PORTABLE ANALYSIS OF ANCIENT WALLS IN POMPEII, ITALY

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Abstract

The ruins of Pompeii, Italy, having been well preserved, allow a unique opportunity to study architectural styles, techniques, and materials on a large scale. The structures in this ancient city consist of volcanic stones set in mortar, a lime-based cement mixed with volcanic aggregate. Visual analysis is often useful for identifying different types of mortar that represent individual construction phases within a single structure. However, visual analysis alone may not be adequate for distinguishing mortar types that are similar in color or composition. In these cases, sample collection and geochemical analysis are often required to confidently identify mortar types and to confirm archaeological interpretations of the construction history of a given structure. Unfortunately, traditional analysis techniques are inherently destructive, and the collection of mortar samples, no matter how small, causes irreparable damage to the walls under study. A field-based, non-destructive protocol for the analysis of historic structures would improve archaeological interpretations without causing damage to fragile structures like those in Pompeii.

To this end, a project was undertaken during the summer of 2008 using the FieldSpec3 spectroradiometer to conduct near-infrared reflectance spectroscopy of different mortar types in the House of the Vestals, an ancient elite house in Pompeii. The long wavelength range of the equipment's detectors, specifically ~2000nm-2300nm, was definitely useful for analyzing the lime component ($CaCO_3$) of different mortars that varied in color. Results showed that the FieldSpec3 was able to clearly distinguish individual types of mortar, confirming the construction history of the House of the Vestals as determined by visual analysis. The FieldSpec®3 allowed for rapid analysis of a larger sample set than would have been possible with traditional laboratory-based techniques. This technology may be utilized effectively in the future within structures built with several types of mortar that may not be so easily distinguished with visual analysis alone.

Introduction

The ancient city of Pompeii was located in Italy's Campania region, a volcanic plain near the Bay of Naples on the Mediterranean Sea (Figure 1). The history of Pompeii and Campania can be summarized as conquest and settlement by a succession of different cultural groups, until eventual Roman colonization in 80BCE. The city was famously buried and preserved for centuries by fallen ash and lapilli that erupted from Mount Somma-Vesuvius in 79CE. Although the ruins were discovered in the 1590s, Pompeii remained buried until excavations began in 1748 (Ling 2005). Today, much of the ancient city stands in relatively good condition, which presents a unique opportunity for archaeologists to study ancient building technologies and techniques on a large, city-wide scale. Architectural studies at ancient sites are typically focused on the identification of the materials used in wall construction and decoration, as well as the sequence of wall construction events throughout a structure's history. Popular building techniques and preferences toward specific materials evolved with the city as Pompeii flourished, so structures are typically assessed to understand where they fit within the basic construction style time-line as it is currently understood (Mau 1899; Richardson 1988).

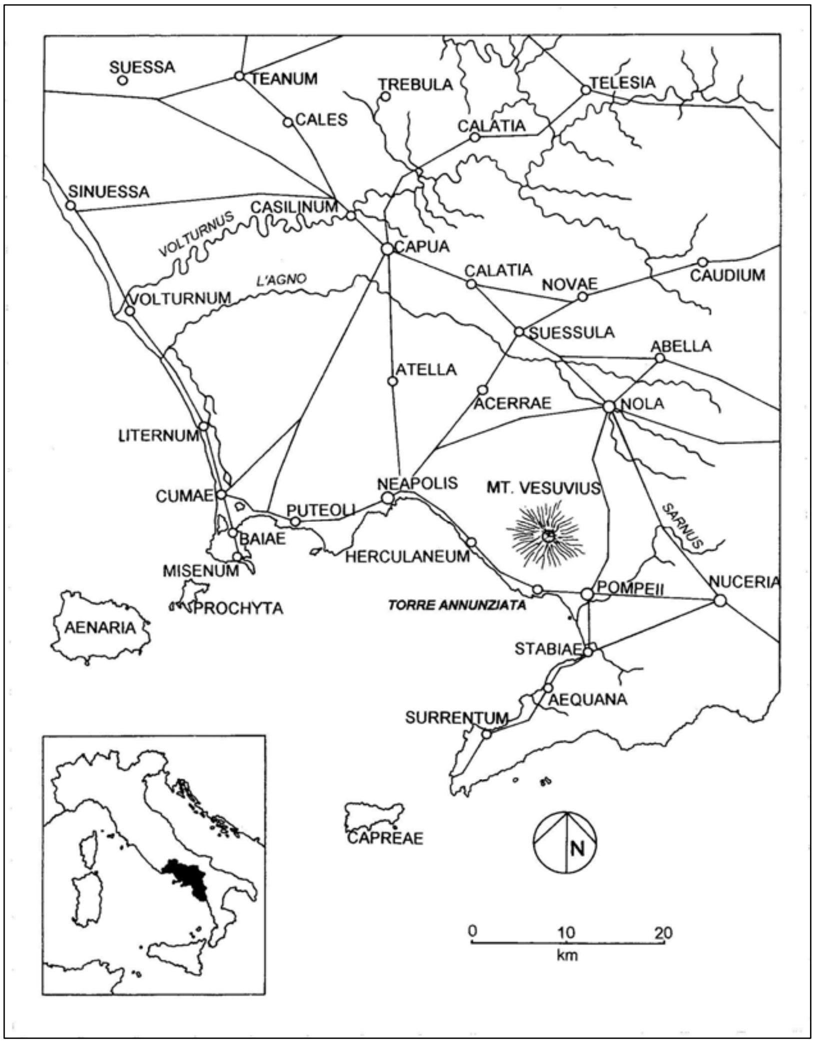

Figure 1: Map of Campania, Italy. Source: Descoeudres et al (1994)

The walls of Pompeii have been built of stone set in mortar, a type of cement composed of a lime-based binder and silicate aggregate materials. To produce a lime-based mortar, a calcium carbonate ($CaCO_3$) material (e.g. limestone, dolostone) is burned in a kiln where it is converted to calcium oxide (CaO) and then mixed with water and an alumino-silicate aggregate (Leslie and Hughes 2002; Orchard 1973). As the mortar sets within the structure, it takes on carbon dioxide (CO_2), reforming $CaCO_3$ within the mortar. Compositional analysis can identify the materials used in mortar production, while binder:aggregate ratios and grain size distribution can reveal the ancient "recipe" of the mortar mixture (Casadio *et al* 2005). The most common techniques for these types of analyses (i.e. X-ray diffraction analysis, X-ray fluorescence spectroscopy, and thin section petrography) consume the sample during preparation, often including mechanical separation of the binder from the aggregate (Genestar *et al* 2006; Elsen 2006). This is problematic when individual samples are small and multiple analytical techniques are desired. Even the sample collection process damages the wall itself. At a fragile monument such as Pompeii, researchers must mitigate potential damage to the site (and the artifacts) before sample selection and collection can begin. This is especially true for the study of standing structures and mortar, where the material under study is actually holding the artifact together, and deteriorating conditions can result in safety hazards.

The use of portable equipment could be ideal for non-destructive data collection where traditional consumable sampling techniques are impractical or impossible. Large data sets could be collected in the field, allowing for a more complete sampling of mortar types to account for the greatest amount of variance within a study site. Near-infrared spectroscopy (NIR) is potentially a viable tool to distinguish mortar types, because it can resolve the $CaCO_3$ in the binder, the component of mortar that forms *in situ* after each construction event (Gaffey 1986). Portable versions of NIR spectroscopic equipment have been used in the earth sciences in recent years for chemical and mineralogical analysis of geological materials, and these techniques are emerging as useful tools in archaeology for non-destructive analysis (Wisseman *et al* 2004). This study is designed to demonstrate how well the FieldSpec®3 spectroradiometer performs in a field setting to identify different types of mortar in ancient structures.

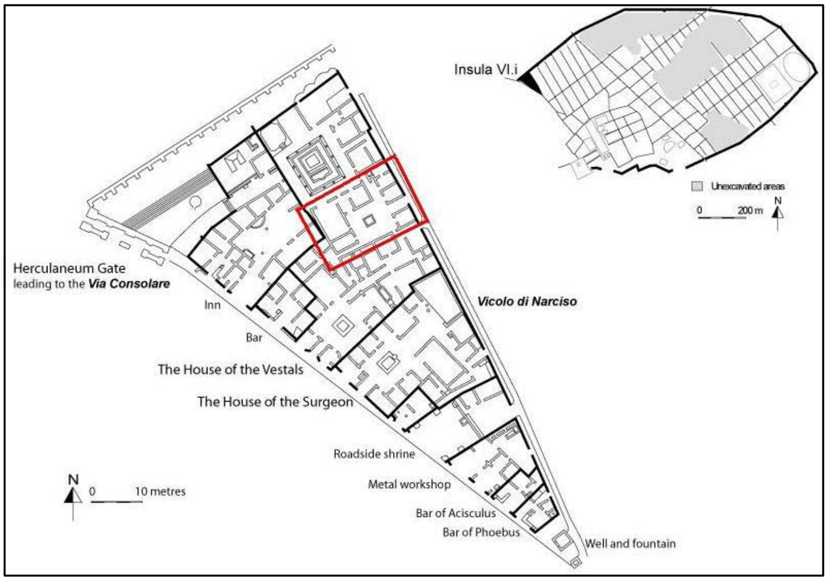

Figure 2: Regio VI. Insula 1 and the House of the Vestals.
After: Jones and Robinson (2004).

The site chosen for study is part of the House of the Vestals, an elite house in the northwest region of Pompeii (Figure 2). Initial architectural study of the early phases of the House of the Vestals has shown that by its final phase, the house had been coalesced from several more modest structures, including properties VI.1.24 and VI.1.25 (Jones and Robinson 2004). The nomenclature represents properties in Regio VI, *insula* 1, and doorways 24 and 25.

These original structures were built with pink-hued mortar containing reddish scoria aggregate (Jones and Robinson 2004). Property VI.1.25 (outlined in red, Figure 2) retained its basic original layout throughout its history, but underwent a number of reconfigurations of the interior walls, including ancient, historic, and modern reconstructions. These reconstruction events have been identified primarily by visible differences in mortar color, including grey, yellow, and brown varieties that clearly contrast with the original pinkish mortar. They also vary in texture, friability, and aggregate inclusion types. Although it was adequate in the House of the Vestals, visual analysis alone may not be adequate for distinguishing mortar types that are similar in color or composition. The obvious differences in mortar types within the property VI.1.25 in the House of the Vestals are ideal for this study, which aims to test how well the binder component of these mortars are distinguished by the FieldSpec®3.

Methods

NIR analysis of the walls of property VI.1.25 was conducted *in situ* with a FieldSpec®3 portable spectroradiometer, manufactured by Analytical Spectral Devices, Inc (ASD). Each target reading was preceded by a reference reading on the Spectralon® reflectance panel (Target #12137-A), a thermoplastic resin that is 96-99% reflective in the 250-2500nm wavelength range (http://www.labsphere.com). Both the hand-held and tripod-mounted configuration of the fiber optic detector were tested on site (Figure 3). In all cases, the fiber optic cable was inserted into the pistol grip and the 5° foreoptic attached. The tripod was placed with the foreoptic 11cm from the wall, creating a desired spot size of approximately 1cm. The nature of the mortar initially suggested that a spot size of approximately 1cm would be adequate to analyze a spot of binder, while avoiding large crystals or rock fragments present as aggregate. When the tripod configuration was unworkable, the pistol grip was held approximately 11cm from the target location. The hand-held configuration at this distance was difficult, because the target location and specific distance from the wall were difficult to maintain. Also, peak shape and the intensity of the signal never stabilized completely, though usually after 3 screen refreshes, the disparities were minimal. In the final test, the pistol grip was held so that the end of the foreoptic was placed ~3cm from the mortar surface, creating a spot size approximately 26mm in diameter. Beginning on the second day of field analysis, this configuration was used exclusively.

Figure 3: Data collection with the FieldSpec® 3. a. Hand-held configuration; b. Tripod mount configuration. Photos by Philip Murgatroyd

The field data-set included six different types of mortar from 18 different walls within property VI.1.25 and one wall in the abutting property, the House of the Surgeon. At every sample location, five spectra were generated, each preceded by the reference panel reading, for a total of 10 files per sample location. The data were recorded by the RS^3 software as “asd” spectral files, which were later converted to text files with ViewSpec Pro software. To complement the *in situ* mortar samples, twenty-four hand samples of mortar samples and one sample of unprocessed lime (collected in 2007 for traditional laboratory analysis) were analyzed with the FieldSpec®3 in Athens, Georgia, in August 2008 using solar illumination during the two hours before and after noon Eastern Daylight Time (UTC-5). The fiber optic cable was again equipped with the 5° foreoptic and mounted onto the pistol grip in the hand-held configuration. Samples were held ~3cm from the end of the foreoptic, matching as closely as possible the spot-size used in the field. A collection of carbonate reference materials, including samples of calcite, gypsum, limestone, dolostone, and marble from the University of Georgia teaching collection, was analyzed in the UGA lab with the FieldSpec® 3 in September 2008. In this case, the ProLamp supplied by Analytical Spectral Devices, Inc. was used as the infrared light source.

Absolute reflectance at each wavelength was later calculated as a ratio of raw data to reference panel data using the ASD Raw Reflectance Data Template, Version 2.1 (2008), a spreadsheet created by Chris MacLellan of the NERC Field Spectroscopy Facility. Water produced large absorption bands in two regions, 1350-1460nm and 1790-1960nm; because these bands caused peaks large enough to obscure other peaks in the graph, they were removed from the data-set. These bands may have included absorption data from materials in the mortar, but these most likely would have been obscured by the dominant water peaks and therefore unresolvable. The resulting spectra needed to be further reduced to remove edge-effects - large anomalies produced by detector inefficiencies at the longest wavelengths (2450-2500nm). Data were truncated at 2450nm for display and statistical analysis. Replicate data from each analysis location were plotted together for graphical comparison (Figure 4). These were later averaged together to provide a single spectrum for each sample location. Representative spectra of each mortar type were created by averaging together individual locational spectra. Averaged spectra from walls, hand samples of mortar, and rock and mineral reference samples were compared for similarities in general spectral patterns and peak location and shape.

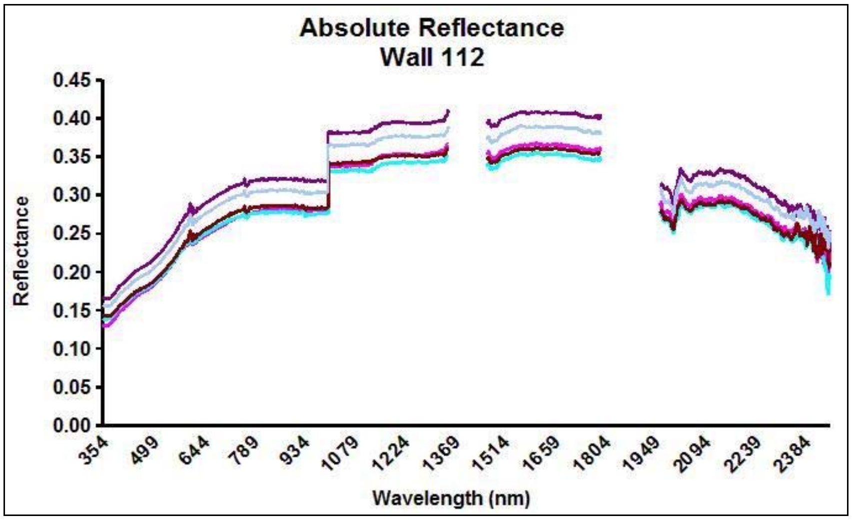

Figure 4: Processed spectra at a single location.

Results

The averaged pattern for pink mortar produced near-infrared spectra that in key wavelengths resembled concrete spectra published by the Jet Propulsion Laboratory. All three spectra have a broad peak at 2000-2250nm (Figure 5). The same basic pattern is present in the mortar tested *in situ*, which all show similar broad peaks in the same band. However, the shape and reflectance values varied in each mortar type (Figure 6). Spectra from collected hand samples were compared to field collected spectra to test whether the samples "matched" the spectra from their original location on the walls. Looking again at the peaks in the 2000-2250nm band, there was not a consistent similarity between the mortar samples and their parent walls. Eight of the 18 walls sampled produced spectra that were well matched to their collected mortar samples in peak shape, breadth, or placement (Figure 7), though the rest varied dramatically (Figure 8).

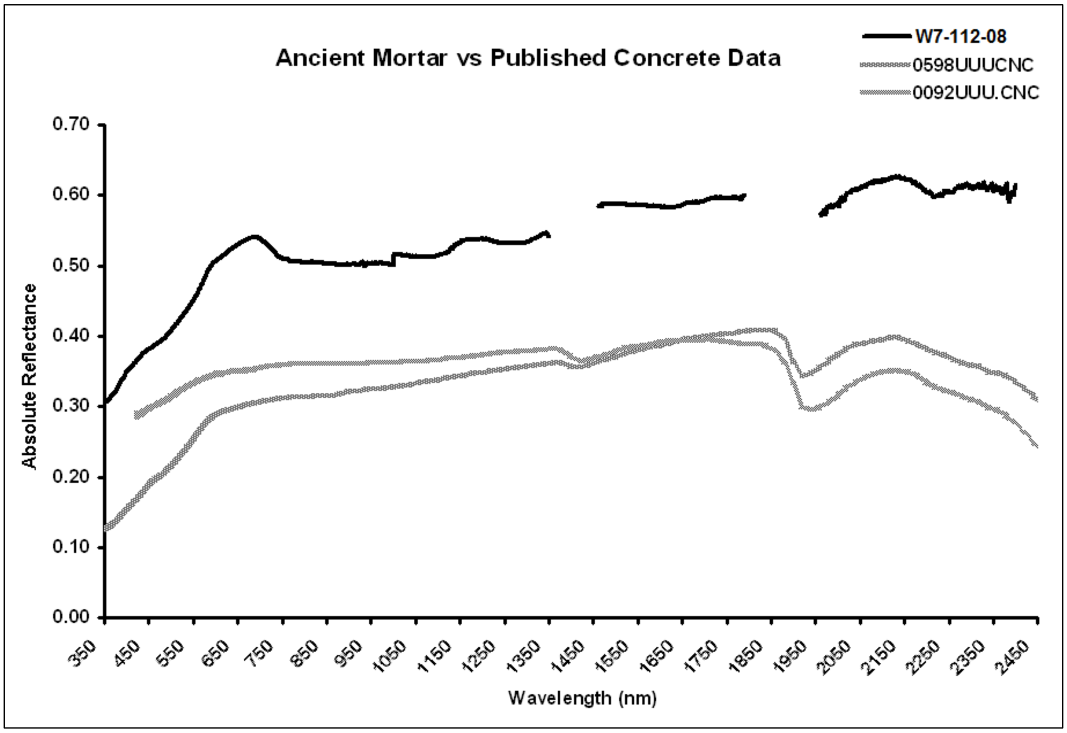

Figure 5: NIR spectra of ancient mortar and modern concrete (published by JPL)

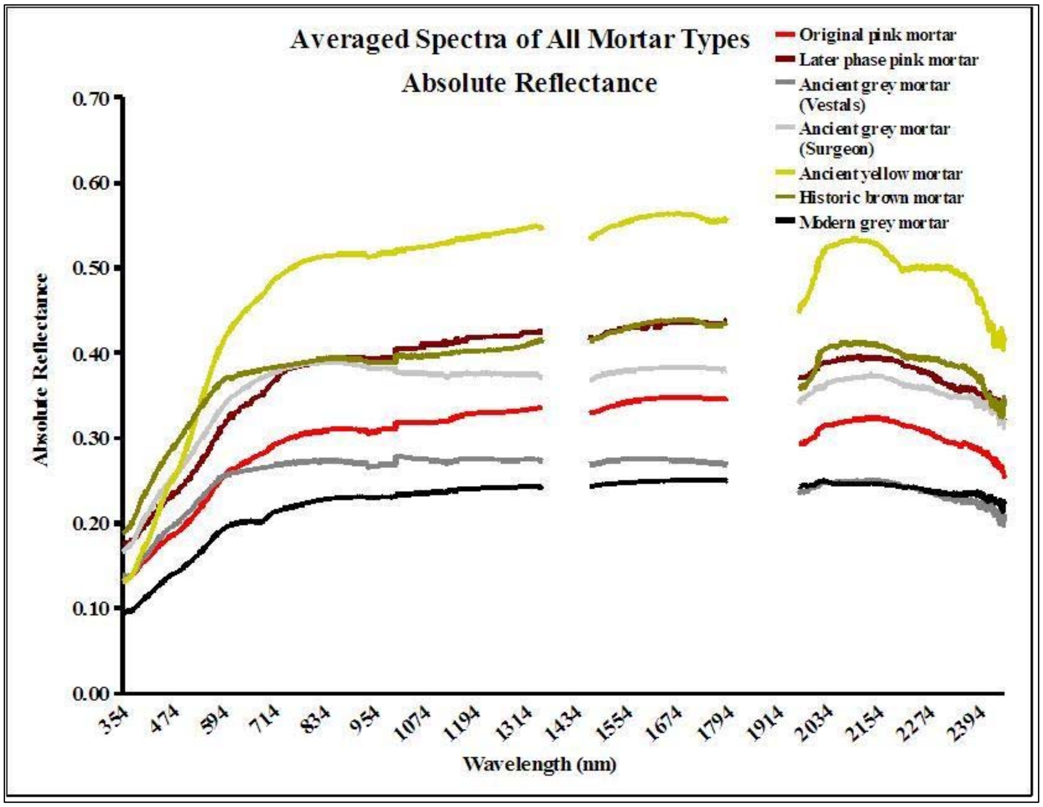

Figure 6: Averaged spectral data of six different types of ancient mortar

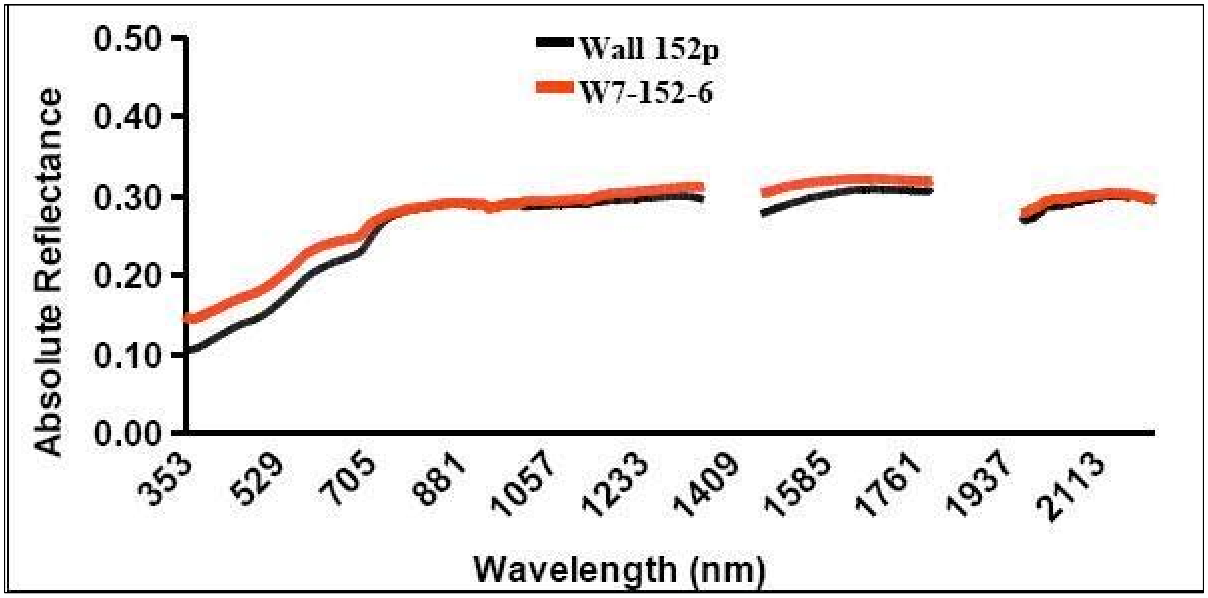

Figure 7: Well-matched spectral data of a pink mortar hand sample (W7-152-6) and in situ mortar from its parent wall (Wall 152p)

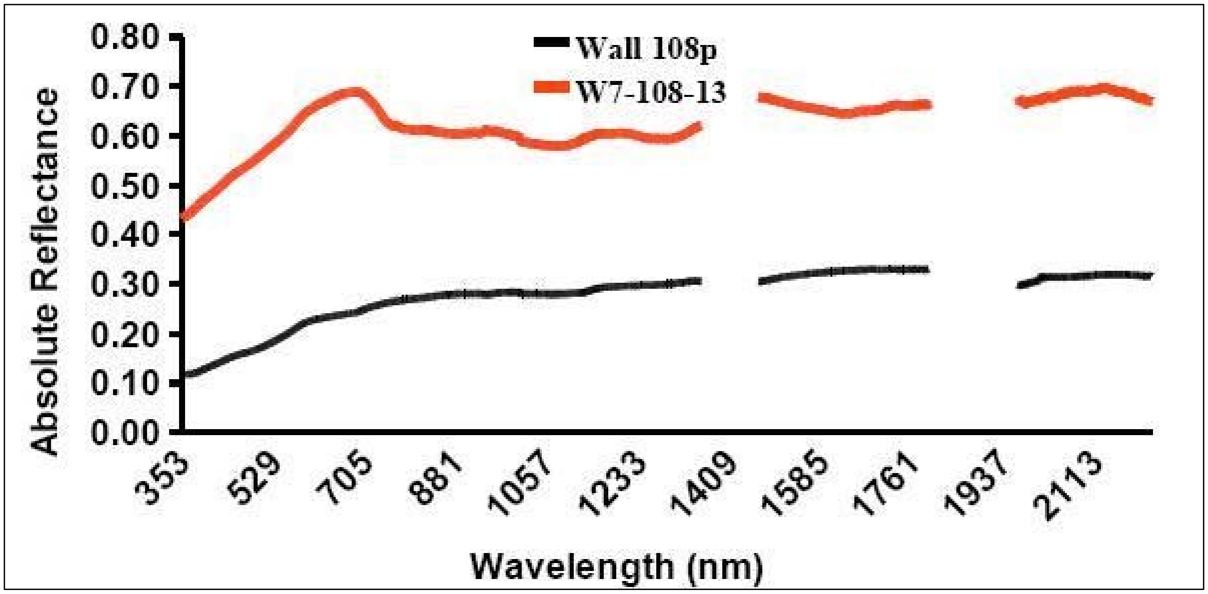

Figure 8: Poorly-matched spectral data of a pink mortar hand sample (W7-108-13) and in situ mortar from its parent wall (Wall 108p)

The reference samples of calcite, marble, and dolostone showed peaks in the bands from 2000-2160nm and 2160-2200nm, an absorption trough at 2330nm, and another peak near 2400nm, though the dolostone was less intense than the others (Figure 9). The large sample of lime from the House of the Vestals exhibited the same basic spectral pattern, although the individual peaks were broader and more difficult to resolve. The intensity and basic shape of the spectrum of the pink mortar sample resembled the data from the reference sample of limestone (Figure 9). Both the mortar and limestone spectra contained low, broad peaks and minimal troughs in roughly the same locations as the calcite and lime spectra, but the intensity of the absolute reflectance levels were significantly lower (Figure 9).

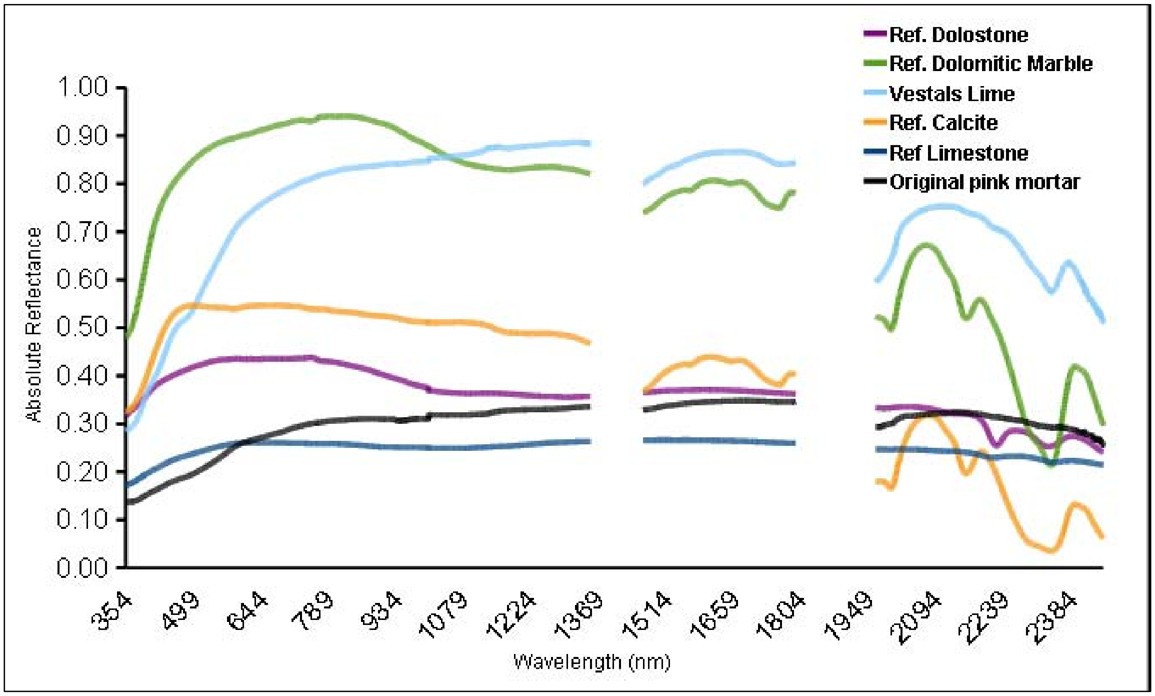

Figure 9: Averaged spectral data of pink mortar compared to averaged spectral data of reference samples

Discussion

Spectral data produced by the FieldSpec®3 fell within expected limits and varied to an expected degree. Infrared activity in the 2000-2350nm band is typically associated with carbonate minerals, indicating that the equipment did indeed resolve the carbonate component within the mortar (Gaffey 1986). As seen in Figure 6, the averaged spectra of different mortar types were quite varied, suggesting that the variation in mortar composition was well-resolved with the FieldSpec®3. The fact that the pink mortar spectra resembled that of limestone more than other carbonate materials suggested the lime may have been produced from an original limestone source. Although further analysis would be necessary to test this interpretation, this is an example of how the FieldSpec®3 could be used to inform the archaeological interpretation of ancient structures.

Data collection with the FieldSpec® 3 was rapid, required no sample preparation, and completely non-destructive. A few difficulties arose during field analysis, however, most of which involved equipment limitations or logistical struggles, and were easily overcome. The equipment performed differently in the tripod and hand-held configurations. The tripod configuration allowed the spectra to stabilize quickly and multiple spectra were repeated in the same location with high precision. This allowed for more consistent results, because the fiber optics were focused on a single target spot without being moved between readings. However, this configuration was problematic because more often than not, the target location was too low for the tripod. While not ideal, the most feasible set-up was the hand-held configuration at ~3cm from the wall. The smaller spot-size allowed for more refined sample selection, and the proximity to the wall allowed for more control over the target location and stability of the pistol grip. The hand-held configuration required the detector to be moved between the reference panel and the target on the wall during data collection. While all efforts of control were made, it was not possible to precisely sample the same spot every time. As seen in Figure 10, the data collected in the hand-held configuration were clearly more variable than those collected while using the tripod, though, this may have actually better represented the extent of variation on and around the target location.

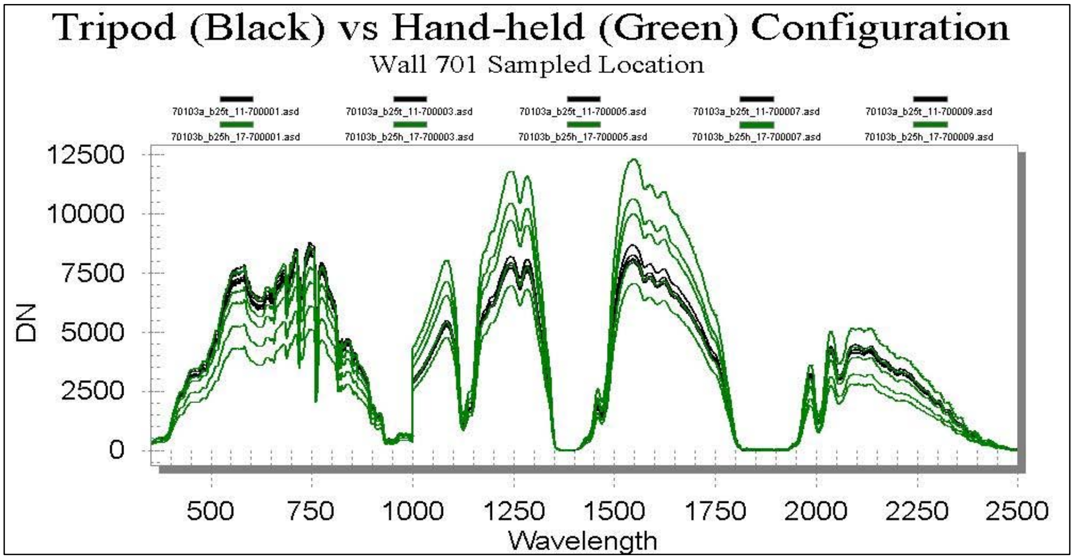

Figure 10: Raw spectra, collected in hand-held and tripod mounted configurations

The most important and sensitive aspect of the FieldSpec®3 was the infrared energy source, specifically, solar illumination. Most days were sunny, but cloud cover and hazy conditions clearly affected both reference and sample readings. As seen in Figure 11, intensity of peaks in the raw spectrum from the reference panel was recorded at just over 12500DN under partial cloud cover, compared to 45000DN in full sun. Similarly, analysis of any individual wall was limited to the time of day when it was in full sun. The East facing walls in VI.1.25 were analyzed before noon Central European Summer Time (UTC+2), when they were fully illuminated, and the West facing walls were analyzed after 1:30 pm. The south facing walls were well illuminated for most of the day, but because of the configuration of the structure, the north facing walls were never illuminated well enough for analysis. Even when a wall was fully illuminated, small shadows could form where wall stones slightly overhang the mortar. This problem was solved by only choosing sample locations uninhibited by overhang shadows.

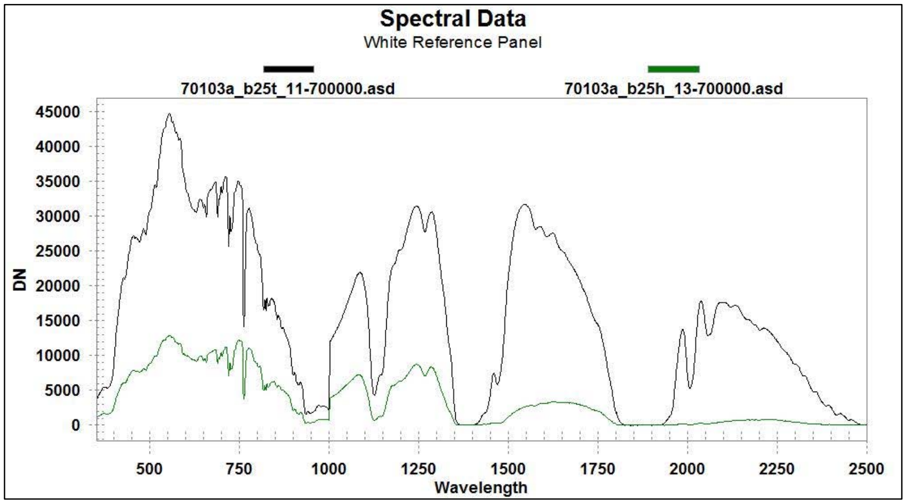

Figure 11: Comparison of raw spectra in full sun (black) and in shade (green)

Conclusion

Preliminary analysis of the NIR spectra and comparison to published data illustrated that the FieldSpec®3 adequately recognized the calcium carbonate in the mortar under study here. Further, the data demonstrated differences in the spectral patterns of mortars with known qualitative differences. This technology could be useful for distinguishing different types of mortar by examining the spectral peaks at 2000-2400nm. This would be most beneficial as a qualitative study to identify the number of different mortars throughout a structure where such distinctions cannot be easily made with visual analysis alone. During the planning phase of such projects, care must be taken that sample locations are chosen not only for their potential for generating useful data, but that they fit within the requirements and limitations of the equipment. Within these parameters, the FieldSpec®3 could serve as a valuable tool for non-destructive analysis of the mortar within ancient structures.

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