PETROGRAPHIC AND IMAGE ANALYSIS OF PLASTER FROM HONEY BEE VILLAGE

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Excellent preservation of the walls and floors in some of the large true pithouses at Honey Bee Village, AZ BB:9:88 (ASM), led to close examination of the prepared surfaces and inquiries about their composition and application. A principal question was if the gray-colored surface on the walls, floors, and hearths was a separately applied plaster. This gray layer overlaid the brown clay comprising the rest of these features, and, in the case of the walls, appeared to have been smoothed with tools and by bare hands, based on impressions visible in the surfaces. An additional question was if caliche was added to this layer to form a lime-plaster and if the surface had been "floated" with water to smooth it after application. Were there differences in the composition or application of surfaces on the walls, floors, and hearths?

A trial study was designed to evaluate these issues. Seven samples were taken from a wall and the floor and hearth of one of the best-preserved large true pithouses, Feature 4015, dated to near the end of the Late Rincon phase (A.D. 1100-1150). Petrographic analysis was conducted to characterize the clay, silt, and sand components and to assess the amount of carbonate. Micromorphological differences were fully described to reveal any dissimilarity in the materials used for the surfaces from the various locations. Differences between the bulk composition of the material and the top layer were highlighted. This work was greatly assisted by image analysis that allowed the porosity, heterogeneity, compaction, and grain orientation and roundness to be more clearly specified. The results suggest some differences in the materials used for various locations and purposes in the house. The lack of added carbonate matter indicates none of the material can be considered a true lime plaster.

SAMPLES AND METHODOLOGY

Three samples were taken from the northern wall, two were from the floor and one was from the hearth located inside the entry of the structure (Figure 1; Table 1). A sample was also taken from the surrounding noncultural soil outside the structure to establish a baseline mineralogy and lithic composition for the local materials. Each sample was obtained as a block from the area of interest and impregnated with resin. To examine the layers, a transverse petrographic thin section was taken. The soil sample was washed and treated with a mild hydrochloric acid mixture. This serves to remove caliche on the grains; it was only done for the soil sample. The sections were stained for feldspar identification and cover slipped.

Using the petrographic microscope, several key features were recorded for each sample. Previous petrographic analyses of daub material from two sites in Hungary (Kovács et al. 2009) identified several features that are important to record, such as grain size, porosity, compaction, and the ratio of non-plastics to matrix. Kovács et al.'s (2009) study identified characteristics for floor samples (coarse grain size, low porosity, compact), wall samples (silt grain size, high porosity), and kiln samples (low porosity). Most of the samples from the current study exhibited a clear difference between the bulk composition of the material and the top or surface layer; thus, these were described separately.

Recorded information for the bulk composition included percent of the sample composed of clay, silt, and sand, the sorting, size range, porosity, compaction, and grain heterogeneity, orientation, contact, sphericity, and roundness. For the surface layer, percent of clay, silt, and sand were recorded, as were sorting, size range, porosity, compaction, and grain contact. Additional information included the amount of voids and cracks that would be indicative of the pressure applied, as well as the amount of caliche, as representative of any lime addition. The monomineralic and lithic inclusions were specified only for the bulk composition, as it was not different from the surface layer.

While the inclusions were similar among the samples, other aspects, such as compaction, heterogeneity, porosity, and grain orientation, were clearly dissimilar. To more accurately characterize these differences, image analysis was performed. This also clarified the micromorphology of the components. This process was initiated by digitally scanning the individual thin sections. Using Canvas 9 software, the images were processed to enhance their quality, primarily through changes in color levels, hue, intensity, brightness, and contrast. Figure 2 illustrates how the images were created from scanning the thin section and the differences in the original image and the image after enhancement. Such enhancement creates a regular and uniform image, as well as homogeneous parameters for further evaluation.

Three of the seven samples were selected for image analysis, based on image homogeneity, uniformity, and quality. Each sample was representative of the wall, floor, and hearth areas. The JMicrovision Inc. software (Roduit 2006) was utilized to analyze the images, because it allows measurement and quantification of components in high-definition images, specifically rock thin sections. In JMicrovision, components are extracted and treated as objects, transforming them into vector drawings and analyzing 40 descriptors for each object. The principal descriptors analyzed for each object are

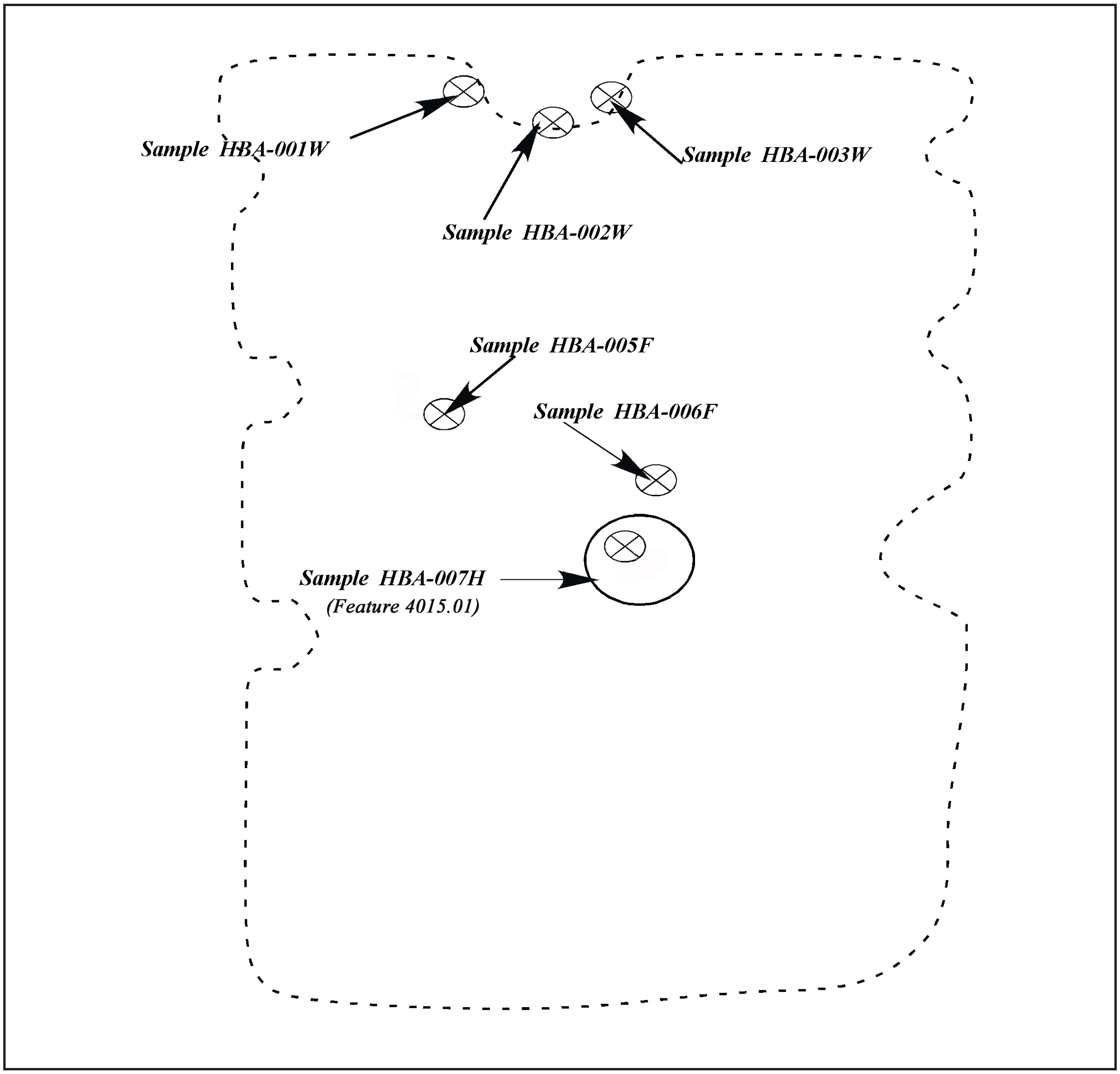

Figure 1. Sample locations, Features 4015 and 4015.01, Honey Bee Village, AZ BB:9:88 (ASM).

area, diameter, orientation (on an X and Y axis), circularity, angularity, spacing between particles, size, compaction, and class differentiation (mineralogical composition).

The analysis began by tiling the images and saving them in Tiff format to maximize the pixels available for analysis. The components in the image were colored by their identity, that is, all feldspars were colored orange, all quartz grains were blue, and so forth (Figure 3). The matrix was colored by whether it was unchanged, fired, or oxidized. This allowed for the quantification of the components and an analysis by the individual grain types. To assess grain size, parameters that matched the Wentworth scale were used. This gave percentages for each sample of fine-fraction material to sand-sized inclusions. Grain shape was analyzed by examining the borders of all the colored grains. For each grain type, a scalar numerical value was assigned, based on the roundness to angularity of the inclusions. Grain orientation was assessed by determining in which direction the greatest diameter of the grain lay. Grain contact was established by calculating, through a percentage, the amount of the border of the grain that was touching another grain. Porosity was determined by the remaining percentage of the border of the grain that was not touching another grain, and thus, that constituted open space. As with individual grain types, information about the pores, such as size and shape, was obtained.

Table 1. Sample inventory, Features 4015 and 4015.01, Honey Bee Village, AZ BB:9:88 (ASM).

Sample No.	Description	Location
HBA-001W	Wall materials	North wall, Feature 4015
HBA-002W	Wall materials	North wall, Feature 4015
HBA-003W	Wall materials	North wall, Feature 4015
HBA-004S	Soil sample	Outside Feature 4015
HBA-005F	Floor materials	Feature 4015
HBA-006F	Floor materials	Feature 4015
HBA-007H	Hearth materials	Feature 4015.01

A final analysis was to extract the matrix to show its extent for each sample and to examine the interaction of the grains and matrix in a granulometric profile (Figure 4). For this, the individual grains were subtracted and shown as black, while the matrix was left as either yellow for the unaltered fine fraction or purple for the fired or oxidized fine fraction. A profile through the slide from exterior (top) to the interior (bottom) was left in the center of the image. The image was then enhanced by pseudo-coloring to show the physical relationships between the grains, thus making the compaction, amount of matrix, grain contact, and changes in grain size more visible. The colored matrix was also visible in the profile, allowing clarification of its relationship to the grains. This type of analysis provided useful information about changes in the matrix from unaltered to altered, as well as differences in the grains in these layers.

RESULTS

The petrographic results revealed that the samples were dominated by granodiorite, alkali-rich granite, granodiorite grading to gneiss, and monomineralic grains derived from these lithic fragments (Table 2). Based on the site setting (see discussion in Miksa, et al. 2012), these rock and mineral types are related to the local geology. This is confirmed by comparison to the soil sample taken near the pithouse. Differences between the plaster samples are due to the amount of clay, silt, and sand, and the degree to which the surface of each was altered. None contain more than a trace amount of caliche, which appears natural to the sediments used for the wall and hearth, and within the sediments of the floor. Image analysis of a sample from each area, wall, floor, and hearth, confirmed these general impressions, and revealed significant differences concerning compaction as well as homogeneity, orientation, and grain size distribution.

The wall samples, HBA-001W, HBA-002W, and HBA-003W, exhibit a fairly uniform appearance and composition throughout the sandy clay material. For the bulk composition, the inclusions were poorly sorted, ranged from silt to granule in size, and were subangular to subrounded with moderate sphericity. Further, porosity, compaction, and grain contact were generally low, while the grains showed no preferred orientation. The upper layer, or wall surface, contained more silt than clay, variable compaction, and increased grain contact. Nevertheless, voids, cracks, and caliche were rare, suggesting lime had not been added and the materials were not heavily compressed. Smoothing was apparent in some areas, but not all, indicating an inconsistent process of smoothing. However, the thin sections provide only a very small view of the overall wall surface. The raw materials are consistent with a local clay, with high amounts of silt and sand, that was not overly processed.

From these samples, there appears to be little evidence for "floating" to create a smooth surface dominated by fine clay and silt particles. The color of the surface layer was the result of burning when the pithouse was burned prehistorically. This created an ashy gray surface on the wall due to a reducing atmosphere, while further into the wall, the material shows some oxidation. The whitish appearance may be due to subsequent weathering of the wall surface. Image analysis revealed that the wall sample was less compact and had greater heterogeneity in the morphologic parameters than samples taken from the floor and hearth (see Figure 4). The sample also contained roughly equivalent amounts of sand (mineral grains) and a mostly unchanged fine fraction (see Figure 3).

Samples from the floor, HBA-005F and HBA-006F, show a gradation in grain sizes and compaction from the floor bottom to the surface. The bulk of the material is very sandy, with little silt and some clay, as well as a low to moderate level of compaction. The silt- to granule-sized inclusions are poorly sorted and subangular to subrounded with moderate sphericity. Grain contact and porosity are low, while the grains are not oriented in any particular direction. Fine sand and silt are more common toward the top, and then show some compaction and grain contact. The sorting of the silt to medium sand-sized grains is moderate, and the porosity is low to moderate. As observed in the wall samples, voids, cracks, and caliche are rare. The overall appearance suggests natural sediments that were prepared by removing large grains and smoothing the surface. This may have been accomplished through sweeping, while the surface could have been compacted by pedestrian traffic. However, because the samples

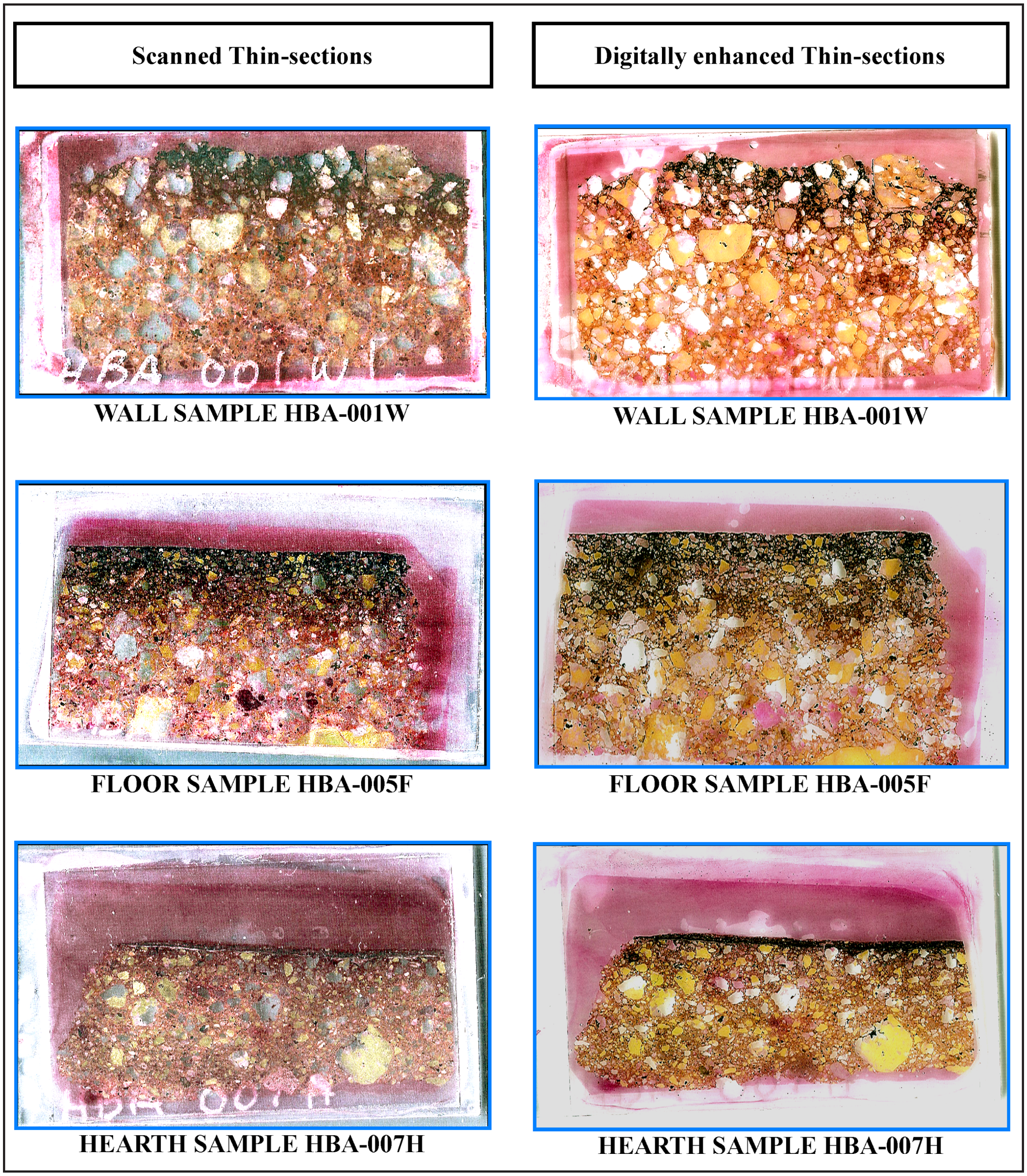

Figure 2. Scanned and enhanced thin sections, Honey Bee Village, AZ BB:9:88 (ASM).

examined were from the last stages of use of the floor, it is difficult to determine if a mud plaster was applied, smoothed, and trampled during use, creating the appearance of a layer of smoothed silt and fine sand. Floors may have been regularly swept and maintained to ensure an even walking surface. How this would affect a mud plaster surface is unknown.

The floor currently shows little evidence for a mud plaster layer, and it appears more similar to a prepared surface. The top layer of the floor is black and brown due to the reducing atmosphere created when the pithouse was burned. Image analysis showed that the floor sample was more homogenous in grain size distribution, orientation, and compaction than samples from the wall and hearth (see Figure 4). The increased sand in the bulk composition is easily discerned, along with the prevalence of the fine fraction at the surface (see Figure 3).

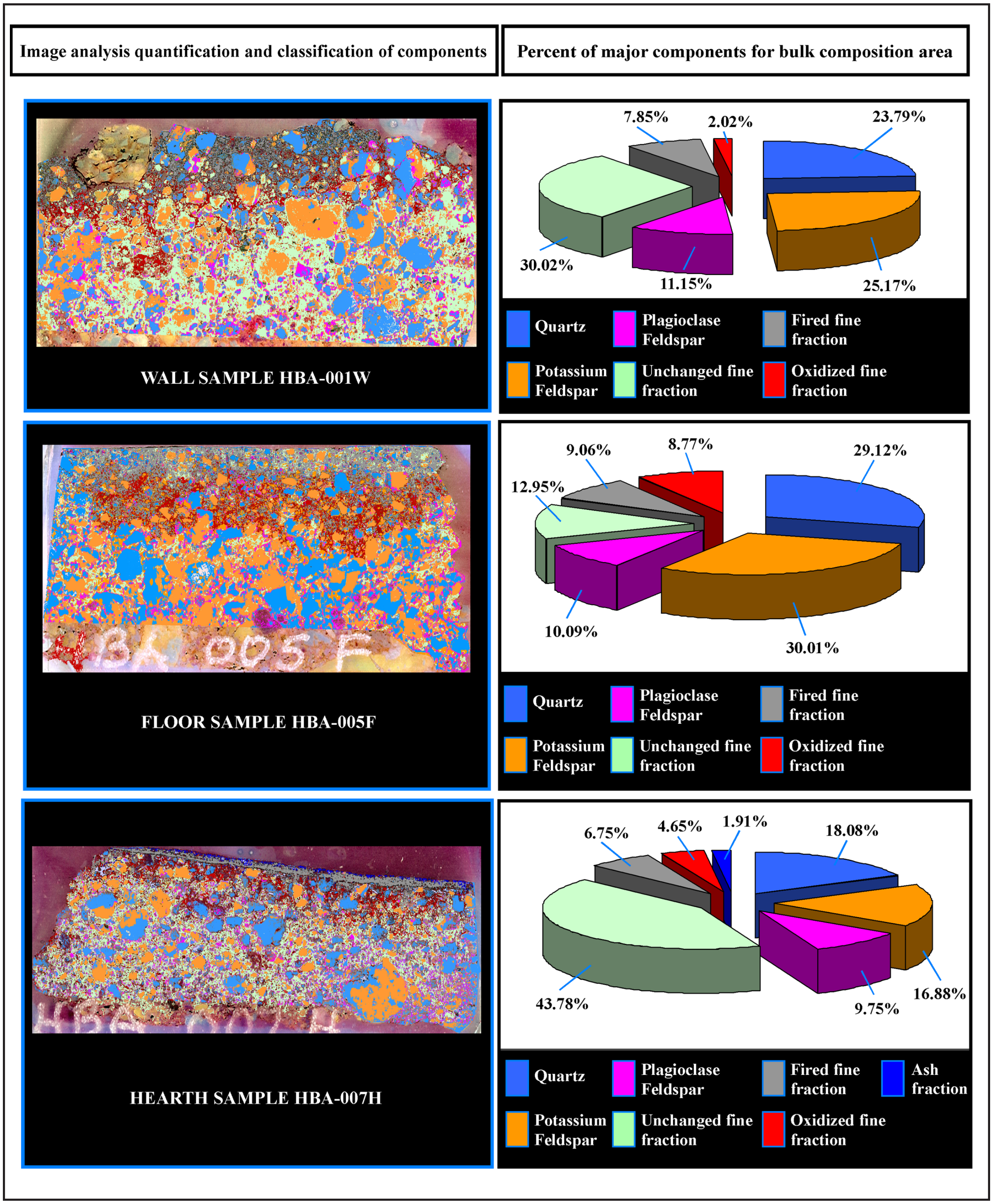

Figure 3. Image analysis quantification and classification of components, Honey Bee Village, AZ BB:9:88 (ASM).

Sample HBA-007H from the hearth consists of four layers. The bulk composition is clay, with a good proportion of silt to granule-sized sand grains. These subangular inclusions are poorly sorted, with moderate sphericity. The disoriented grains have moderate contact, while the porosity is low, and compaction is low to moderate. Directly on top of this material is a very thin layer of almost pure ash. Above this is a mixture of ash, clay, and silt, which is poor to moderate in sorting. Compaction remains low to moderate, but porosity is moderate, and grain contact is low. Voids and cracks are rare,

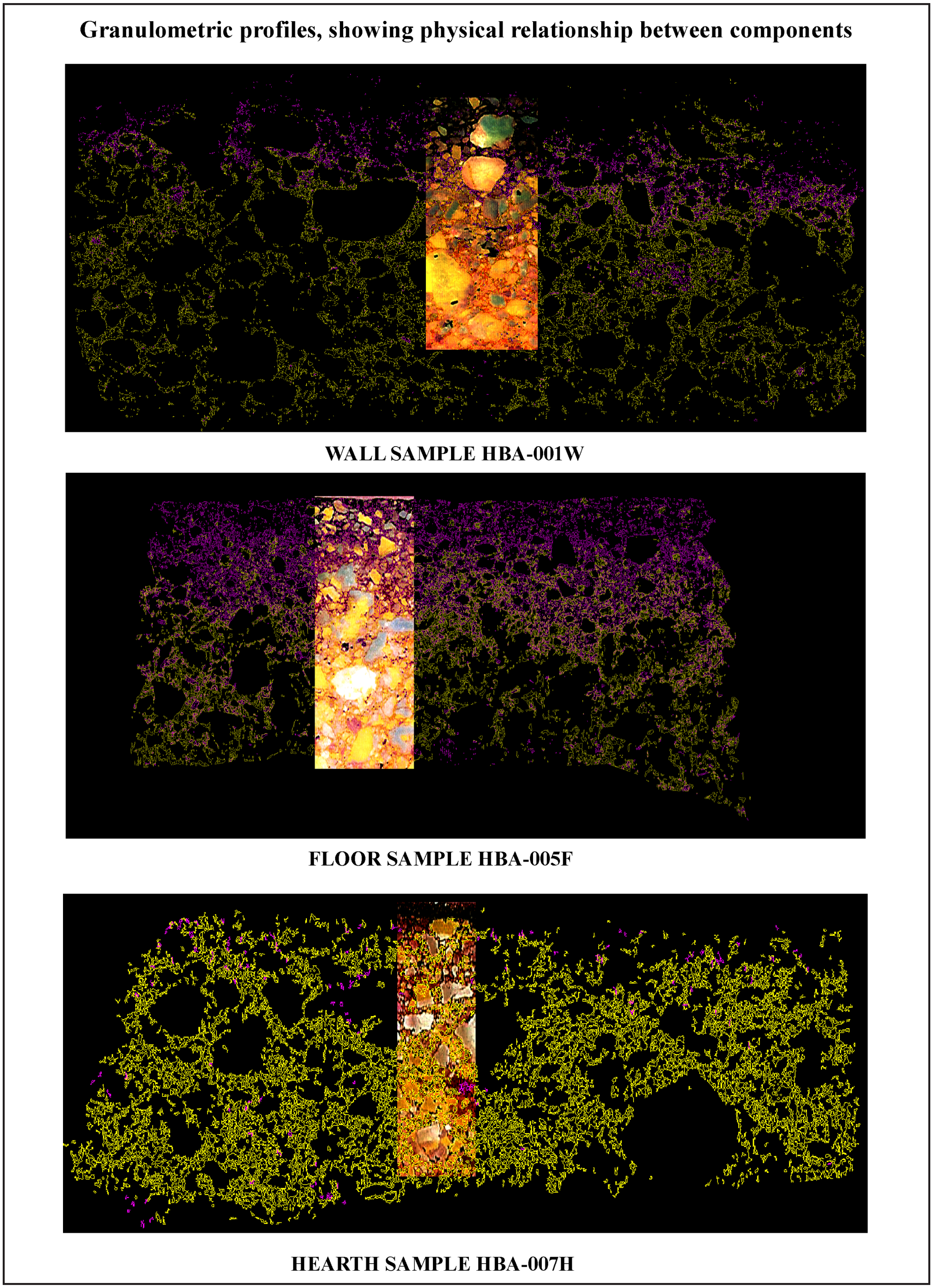

Figure 4. Granulometric profiles, showing physical relationship between components, Honey Bee Village, AZ BB:9:88 (ASM).

Table 2. Characteristics of the (a) bulk composition and (b) the surface layer composition, Honey Bee Village, AZ BB:9:88 (ASM).

Table 2a.

Sample No.	Percent of Clay	Percent of Silt	Percent of Sand	Sorting	Size Range	Porosity	Compaction	Heterogeneity	Grain Orientation	Grain Contact	Sphericity	Roundess	Monomineralic Inclusions	Lithic Inclusions
HBA-001W	40-50	5-10	30-40	Poor	Silt to granule	Very low to low	Low	High for grain size, low for composition	Disoriented	Low	Moderate	Subangular to subrounded	Quartz ± 40%; plagioclase feldspar ± 10-20%; potassium feldspar ± 10-20%; biotite/chlorite ± 2-10%; amphiboles ± 2-10%; opaques ± 1-3%; sphene trace to 1%; epidote trace	Granodiorite, alkaline granite, granodiorite grading to gneiss
HBA-002W	40-50	5-10	30-40	Poor	Silt to granule	Very low to low	Low	High for grain size, low for composition	Disoriented	Low	Moderate	Subangular to subrounded	Quartz ± 40%; plagioclase feldspar ± 10-20%; potassium feldspar ± 10-20%; biotite/chlorite ± 2-10%; amphiboles ± 2-10%; opaques ± 1-3%; sphene trace to 1%; epidote trace	Granodiorite, alkaline granite, granodiorite grading to gneiss; presence of well-rounded, medium-sized clay lumps (from 1% to barely 2%); caliche lump
HBA-003W	40-50	5-10	30-40	Poor	Silt to granule	Very low to low	Low to moderate	High for grain size, low for composition	Disoriented	Low to moderate	Moderate	Subangular to subrounded	Quartz 30-50%; plagioclase feldspar ± 20-30%; potassium feldspar ± 20-30%; biotite/chlorite ± 2-10%; amphiboles ± 2-10%; opaques ± 2-10%; sphene trace to 1%; epidote trace to 1%	Granodiorite, alkaline granite, granodiorite grading to gneiss; there is a small lens of caliche
HBA-004S	N/A	N/A	N/A	Poor	Silt to granule	N/A	N/A	High for grain size, low for composition	N/A	N/A	Moderate	Mostly subangular, few grains are angular (platty minerals and opaques) and few are rounded	Quartz ± 40%; plagioclase feldspar ± 10-20%; potassium feldspar ± 10-20%; biotite/chlorite ± 2-10%; amphiboles ± 2-10%; opaques ± 1-3%; sphene trace to 1%; epidote trace	Granodiorite, alkaline granite, granodiorite grading to gneiss; there is trace caliche
HBA-005F	30	10	60	Poor	Silt to granule	Low	Low to moderate	High for grain size, low for composition	Disoriented	Low	Moderate	Subangular to subrounded	Quartz ± 30%; plagioclase feldspar ± 20%; potassium feldspar ± 20%; biotite/chlorite ± 10%; amphiboles ± 10%; opaques ± 2-10%; sphene trace; epidote trace	Granodiorite, alkaline granite, granodiorite grading to gneiss
HBA-006F	30	10	60	Poor	Silt to granule	Low	Low to moderate	High for grain size, low for composition	Disoriented	Low	Moderate	Subangular to subrounded	Quartz ± 30%; plagioclase feldspar ± 20%; potassium feldspar ± 20%; biotite/chlorite ± 10%; amphiboles ± 10%; opaques ± 2-10%; sphene trace; epidote trace	Granodiorite, alkaline granite, granodiorite grading to gneiss; this is not a good thin section to evaluate parameters, grains were pulled off during preparation and plaster was broken, etc.
HBA-007H	30	30	40	Poor	Silt to granule	Low	Low to moderate	High for grain size, low for composition	Disoriented	Moderate	Moderate	Subangular	Quartz ± 30%; plagioclase feldspar ± 20%; potassium feldspar ± 20%; biotite/chlorite ± 10%; amphiboles ± 10%; opaques ± 2-10%; sphene trace; epidote trace	Granodiorite, alkaline granite, granodiorite grading to gneiss

Table 2b.

Sample No.	Percent of Clay	Percent of Silt	Percent of Sand	Sorting	Size Range	Porosity	Compaction	Grain Contact	Voids	Cracks	Caliche Content
HBA-001W	30	30	40	Poor	Silt to granule	Low to variable	Low to variable	Low to moderate	Rare	Rare	Rare
HBA-002W	30	30	40	Poor	Silt to granule	Low to variable	Moderate	Moderate	Trace	Rare	Rare
HBA-003W	30	30	40	Poor	Silt to granule	Low to variable	Low to variable	Low to moderate	Rare	Rare	Rare
HBA-005F	40	30	30	Poor to moderate	Silt to medium sand	Low	Moderate	Moderate	Rare	Rare	Rare
HBA-006F	40	30	30	Poor to moderate	Silt to medium sand	Low to moderate	Moderate	Moderate	Rare	Rare	Trace
HBA-007H	50	40	10	Poor to moderate	Silt to fine sand	Moderate	Low to moderate	Low	Rare	Rare	Trace

and caliche is present in a trace amount. This layer grades into a layer of pure silt to very fine sand with similar attributes.

These features indicate a silty to sandy mud was used to create the shape of the hearth after a shallow pit had been dug. There is little evidence for compaction of this material or considerable effort to create a smooth surface. The mud was almost certainly smoothed gently as it was applied. The upper layers are those relating to the last phase of use of the hearth and imply that most of the ash was removed. Then, due to gravity, sediment and ash collected at the bottom of the hearth before a clean layer of sediment was deposited on top. These last two layers may be the result of abandonment and/or excavation of the hearth. Image analysis of this sample showed a slightly higher degree of compaction and an increased amount of clay and silt relative to the floor and wall samples (see Figures 3-4).

DISCUSSION

Several other studies of adobe or mud plaster in Arizona have focused on the amount of caliche, or calcium carbonate ($CaCO_3$), present and the degree of compaction. Prehistoric pits for extracting caliche have been identified in the Phoenix area at Snaketown, AZ U:13:1 (ASM); Pueblo Grande, AZ U:9:7 (ASM); and the Rock Ball Court site, AZ T:13:9 (ASM), near Gila Bend (Burton et al. 1972; Gladwin et al. 1937; Wasley and Johnson 1965). These pits were linked to adobe creation under the hypothesis that the addition of caliche to mud is thought to strengthen the adobe to create more robust walls. This hypothesis has been tested by several studies in the Tucson and Phoenix areas.

Howell (2004) examined the levels of $CaCO_3$ and density of adobe samples from the Marana Platform Mound site, AZ AA:12:251 (ASM). Compared with the local soil, which had a low amount of carbonate, the adobe samples consistently had higher levels of $CaCO_3$. Further, the level of caliche in the samples was uniform, regardless of whether the sample was from a compound wall, room wall, floor, or puddling pit. Not surprisingly, the architectural mud was less porous and more compact than the comparative soil samples. There was no evidence that organic matter had been added to strengthen the adobe.

A similar approach was taken in an examination of eight wall samples from University Indian Ruin, AZ BB:9:33 (ASM) (Howell 2004). Those results indicated the wall adobe had a high carbonate content and was denser and less porous than the soil samples. A study of $CaCO_3$ levels in wall adobe from Brady Wash, NA 18,003, and McClellan Wash, NA 18,031, using only hydrochloric acid digestion, revealed that levels of carbonate in the adobe material were only slightly higher than that in local soils (Hovezak 1988). Particularly for solid adobe walls, there appeared to be minimal caliche to create these sturdy structures, and rather, they had increased amounts of gravel. Although Howell (2004) thinks caliche was added to soil sediments to create a more strongly bound material, there is the possibility that soil with a relatively high natural amount of caliche was intentionally selected, because the presence of caliche can vary within different soils and is more common and well developed in stable Pleistocene sediments (Field et al. 1993). Hovezak (1988) also posited that sediments naturally high in $CaCO_3$ could have been selected for some adobe wall construction.

From the Phoenix area, Howell (2004) examined wall samples from Mesa Grande, AZ U:9:5 (ASM); Rowley, AZ U:9:49 (ASM), and Las Piedras, AZ T:7:5 (ASU), by the same methods applied to the Marana Platform Mound samples. In comparison to soil samples, the wall adobe from Mesa Grande had a higher carbonate amount and was lower in porosity and higher in density. Unfortunately, no soil samples were available from Las Piedras or Rowley, and the submitted samples were too small for a bulk density measurement. However, the carbonate results revealed relatively high levels of caliche similar to the Mesa Grande samples.

Additionally, analysis of carbonate content in wall samples from Casa Grande, AZ AA:2:14 (ASM), and Pueblo Grande were found to be quite high, 22-35 percent and 26-38 percent, respectively (Burton et al. 1972; Wilcox and Shenk 1977). Compared to the Tucson Basin, these Classic period sites from the Phoenix area had noticeably higher amounts of caliche. This may be due to the increased natural $CaCO_3$ in Phoenix Basin soils as compared to those in the Tucson area. Howell (2004) proposes that the multistory architecture common to Phoenix sites may have required stronger adobe, which was possible due to the carbonate-rich soils. However, that caliche pits are known only from the Phoenix area may imply the intentional addition of carbonate to adobe materials. Interestingly, the porosity and bulk density of samples from both areas were analogous, suggesting similar methods of adobe application and finishing.

The current study is unique in applying petrographic methods to the analysis of lime content in mud plaster in the Southwest. The basis for establishing that the caliche seen in the analyzed thin sections are natural to the sediments derives from their infrequency and lumped appearance when seen. None of the samples had a continuous matrix of $CaCO_3$, rather, calcium carbonate was embedded in the clay matrix with clear boundaries. Experimental studies of lime plasters utilizing thin sections have confirmed that these features are more common to sediments with natural carbonate material (Karkanas 2007). However, most of these studies have focused on lime plasters, in which the lime had been heated to produce quick lime. There is currently no evidence that caliche fragments were heated to manufacture quick lime to make true lime plasters in the Southwest. In thin section, such material would show carbonization features, particularly shrinkage fractures and an isotopic appearance under cross-polarized light. Further research utilizing thin sections may provide such evidence and clarify the extent and usage of caliche in adobe.

CONCLUSIONS

The petrographic and image analysis of seven plaster samples from Feature 4015 at Honey Bee Village revealed the probable intentional use of certain mixtures based on where they were applied within the house. Adobe used for the walls was not significantly refined or heavily compacted. As its purpose was primarily to reduce the potential for wall collapse and prevent dirt and dust from the wall falling into the house, some compaction was necessary. The physical remains of tool marks and fingerprints indicate the desire to have a smooth, finished appearance to the wall, although further smoothing efforts, such as floating, were probably not conducted. Floors may have been prepared to reduce the amount of large grains that would have created an uneven and potentially hazardous (for bare feet) surface. While a mud plaster material may have been originally applied to the floor, this was difficult to determine, and compaction may have been intentional and/or the result of pedestrian traffic. The mud plaster used for the hearth was similar to that used for the walls, although it may have been refined, or a clay with more silt and less sand chosen. Surprisingly, the hearth mud plaster showed little compaction to create a robust surface that could withstand repeated heating and cooling. Clearly, that was not necessary for the hearth to function correctly. Finally, none of the samples showed a significant quantity of added caliche to create a lime plaster, suggesting this technology was not practiced at Honey Bee Village, even though caliche deposits are widely available in the Pleistocene-aged sediments where portions of the site are situated (Field et al. 1993). Additional chemical analysis of the mud plaster, compared to the natural soil, may clarify this supposition.

The application of image analysis to three of the thin sections greatly clarified their features and suggested different processes were used to create the materials. However, the initial processing and enhancement of the images to improve their quality can be quite a task, primarily because thin section preparation and staining can make it difficult to see the individual grains separate from the matrix. However, the use of enhanced images does provide a better way to characterize the differences seen in thin sections, which is particularly relevant for computational methods, such as image analysis, that require identification of the individual components. The resulting data provide a thorough and objective approach to obtaining micromorphological information about grain size, shape, and orientation, percentage of inclusions, porosity, and compaction. For quantification of small particles, such as the clay matrix, image analysis is ideal. However, its effectiveness depends on image quality and the petrographic knowledge to identify the components. Therefore, the method is an excellent supplement to traditional petrographic analysis.

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