**Analysis of Pottery Samples from Bourewa, the earliest known *Lapita* site in Fiji**

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**Abstract**

We have carried out a thorough mineralogical analysis of 16 pottery samples from the *Lapita* site of Bourwera in Fiji, using micromorphological techniques with optical and polarising microscopes. While the overall mineralogy of all of the samples is similar the samples clearly divide into two groups, namely those with or without the mineral calcite. Our findings are backed up by chemical analysis using SEM-EDX and FTIR. SEM-EDX shows the clear presence of inclusions of calcite in some of the samples; FTIR shows bands arising from calcite in these samples. The study suggests that it is likely that more than one clay source was used for production of this pottery, but that most of the pottery comes from a single source. This finding is in line with previous studies which suggest some trading of pottery between the Fijian islands but a single source of clay for most of the pottery found at Bouwera. We found no evidence for the destruction of CaCO3 by heating upon production of the pottery in line with the known technology of the Lapita people who produced earthenware pottery but not high temperature ceramics.

**Introduction**

*Lapita* is the term given to the earliest settlers (ca. 1350-550 BC) in the Pacific Islands. Despite the archaeological significance of this culture, much remains unknown about the people, their origins and subsistence livelihoods. *Lapita* settlement sites are generally identified through the presence of pottery, made using the distinctive technique of dentate-stamping [1]. Abundant dentate-stamped potsherds have been recovered from the Bourewa site in Fiji, the earliest known *Lapita* site in this island group, dating to at least 1100 BC [2,3], which was excavated during seven field seasons between 2003 and 2009. Shell-midden deposits at Bourewa are up to 1.8 m thick and demonstrate the importance of seafood in the diet of the population [4]. Preliminary analysis of phytoliths (mineralised plant cells) from these midden deposits also suggests the cultivation of taro and yam at the site within 200 years of initial occupation [5]

Much attention has also focused on trying to reconstruct ancient human migration routes within the Pacific Islands using sand-temper analysis [6]; a clear conclusion is that little pottery was moved between island groups; almost all was manufactured in situ. Kumar [7] studied *Lapita* ceramic tempers on Moturiki Island in Fiji and found that, while 70% of sherds were probably made on this island, the remainder were made on other islands in the Fiji group.

For Fiji, Cochrane et al. [8] have used laser-ablation inductively-coupled-plasma-mass spectrometry (LA-ICP-MS) to compare clays used in pottery manufacture from different islands. Their approach utilised Principal Component Analysis employing both chemical and geological information. They concluded that some pottery was traded between nearby islands. Neff [9] used the same technique to analyse plumbate surfaces on glazed ceramics from Mesoamerica. Kennett et al. [10] utilised ICP-MS to try to identify the origins of pottery sherds found on different island groups in Oceania. Clear differences were found between the ceramics from each group of islands suggesting great potential for ICP-MS in investigating the transfer of *Lapita* ceramics in Oceania. A similar question was addressed by Descantes et al. [11] using neutron activation analysis. In this study it was found that while the exact clay source could not be identified unambiguously, the island of origin could be determined.

For the current project, we analysed pottery samples from the Bourewa site with micromorphological methods using optical and mineralogical microscopes backed up by elemental and mineralogical analysis using a combination of infrared spectroscopy (including microscopic mapping), X-ray fluorescence (including Scanning Electron Microscopy-Energy Dispersive X-ray (SEM-EDX) Analysis), and X-ray diffraction. Microscopy has long been used for studying mineralogical inclusions in pottery samples, a good example being the work of Broekmans et al. to understand the preparation and firing of pottery from the Neolithic site of Tell Beydar in northeast Syria [12]. Infrared spectroscopy has been used less for this purpose, although a good example of its applicability comes from Tell Brak, another Syrian site, where Eiland et al. used the technique to determine the presence or absence of calcite (CaCO3) and estimate the firing temperature of pottery [13]. Calcite decomposes to CaO and CO2 at 880 oC, so its absence suggests a firing temperature in excess of this.

Our specific aims in the current project were as follows.

* To characterise the pottery materials from this important site as thoroughly as possible,
* To determine whether the pottery samples came from different clay sources. Is there any evidence that more than one clay source was used?
* To investigate whether there is evidence from the presence or absence of calcite for different firing temperatures.

**Experimental Section**

Samples were collected by one of the authors (L-MS) during fieldwork in Fiji in December 2007 and brought to the UK for analysis. Thin sections of 16 pottery samples were prepared using standard methods [14]. In the case of samples 1, 4, 5, 6, 7 and 10 more than one section was made and these are labelled (a), (b) *etc*. These sections were used for optical microscopic investigation and for SEM-EDX studies which were made using an Oxford Instruments FEI Quanta FEG 600 Environmental SEM fitted with energy and wavelength dispersive elemental analysis. “Bulk” samples of samples 3, 5, 6 and 14 were further studied by powder X-ray diffraction (using a Bruker D8 powder diffractometer) , X-ray fluorescence (using a Thermo Scientific NITON XLt Portable X-Ray fluorescence spectrometer) and IR spectroscopy (as KBr discs using a Perkin Elmer 100 FTIR spectrometer).

**Results and Discussion**

Thin sections of 16 pottery samples were prepared and their mineralogical composition was studied using optical and polarising microscopy [14]. The following characteristics were studied: colour, refractive index, cleavage, pleochroism (the appearance of a mineral as being of different colours when observed at different angles under a polarising microscope), birefringence and twinning. This allows ready identification of a range of minerals including: quartz, SiO2 (high refractive index; no twinning or cleavage); calcite, CaCO3 (very high birefringence); plagioclase feldspar, NaAlSi3O8-CaAlSiO2O6, (parallel cleavage, multiple twinning and first order birefringence); olivine, (Mg,Fe)2SiO4 (high refractive index, high interference colours with bright second order birefringence); orthopyroxene, (Mg,Fe)SiO3 (similar to olivine but shows cleavage and first order birefringence only); hornblende, {NaCa2(Mg,Fe,Al)5(AlSi)8O22(OH,F)2} (pronounced pleochroism from pink to green in plane light, low-to-moderate birefringence); kaersutite (NaCa2(Mg4Ti)Si6Al2O23(OH)2, (strong cleavage in some crystals and brown colour in plane light).

The minerals detected in each sample in this way are summarised in table 1, while a full description of the mineralogy is given in table S in supplementary material to this paper. It may be seen that a range of minerals are identified. The exact content of silicate minerals varies slightly from sample to sample, but the most striking difference is that samples 5, 7, 12, 13 and 15 contain no calcite. Lapita pottery is all earthenware, not ceramic, and it is known that Lapita people had few options for firing pottery [2,3]. This discounts any possibility that calcite in the clay used for the pottery has been destroyed by firing at high temperature. Rather it suggests two different sources for the clay. In order to probe this point further and to provide a more quantitative analysis X-ray diffraction and X-ray fluorescence were carried out on four samples i.e. samples 3, 5, 6 and 14, one of which (5) is thought, on the basis of optical microscopy to contain no calcite. In table 2 the percentages of minerals observed by X-ray diffraction in these four samples are listed. No calcite is detected in sample 5. In the other samples the percentage of calcite varies from 51% in sample 3, through 22% in sample 14 to 4% in sample 6. Quartz is detected in all samples, as are silicate minerals and these findings are as expected from the results of micromorphological analysis under the optical microscope. Heamatite is detected and this was not seen by optical microscopy. Its presence may well account for the observed colour of the samples ranging from “very red” (sample 5; 5.8 % haematite), through “red” (sample 6, 2.5 % haematite) and “orange-brown” (sample 14, 1.9% haematite) to “yellowy” (sample 3, no haematite). It should be noted that investigation under the optical microscope is an excellent method to determine the nature of inclusions within a sample it is not such a good method to identify minerals that are present at a low “background” level throughout the sample. Powder XRD, by contrast, gives an average content of the whole sample studied. This is why some differences in the silicate minerals observed by the two methods may be expected. The absence of calcite from some of the samples is, however, very clear from both methods. The elemental concentrations determined by X-ray fluorescence back up these findings. Sample 5 has the lowest Ca concentration (1.47%), sample 3 the highest (12.08%). Minerals other than calcite may account for some of this calcium content, of course. The absence of calcite from sample 5 is confirmed by the infrared spectra illustrated in Figure 1. Sample 3 (Figure 1a) clearly shows bands associated with the carbonate ion [13]. These bands are absent from the spectrum of sample 5 (Figure 1b). Bands associated with quartz are also clearly seen.

More detailed study of the X-ray fluorescence data suggests that samples of this type may be further differentiated by studying the trace element concentrations. Sample 3 shows a particularly high level of Sr. This matches the high level of Ca and suggests that Sr is replacing Ca e.g. in carbonate minerals – a well-known process [14]. However, the level of Rb in this sample is particularly low and matches the low level of K; it is expected that Rb may exchange for K in some minerals.

Perhaps one of the most interesting observations from the X-ray fluorescence data in that there is little obvious difference between sample 5 and the other three samples studied in terms of their trace element composition. Sample 3 is a little higher in V and Cr, sample 14 higher in Ni, Co, Zn and Pb. Some elemental concentrations are quite consistent from sample to sample e.g. Zn whereas others such as Pb show more variance with sample 14 showing ten times more Pb than sample 6. Interestingly the Fe concentration is very consistent from sample to sample despite the different amounts of haematite present. This is because of the presence of other iron-containing minerals such as olivine.

 In order to identify the mineral inclusions in the clay samples more precisely and to search for further differences between the sample, elemental mapping using SEM-EDX was carried out. A series of elemental maps are shown for sample 6 in Figure 2. The aluminium map shows the background of clay minerals, while the dark areas, which are low in aluminium, indicate inclusions. It may be seen that most of these inclusions are also low in silicon – but are high in calcium and may be identified as calcite. A small number of inclusions are low in aluminium and calcium but high in silicon and may be identified as quartz. This tallies with the observations reported previously in this paper that this sample consists of clay minerals with inclusions of calcite and quartz. In sample 14 areas high in both calcium and magnesium were identified which probably come from the mineral dolomite. It was not possible to search directly for haematite inclusion by this method because of the presence of iron in many of the clay minerals present (see Table 1).

 Our work shows that grouping of the samples in possible. In particular a particular difference is that some contain calcite and some do not, while some samples contain haematite. There are a number of rather subtle mineralogical differences. For example,olivine is found in all samples except 9, 11, 12 and 13 while hornblende is only found in sample 6. Sample 6 is the only one to contain hornblende and samples 12 and 13 are the only ones which contain neither calcite nor olivine.

The absence of calcite from some samples is not indicative of high firing temperatures. If calcite were destroyed by firing one would still expect to find a relatively high level of calcium within the sample *e.g*. as a calcium silicate on reaction with other minerals. Sample 5, which X-ray diffraction and IR spectroscopy indicate to have no calcite, is also shown by X-ray fluorescence to have a low level of calcium. This suggests that the original clay did not contain calcite, rather than that the calcite has been destroyed on heating. The clear differences seen between the IR spectra of samples 5 and 14 (Fig. 1) and the very clear calcite inclusions seen by SEM-EDX (Fig. 2) suggest very strongly that there are two distinct clay sources used for the pottery samples studied i.e. one that contains calcite and one that does not. However, further experiments would be necessary to determine if either of these sources was likely to be from outside the island of Fiji. Recent investigations [2] have suggested that clay for use for making most of the pottery at Bouwera was collected from a site called Matelita Tree, in the delta of the Tuva River. It is thought that from here the Lapita people placed the clay into canoes and paddled it around to Bourewa.  Useful further research would be to study the mineralogy of clay from this source. The analysis reported in the current paper shows either that the clay from Matelita Tree is varied in composition, with some samples containing calcite (and/or haematite and olivine) or that an alternative source was used for some of the pottery found at Bouwera. This is entirely in line with the previous work of Kumar [7] and Cochrane [8] who concluded that most pottery on the Fijian islands was made from a single source but that a proportion – up to about 30% - was traded between islands. In this context it is of interest that we find that about 30% (5/16) of the samples that we studied are different from the others in that they contain no calcite.

Our results show that it is necessary to use a wide range of techniques to fully characterise samples of this type. As a minimum we would suggest that X-ray diffraction and X-ray fluorescence are used alongside micromorphology using an optical microscope to obtain mineral and elemental compositions for the samples. This combination of techniques allows a thorough characterisation of the pottery samples to be made and allows the origin of the clay used for the pottery samples to be explored.

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**Table 1: Mineral Content of Each Sample as Determined by Optical Microscopy on Thin Sections**

|  |  |
| --- | --- |
| Sample Number | Minerals Present (a) |
| 1b | Quartz, Calcite, Olivine, Orthopyorxene, Plagioclase, Sanidine, Microcline |
| 2 | Quartz, Calcite, Kaersutite, Orthopyorxene, Plagioclase, Sanidine  |
| 3 | Quartz, Calcite, Olivine, Monticellite, Sanidine (b) |
| 4a | Quartz, Calcite, Olivine, Plagioclase, Sanidine, Kaersutite |
| 4b | Quartz, Calcite, Olivine, Plagioclase, Sanidine, Monticellite, Kaersutite |
| 5a | Quartz, Olivine, Orthopyorxene, Plagioclase, Sanidine, Monticellie |
| 6b | Quartz, Calcite, Plagioclase, Hornblende, Olivine (b,c) |
| 6c | Quartz, Calcite, Olivine, Plagioclase, Sanidine, Monticellite |
| 7a | Quartz, Plagioclase, Sanidine (b) |
| 7b | Quartz, Olivine, Plagioclase, Monticellite |
| 9 | Quartz, Calcite, Plagioclase, Sanidine (b,c) |
| 10b | Quartz, Calcite, Olivine, Plagioclase |
| 10c | Quartz, Calcite, Olivine, Plagioclase, Sanidine |
| 11 | Quartz, Calcite, Plagioclase |
| 12 | Quartz, Orthopyorxene, Plagioclase, Sanidine, Kaersutite |
| 13 | Quartz (b,c) |
| 14 | Quartz, Calcite, Olivine, Plagioclase |
| 15 | Quartz, Olivine, Plagioclase, Sanidine (c) |
| 16 | Quartz, Calcite, Olivine, Orthopyorxene |

(a) Chemical formulae:- Quartz, SiO2; Calcite, CaCO3; Olivine, (Mg,Fe)2SiO4; Plagioclase, NaAlSi3O8CaAl2Si2O8 ; Sanidine, (K,Na)AlSi3O8; Monticellite, Ca(Mg,Fe)2SiO4; Microcline, KAlSi3O8; Kaersutite, NaCa2(Mg4Ti)Si6Al2O3(OH)2;Orthopyorxene, (Mg,Fe)SiO3.

(b) also contains an unknown black mineral

(c) also contains an unknown red mineral

**Table 2: Total mineral percentages for samples 3, 5, 6 and 14 as Determined by X-ray Diffraction on Bulk Samples.**

**(a) Sample 3**

|  |  |  |  |
| --- | --- | --- | --- |
| Mineral name (a) | Peak height (mm) | ‘H' factor | Percentage of mineral in sample (%) |
| Calcite | 103 | 0.264 | 51.1 |
| Quartz | 72 | 0.220 | 29.7 |
| Albite | 32 | 0.3199 | 19.2 |

**(b) Sample 5**

|  |  |  |  |
| --- | --- | --- | --- |
| Mineral name (a) | Peak height (mm) | ‘H' factor | Percentage of mineral in sample (%) |
| Quartz | 94 | 1.00 | 83.9 |
| Albite | 34 | 0.3199 | 9.7 |
| Haematite  | 14 | 0.4625 | 5.8 |
| Tremolite | 6 | 0.12 | 0.6 |

**(c) Sample 6**

|  |  |  |  |
| --- | --- | --- | --- |
| Mineral name (a) | Peak height (mm) | ‘H' factor | Percentage of mineral in sample (%) |
| Quartz | 76 | 1.0 | 67.6 |
| Albite | 92 | 0.3199 | 26.2 |
| Calcite | 16 | 0.264 | 3.8 |
| Haematite  | 6 | 0.4625 | 2.5 |
| Montmorilionite | Immeasurable due to high background levels | 1.1997 | N/A |

**(d) Sample 14**

|  |  |  |  |
| --- | --- | --- | --- |
| Mineral name (a) | Peak height (mm) | ‘H' factor | Percentage of mineral in sample (%) |
| Quartz | 101 | 0.22 | 30.8 |
| Albite | 103 | 0.3199 | 45.7 |
| Calcite | 59 | 0.264 | 21.6 |
| Haematite  | 3 | 0.4625 | 1.9 |

(a) Chemical formulae: Quartz, SiO2; calcite, CaCO3,; albite, NaAlSi3O8; tremolite, Ca2Mg5Si8O22(OH)2; haematite, Fe2O3; montmorillonite, (Na,Ca)0.33(Al,Mg)2(Si4O10)(OH)2.*n*H2O.

**Table 3: Elemental Concentrations in Samples 3, 5, 6 and 14 as Determined by X-ray Fluorescence on Bulk Samples.**

|  |  |  |
| --- | --- | --- |
|   | **Element percentages (%)** |  |
| **Sample number** | **Na** | **Mg** | **Al** | **Si** | **P** | **K** | **Ca** | **Ti** | **Mn** | **Fe** |  |
| 3 | 0.40 | 0.43 | 4.18 | 19.41 | 0.08 | 0.08 | 12.08 | 1.34 | 0.05 | 5.11 |  |
| 5 | 0.34 | 0.57 | 4.85 | 30.67 | 0.03 | 0.51 | 1.47 | 0.54 | 0.04 | 3.34 |  |
| 6 | 0.55 | 0.78 | 5.15 | 27.40 | 0.09 | 0.24 | 2.14 | 0.67 | 0.04 | 4.51 |  |
| 14 | 0.75 | 1.06 | 4.60 | 21.90 | 0.04 | 0.14 | 5.18 | 1.04 | 0.09 | 4.68 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|   | **Trace elements (ppm)** |
| **Sample number** | **V** | **Cr** | **Co** | **Ni** | **Cu** | **Zn** | **Pb** | **Rb** | **Sr** | **Y** | **Zr** |
| 3 | 388 | 455 | 16 | 25 | 46 | 59 | 16 | 4 | 1876 | 11 | 89 |
| 5 | 169 | 138 | 11 | 16 | 15 | 55 | 10 | 25 | 250 | 12 | 108 |
| 6 | 282 | 135 | 23 | 28 | 44 | 56 | 3 | 14 | 381 | 14 | 95 |
| 14 | 258 | 242 | 35 | 59 | 47 | 89 | 31 | 10 | 568 | 30 | 160 |

**Figure 2: SEM-EDX Maps of Elemental Concentrations Recorded on Thin Sections of Sample 6: Left-to-Right, Al, Ca, Si**

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**Figure 1. IR Spectra recorded on Bulk samples (KBr Discs) of Samples 3 and 5.**

4000.0

3000

2000

1500

1000

400.0

7.0

10

12

14

16

18

20

22

24

26

28

30

32

34

36

38

40

42

44

46

47.7

cm-1

%T

3431 (O-H)

1636 (O-H)

1427 (CO32- - stretching mode)

1032 (Si-O)

 471 (Si-O-Si)

2515

1795

875 (CO32- - bending mode)

710 (CO32- - bending mode)

 534 (Al-O-Si)

(Overtones of carbonate)

**(a) Sample 3**

4000.0

3000

2000

1500

1000

400.0

13.0

16

18

20

22

24

26

28

30

32

34

36

38

40

42

44

46

48

50

52

54

56.1

cm-1

%T

3431 (O-H)

1028 (Si-O)

1639 (O-H)

777 (quartz)

797 (quartz)

531(Al-O-Si)

690 (quartz)

**(b) Sample 5**

**Supplementary Material**

**Table S: Mineral Content of Samples as Determined by Optical Microscopy on Thin Sections**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Sample number | Appearance of thin section  | Munsell Colour | Inclusion characteristics | Inclusion identities  |  |
|  |  | Hue | Value | Chroma | Colour | Frequency  | Size range | Sorting | Roundness / Shape | Name | Chemical composition |
| 1b | Orangey red with black core | 5 YR (main)2.5 YR (core) | 42.5  | 61 | Yellowish redBlack  | Abundant | Mostly 0.1 – 0.5 mm, some bigger 1.0 – 1.5 mm  | Very Poor | Very angular and sub rounded | Quartz | SiO2 |
| Calcite | CaCO3 |
| Olivine | (Mg,Fe)2SiO4 |
| Orthopyroxene | (Mg,Fe)SiO3 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| Sanidine | (K,Na)AlSi3O8 |
| Microcline | KAlSi3O8 |
| 2 | Reddish black | 5 YR | 2.5 | 1 | Black | Abundant | 0.05 – 1.0 mm, most around 0.2mm | Very poor | Angular  | Quartz | SiO2 |
| Calcite | CaCO3 |
| Kaersutite | NaCa2(Mg4Ti)Si6Al2O3(OH)2 |
| Sanidine | (K,Na)AlSi3O8 |
| Orthopyroxene | (Mg,Fe)SiO3 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| 3 | Yellowy red | 5 YR | 4 | 6 | Yellowish red | Moderate  | Mostly 0.1 – 0.2 mm, few larger around 0.5mm | Poor | Mostly sub rounded, few larger angular ones | Quartz | SiO2 |
| Calcite | CaCO3 |
| Olivine | (Mg,Fe)2SiO4 |
| Monticellite | Ca(Mg,Fe)2SiO4 |
| Sanidine | (K,Na)AlSi3O8 |
| Unknown black mineral |  |
| 4a | Orangey Red | 5 YR | 5 | 6 | Yellowish red | Abundant | 0.2 – 0.5 mm | Poor | Angular and sub rounded  | Quartz | SiO2 |
| Calcite | CaCO3 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| Sanidine | (K,Na)AlSi3O8 |
| Olivine | (Mg,Fe)2SiO4 |
| Kaersutite | NaCa2(Mg4Ti)Si6Al2O23(OH)2 |
| 4b | Yellowish brown | 10 YR | 5 | 6 | Yellowish brown | Sparse | 0.3 – 1.0 mm – mostly around 0.5 mm | Very Poor | Very Angular | Quartz | SiO2 |
| Calcite | CaCO3 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| Sanidine | (K,Na)AlSi3O8 |
| Olivine | (Mg,Fe)2SiO4 |
| Monticellite | Ca(Mg,Fe)2SiO4 |
| Kaersutite | NaCa2(Mg4Ti)Si6Al2O23(OH)2 |
| 5a | Very red | 10 R | 4 | 6 | Red | Moderate | 0.1 – 0.3 mm | Very poor | Angular | Quartz | SiO2 |
| Sanidine | (K,Na)AlSi3O8 |
| Olivine | (Mg,Fe)2SiO4 |
| Orthopyroxene | (Mg,Fe)SiO3 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| Monticellite | Ca(Mg,Fe)2SiO4 |
| 6b | Red with thin black core | 5 YR (main)5 YR (core) | 53 | 64 | Yellowish redDark reddish brown | Abundant | 0.5 – 1.5 mm | Very poor | Very angular | Unknown black / red mineral |  |
| Kaersutite | NaCa2(Mg4Ti)Si6Al2O23(OH)2 |
| Quartz | SiO2 |
| Calcite | CaCO3 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| Hornblende | NaCa2(Mg,Fe,Al)5(Al,Si)8O22(OH,F)2 |
| Olivine | (Mg,Fe)2SiO4 |
| 6c | Pale red | 2.5 YR | 5 | 6 | Strong brown | Very abundant | 0.05 – 0.5 mm | Fair | Mostly angular | Calcite | CaCO3 |
| Quartz | SiO2 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| Sanidine | (K,Na)AlSi3O8 |
| Olivine | (Mg,Fe)2SiO4 |
| Monticellite | Ca(Mg,Fe)2SiO4 |
| 7a | Red | 2.5 YR | 4 | 6 | Red | Very abundant | Most 0.05 – 0.1 mm, rest 0.3 – 0.5 mm | Fair | Sub rounded with few larger very angular | Quartz | SiO2 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| Sanidine | (K,Na)AlSi3O8 |
| Unknown black / red mineral |  |
| 7b | Red | 2.5 YR | 4 | 6 | Red | Abundant | Large range 0.2 -1.0 mm | Poor | Angular | Quartz | SiO2 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| Olivine | (Mg,Fe)2SiO4 |
| Monticellite | Ca(Mg,Fe)2SiO4 |
| 9 | Pale red | 5 YR | 5 | 6 | Yellowish red | Abundant | Mostly 0.1 -0.2 mm with fewer larger 1.0 -1.5 mm | Poor | Sub angular and rounded | Quartz | SiO2 |
| Calcite | CaCO3 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| Sanidine | (K,Na)AlSi3O8 |
| Unknown black / red mineral |  |
| 10b | Black with red edges | 5 YR (main)2.5 YR(edge) | 34 | 38 | Dark reddish brownRed | Very abundant | Large range – all sizes from 0.05 – 1.0 mm  | Very poor | Very angular | Quartz | SiO2 |
| Calcite | CaCO3 |
| Olivine | (Mg,Fe)2SiO4 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| 10c | Red | 5 YR | 4 | 4 | Reddish brown | Very abundant | 0.1 - 0.2 mm | Fair | Angular  | Quartz | SiO2 |
| Calcite | CaCO3 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| Sanidine | (K,Na)AlSi3O8 |
| Olivine | (Mg,Fe)2SiO4 |
| 11 | Grey / brown | 5 YR | 3 | 1 | Very dark grey | Abundant  | Mostly 0.1 mm or less, few larger ones | Very poor | Sub angular and sub rounded  | Quartz | SiO2 |
| Calcite | CaCO3 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| 12 | Black / grey with lighter brown edges | 10 YR (main)5 YR  | 23 | 13 | BlackDark reddish brown  | Moderate | 0.2 – 0.5 mm | Poor | Very angular | Quartz | SiO2 |
| Plagioclase | NaAlSi3O8 – CaAl2Si2O8 |
| Sanidine | (K,Na)AlSi3O8 |
| Orthopyroxene  | (Mg,Fe)SiO3 |
| Kaersutite | NaCa2(Mg4Ti)Si6Al2O23(OH)2 |
| 13 | Red with thin black core | 10 R (main)2.5 YR(core) | 32.5 | 61 | Dark redReddish black | Moderate | Mixture of 0.1 – 0.2 mm and 0.5 – 1.0 mm  |  Poor | Mixture of very angular and very rounded | Quartz | SiO2 |
| Unknown black / red mineral |  |
| 14 | Orange / brown | 2.5 YR | 3 | 6 | Dark red | Abundant  | Most around 0.5mm, few larger ones up to 2.0 mm | Very poor | Mostly sub angular, some larger rounded ones | Quartz | SiO2 |
| Plagioclase  | NaAlSi3O8 – CaAl2Si2O8 |
| Calcite | CaCO3 |
| Olivine | (Mg,Fe)2SiO4 |
| 15 | Red with black edge on one side | 2.5 YR (main)2.5 YR (edge) | 32.5 | 61 | Dark redReddish black | Abundant | 0.1 – 0.5 mm | Very poor | Mostly angular and sub angular | Quartz | SiO2 |
| Olivine | (Mg,Fe)2SiO4 |
| Plagioclase  | NaAlSi3O8 – CaAl2Si2O8 |
| Sanidine | (K,Na)AlSi3O8 |
| Unknown red mineral |  |
| 16 | Pale yellow  | 2.5 Y | 6 | 6 | Olive yellow | Abundant  | 0.2 – 0.5 mm | Fair  | Mostly sub rounded and irregular  | Olivine | (Mg,Fe)2SiO4 |
| Orthopyroxene | (Mg,Fe)SiO3 |
| Quartz | SiO2 |
| Calcite  | CaCO3 |