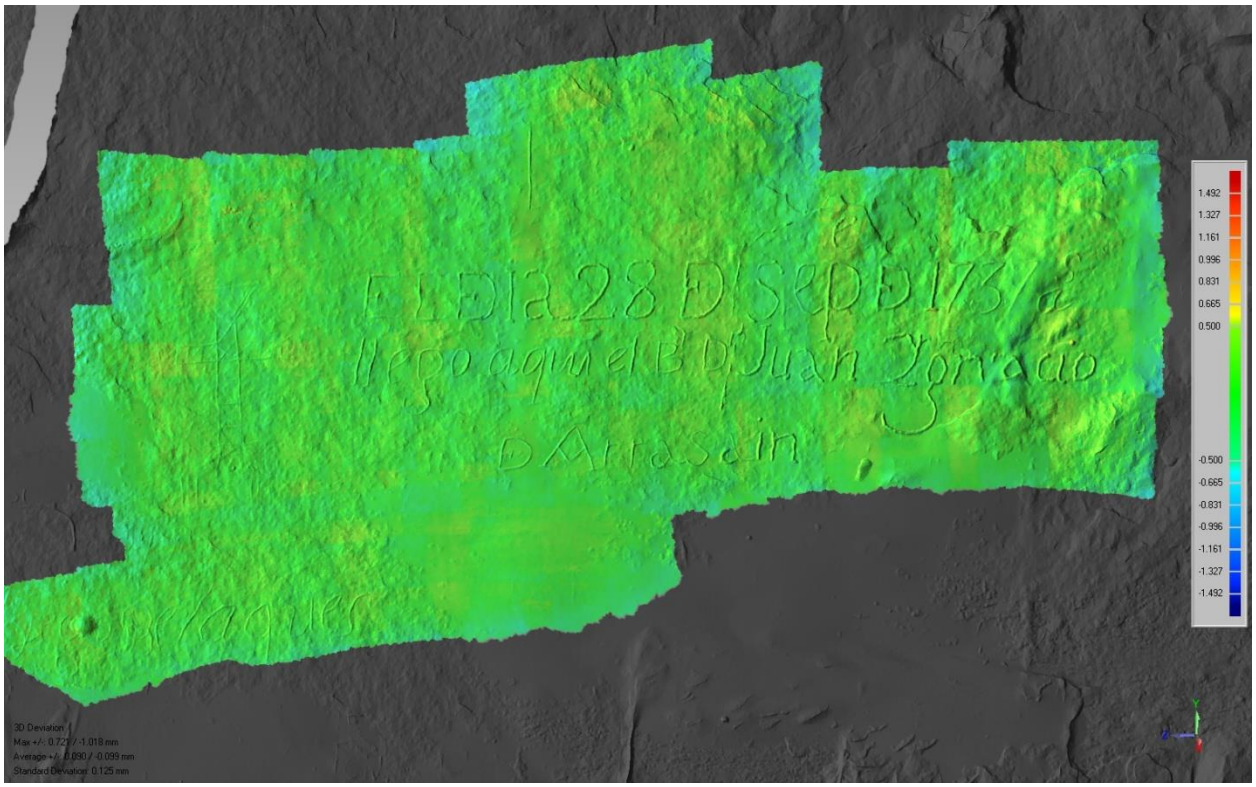


Figure 25 – Panel 9 Comparison of 2006 and 2010 scan worlds

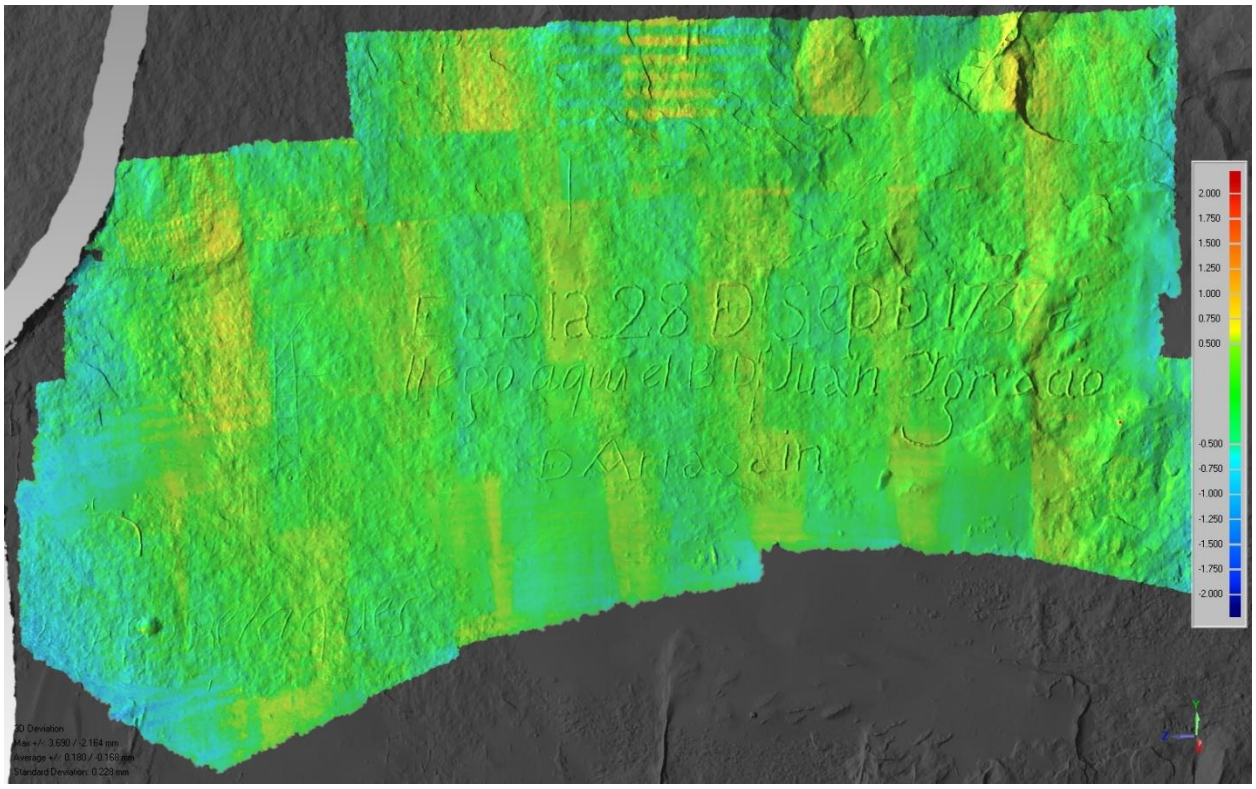


Figure 26 – Panel 9 Comparison of 2007 and 2010 scan worlds

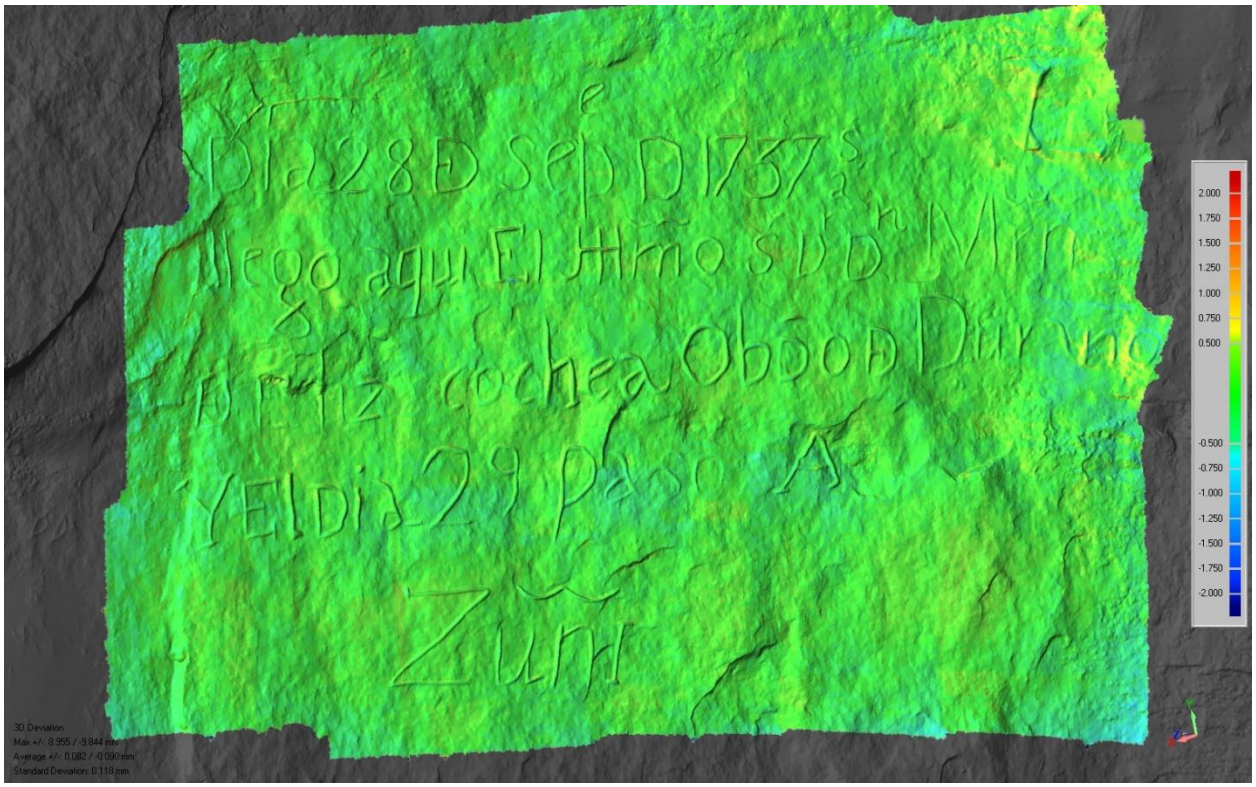


Figure 27 – Panel 10 Comparison of 2006 and 2007 scan worlds

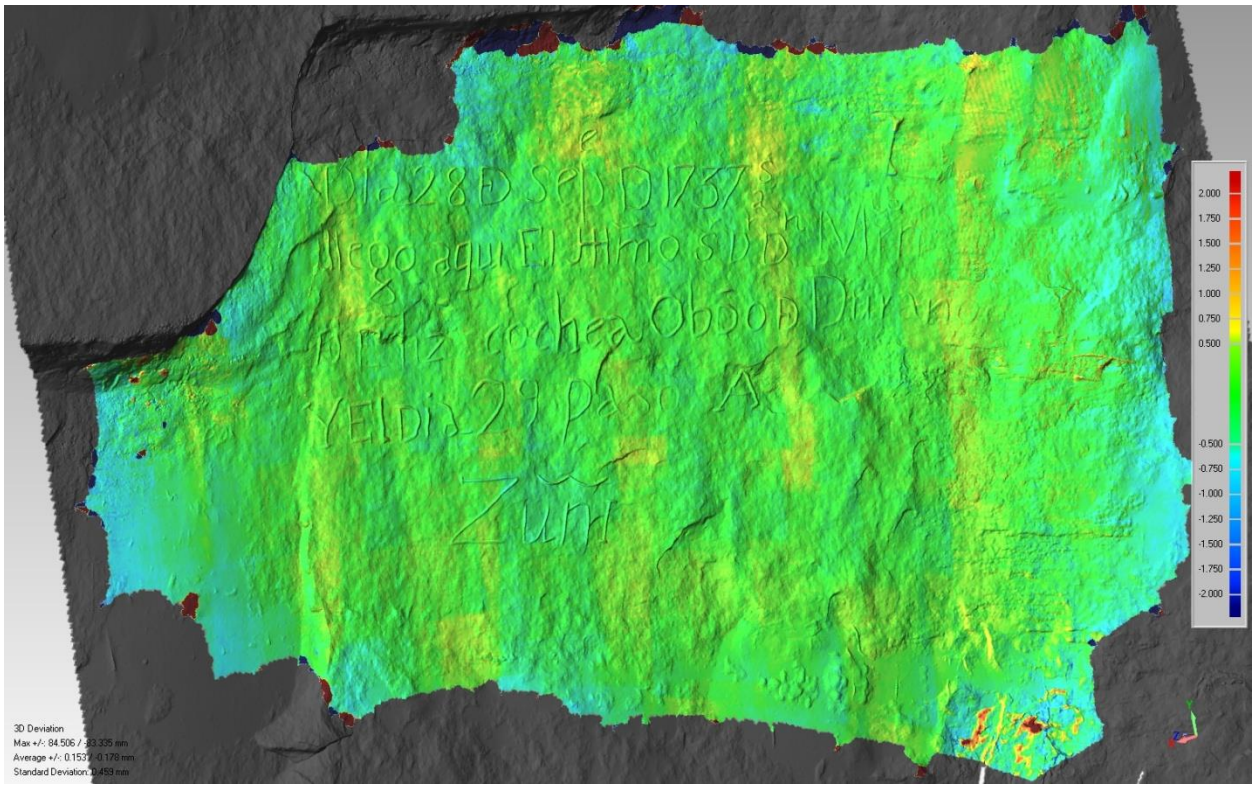


Figure 28 – Panel 10 Comparisons of 2007 and 2010 scan worlds

Summary and Evaluation

This project suffered from unrealistic expectations of the capabilities of the Minolta VIVID 910 3D Digitizer and the Polyworks Imagealign software. Panels 1,2, 6 and 8 were simply too large to utilize this combination of scanner and software to expect accurate results. Compounding this problem, the Vivid scanner simply was not designed to work in bright sunlight, and field conditions that included mixtures of shade and bright sunlight created scanning conditions that would not allow for accurate scans.

Looking at the scanning results in aggregate, there was a marked difference in the quality of the scans between years 2006 and 2007. In 2006 our scanner operator spent more time physically moving the scanner from position to position, ensuring that the scanner's infrared emitter remained relatively perpendicular to the surface of the stone being digitized. In 2007, faster scans were achieved by keeping the scanner's position relatively more unchanged, but tilting the scanner so that the stone surface could be digitized from a more oblique angle. In hindsight, this was a serious mistake. In almost every case, the 2007 scans showed more statistical noise than the 2006 scans, and this noise cannot be explained by any other environmental factors.

Despite these disappointments, the three years scans have provided a baseline set of data that will remain useful to El Morro National Park in the future, and with some careful thought, this data could easily be re-analyzed to generate more accurate and more meaningful results. One problem that plagued the analysis of these scans was the gaps created by missing data for each of the large area scans. If we were able to subsample the scans to only compare specific glyphs or specific letters within specific inscriptions we would not have to deal with the statistical errors generated by trying to align large sets of small scans into single scan worlds. We had hoped to take such an approach with the analysis of this data, but the comparisons between the scan worlds consumed the entire project's analysis budget.

To facilitate future research, all scan data created by this project and the appropriate metadata for this project will be deposited in the tDAR digital archaeological repository for future research.

Project Photography

For each year of the scanning project, detailed photographs for each of the individual panels was also collected. All project photography is included on disk number 4.

References Cited

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Oliver, Anne and Antoinette Padgette. "A History of Inscription Preservation at El Morro National Monument 1849-2005." draft. Historic Architecture Group, National Park Service, United States Department of the Interior, Intermountain Support Office, Santa Fe, New Mexico, October, 2005.

Snethledge, R. and E. Wendler. "Moisture Cycles and Sandstone Degradation." In Saving Our Architectural Heritage: The Conservation of Historic Stone Structures,Dahlem Workshop, Berlin, March 3-8, 1996. ed. N.S. Baer and R. Snethlage, 7- 24. Chichester: Wiley, 1997.

St. Clair, Larry L. and Katy B. Knight. "Impact of (Lichens) on the Condition of the Sandstone and Inscriptions at El Morro National Monument, Ramah, New Mexico." Brigham Young University, Provo, Utah, August 15, 2001.

Appendix I – UTM Coordinates for scanning microtargets

DAI Point ID	Least Squares Adjusted Coordinates[a]			Panel Number	Photo Control ID
	Easting	Northing	Elevation		
162	741633.036	3880614.802	2208.428	1	1
163	741632.904	3880614.942	2208.430	1	2
164	741632.765	3880615.112	2208.426	1	3
165	741632.588	3880615.360	2208.431	1	4
166	741632.308	3880615.661	2208.538	1	5
168	741632.102	3880615.880	2208.488	1	6
170	741631.923	3880616.012	2208.189	1	7
171	741632.032	3880615.873	2208.028	1	8
172	741632.286	3880615.668	2208.053	1	9
174	741632.615	3880615.416	2207.996	1	10
176	741633.007	3880614.955	2207.954	1	11
175	741632.811	3880615.197	2207.968	1	11
177	741633.082	3880614.776	2208.096	1	12
179	741633.059	3880614.780	2208.253	1	13
167	741632.135	3880615.852	2208.485	1	1a
173	741632.327	3880615.634	2208.070	1	2a
178	741633.076	3880614.777	2208.189	1	3a
107	741594.671	3880746.100	2212.365	2	1
108	741595.011	3880746.102	2212.363	2	2
109	741595.317	3880746.090	2212.376	2	3
110	741595.854	3880746.076	2212.349	2	4
111	741595.785	3880746.208	2211.371	2	5
113	741595.236	3880746.262	2211.346	2	6
114	741594.692	3880746.257	2211.421	2	7
115	741594.675	3880746.213	2211.789	2	8
112	741595.495	3880746.208	2211.382	2	1a
91	741655.940	3880776.323	2209.357	3	1
93	741656.410	3880776.855	2209.212	3	2
95	741656.136	3880776.539	2208.890	3	3
96	741655.962	3880776.297	2208.971	3	4
92	741656.201	3880776.614	2209.397	3	1a
94	741656.169	3880776.586	2208.801	3	2a
97	741655.934	3880776.290	2209.193	3	3a
85	741656.525	3880777.118	2209.055	4	1
87	741656.353	3880777.640	2209.052	4	2
88	741656.346	3880777.829	2208.850	4	3
86	741656.373	3880777.518	2209.048	4	1a
89	741656.429	3880777.703	2208.634	4	2a
90	741656.526	3880777.299	2208.724	4	3a
77	741654.645	3880783.313	2209.019	5	1

78	741654.877	3880783.643	2209.071	5	2
80	741655.142	3880783.954	2209.058	5	3
81	741655.344	3880784.123	2208.755	5	4
82	741654.850	3880783.620	2208.692	5	5
83	741654.615	3880783.341	2208.733	5	6
79	741654.900	3880783.674	2209.083	5	1a
84	741654.584	3880783.330	2208.692	5	2a
59	741691.929	3880797.966	2206.220	6	1
60	741692.204	3880798.142	2206.277	6	2
61	741692.524	3880798.340	2206.252	6	3
62	741692.813	3880798.516	2206.191	6	4
64	741692.880	3880798.576	2205.797	6	5
65	741692.818	3880798.654	2205.450	6	6
66	741692.688	3880798.658	2205.123	6	7
68	741692.718	3880798.611	2204.722	6	8
69	741692.613	3880798.486	2204.418	6	9
70	741692.456	3880798.357	2204.485	6	10
71	741692.167	3880798.133	2204.499	6	11
73	741691.572	3880797.662	2205.162	6	14
74	741691.767	3880797.851	2205.987	6	15
63	741692.884	3880798.570	2205.886	6	1a
67	741692.749	3880798.656	2204.786	6	2a
72	741691.531	3880797.621	2205.093	6	3a
44	741731.889	3880803.316	2201.290	7	1
45	741732.197	3880803.378	2201.419	7	2
47	741732.604	3880803.418	2201.439	7	3
48	741732.856	3880803.332	2201.190	7	4
49	741733.028	3880803.291	2201.062	7	5
50	741732.996	3880803.104	2200.823	7	6
52	741732.750	3880802.896	2200.675	7	7
53	741732.424	3880802.796	2200.686	7	8
54	741732.020	3880802.850	2200.705	7	9
55	741731.841	3880802.966	2200.810	7	10
56	741731.867	3880803.270	2201.084	7	11
46	741732.571	3880803.411	2201.416	7	1a
51	741732.949	3880803.025	2200.676	7	2a
33	741762.857	3880816.484	2198.463	8	1
35	741762.340	3880817.067	2198.317	8	2
37	741762.001	3880817.181	2197.750	8	4
39	741762.752	3880816.752	2197.410	8	5
40	741762.920	3880816.520	2197.665	8	6
41	741762.949	3880816.552	2197.977	8	7
34	741762.598	3880816.801	2198.177	8	1a
36	741761.860	3880817.188	2198.236	8	2a
38	741762.519	3880816.954	2197.418	8	3a
13	741700.911	3880827.985	2210.717	9a	1

14	741700.378	3880827.899	2211.053	9a	2
16	741699.548	3880827.822	2210.855	9a	3
17	741699.576	3880827.850	2210.383	9a	4
19	741700.206	3880827.917	2210.252	9a	5
21	741700.933	3880828.008	2210.088	9a	6
15	741700.213	3880827.886	2211.047	9a	1a
18	741699.700	3880827.861	2210.342	9a	2a
20	741700.540	3880827.955	2210.273	9a	3a
24	741697.615	3880827.566	2211.484	9b	1
26	741696.673	3880827.220	2211.524	9b	2
27	741696.767	3880827.278	2211.100	9b	3
29	741697.608	3880827.593	2211.067	9b	4
25	741696.720	3880827.219	2211.649	9b	1a
28	741697.069	3880827.407	2210.890	9b	2a
30	741697.600	3880827.566	2211.408	9b	3a

[a]All coordinates are UTM Z12 grid values (GAF=1.000), NAD83(CORS96:2002), NAVD88(03), metric