# HD Analytical Solutions Technical Report

## Results of Petrographic Analysis of Alabama Site Clays, Pottery and Building Materials

By Dr. Linda Howie

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## Section 1 Project Summary

### The Sample Set and Objectives

The sample set from Alabama includes 6 pottery samples (SCP 1 and 3-7), two building material samples (SCP 2 and 8) and 6 fired clay samples (SCP 9614), prospected from different geographic localities in the area surrounding the site. The pottery samples derive from jars or dishes, and the building materials include a sample of 'duab' (SCP 8)and a sample from a 'work surface' (SCP 2).

The objectives of the petrographic study of the samples form the Alabama site were:

***Clay samples***

1. Explore & identify local-level variation in the geological characteristics of raw materials available for pottery production
2. Establish a local baseline to compare to pottery samples

***Pottery samples***

1. Identify locally-made pottery and pottery made elsewhere
2. Explore socioeconomic connections to other areas

***Building material samples***

1. Explore exploitation of geological resources used for other activities
2. Extend local geological baseline to include clay resources known to and used by the Maya

### Methodology

Thin section petrography is well-established as a powerful and effective means of analyzing compositional variation among pottery vessels on the microscopic level, and of differentiating and characterizing them according to the geological characteristics of the raw materials used in their production (e.g. Shepard 1956; Peacock 1970; Shotton and Hendry 1979; Bishop et al. 1982; Freestone 1991; Whitbread 1995). This data, once integrated with comparative geological information (published maps and descriptions and the results of analyses of rock and clay samples prospected from the area of interest) enables the analyst to predict, or in some cases to identify the area or region in which different fabrics (or pastes) were produced. The potential to differentiate among ceramic products based on their raw materials and to link different fabrics to the geological landscape has led to the technique's widespread application in studies aimed at elucidating patterns of trade, exchange and group interaction.

Over the past two decades, the focus of thin section petrography, as applied in ceramic studies, has expanded to include an assessment of the technological characteristics of ceramic bodies and a wider range of petrographic attributes. This expanded perspective on microscopic analysis and characterization has greatly enhanced the potential of ceramics to inform about a range of past human behaviours related to the production, circulation and use of pottery on various scales of analysis, especially when the technique is used in concert with other means of characterization – for example, conventional typological frameworks focused on stylistic and other visual attributes. Fundamental to this approach is the principal that a ceramic fabric (paste) does not only reflect the geological reality of a particular area, but also human habit/choice in manufacturing procedures (Day et al. 1999; Day 2004). Viewed from this perspective, ceramic fabrics not only inform about the ways in which pottery items were made, but also can be considered as material expressions of group identity and interaction.

### *Sample Preparation*

Thin sections were prepared from the 14 fired clay and artifact samples according to standard procedures. To prepare the thin sections, a cross sectional sample (approximately 2cm in length and 1cm wide) was cut from each of the pottery and pipe fragments submitted for analysis and then trimmed to a size amenable to mounting on a standard-sized geological slide (27mm x 46mm). These samples were then ground on a lap wheel until the surface to be mounted was completely flat and impregnated in epoxy resin blocks under vacuum conditions. The impregnated specimens were subsequently ground and polished on a lap wheel and mounted on glass slides with UV curing optical adhesive. The slide mounted blocks were then trimmed to a 1-2 mm thickness and ground and polished to a uniform thickness of 30 microns.

### *Examination, Characterization and Description of Samples*

When ceramic and geological samples (at a thickness of 30 microns) are examined under a polarizing light microscope in plane polarized (PPL) and cross-polarized light (XPL), and at various magnifications, (x20-x400), rock and mineral inclusions, as well as other compositional features, can be assessed and identified based on their optical properties. Other characteristics that can be examined and described include: physical properties of the clay matrix including colour and birefringence; the nature and abundance of voids; textural properties such as the size (both range and mode), distribution, sorting and packing of aplastic inclusions; the physical properties of aplastic inclusions (e.g. roundness, spheriosity and shape); and the nature and abundance of pedofeatures (e.g. textural, amorphous and crystalline concentration features). These characteristics are assessed using comparative standards. Taken together, these criteria provide a basis for characterizing and comparing a selected sample of specimens based on their geological, compositional and, in the case of ceramic specimens, their technological characteristics. This information enables investigation of provenance (origin of manufacture) based on the source of raw material ingredients or parent geological deposits and formations and, in the case of ceramics, based on shared technological characteristics such as the choice and processing of raw material ingredients, paste recipe and evidence of firing and vessel forming methods.

### *Assessment of Ceramic Samples*

The method of analysis and description employed in the assessment the samples from the Alabama Site follows the descriptive system developed by Whitbread (1989, 1995: 365-396) specifically for the examination and characterization of 'ceramic fabrics'. As used by Whitbread (1995:368), the term ceramic fabric refers to 'the arrangement, size, shape, frequency and composition of components' of a ceramic material, and therefore encompasses both microstructural and compositional characteristics of ceramic bodies. This conceptual approach represents a significant methodological advancement in ceramic petrography, expanding the focus of analysis and characterization beyond a basic description of the rock and mineral content of a ceramic body based on a statistical estimate of the relative frequencies of the different rock and mineral inclusions present, as is the case with point count analysis and other techniques deriving from sedimentary petrology. Whitbread's analytical framework takes into consideration a broader range of physical criteria. These properties and features not only characterize inclusion content, but also the nature of the clay matrix, the character, spatial distribution and frequency of voids, and pedofeatures (features of the clay matrix distinguishable from adjacent material by a difference in concentration in one or more of their components) and the interrelationships of these different components. This comparatively holistic approach to the examination, characterization and description of ceramic bodies acknowledges their inherent compositional complexity and composite nature, that they are 'man-made' materials and, consequently, that fabric properties not only reflect geological characteristics of the raw materials used to create them, but also processes of fabrication. The strength of Whitbread's framework is that it enables a simultaneous assessment of provenance (the source of raw material ingredients) and technological characteristics (the specific way in which a pot was made). Another important advantage of the system is that it permits examination and comparison of multiple aspects of technology, including the selection and treatment of raw materials, paste recipe (the choice and proportions of raw material ingredients), forming techniques and firing strategies (Freestone 1991; Whitbread 1989, 1995, 1996; Tomkins et al. 2004). This information not only informs about production methods, in a general sense, but also variation in technical practices, enabling an additional basis for differentiating a population of ceramic fabrics according to technological criteria (i.e. observable differences fabrication processes). Another advantage is that it permits examination of the association of rock and mineral inclusions and, as a visual technique, textural criteria, enabling fabrics to be subdivided or discriminated based on their geological characteristics, even when they are mineralogically similar.

***Assessment of Comparative Geological Samples***

The geological 'consistency' of modern rock, soil and sediment samples with the clay and temper (if present) components of ceramic fabrics can be assessed and demonstrated through direct comparison of their textural, compositional and physical properties and features. For example, once it has been established that a portion of the rock and mineral fragments present in a ceramic body represents a tempering material that was intentionally added to the clay by the potter, the nature of the parent material from which the temper derives can be inferred based on a range of observable properties, including mineralogical characteristics. Relevant geological samples (e.g. rock samples when is has been established that the temper is a crushed rock) can then be examined and compared for similarity, enabling a means of demonstrating (or discounting) compatibility with geological resources deriving from known physical locations on the landscape. The approach is generally the same for assessing the similarity of the clay component of a ceramic material to samples of clayey soils (ancient or modern); expect that a broader range of characteristics must be taken into consideration, in addition to the physical properties and mineralogy of naturally occurring rock and mineral inclusions. Fundamental to this assessment is the systematic study and characterization of micromorphological attributes and naturally occurring pedofeatures (textural, amorphous and crystalline concentration/depletion features) reflecting soil genesis and, thus, the environmental and depositional context and history of the clay component. The compatibility of Whitbread's descriptive system for technological and a provenance assessment of ceramic materials with that for soils devised by Kemp (1985) and Bullock et al. (1985) enables direct comparison of clayey soils deriving from known sources with the clay component of ceramic bodies and, accordingly, a means of establishing (or discounting) a geological connection between ceramic artifacts and clay resources.

Comparison of ceramic artifacts to geological samples deriving from area surrounding the archaeological site from which the artifacts were recovered provides a means of identifying ceramic objects that were manufactured using raw material resources available in the local area and of discriminating them from comparable objects manufactured elsewhere. The process of demonstrating the 'geoforensic' compatibility of archaeological and geological samples (or lack thereof) based on microscopic evidence begins with establishing a local geological baseline to which the compositional characteristics and properties of the archaeological specimens can be compared. In the study of the Alabama pottery artifacts and building materials, this baseline was constructed by conducting a characterization study of two different building materials and fired samples of clays prospected from the area surrounding the archaeological site using the same assessment criteria as for the archaeological samples. The end result is a descriptive summary of local geological resources not only available for use by the site's inhabitants, but also known to have been exploited by them for other purposes. The main advantages of this approach are that 1) it generates information that is meaningful to the ultimate objective of the study, which is to delineate the technological and provenance characteristics of pottery from three sites under investigation, and 2) it emphasizes the relevant characteristics of local geological resources at a scale appropriate to detailed laboratory analysis. It should be noted, however, that this baseline constitutes a preliminary characterization based on an extremely small sample set of comparative geological samples. It requires expansion through assessment of additional samples (geological and archaeological) and incorporation of information from relevant geological/earth sciences studies and publications.

**Geological Context**

The geology southern Belize, the broad region from which the archaeological samples in this study derive, is rather complex, comprising a wide range of igneous, sedimentary and metamorphic rocks and derived sediments. The cockscomb batholith, which is basically a large body of granite, formed during the Silurian Period, when magma intruded up through the pre-existing sedimentary rock formations of sandstone, shale and limestone. As a result of this intrusion, adjacent areas of sedimentary rock were altered by temperature and pressure, as was the new igneous rock that had formed up against the sedimentary rock, forming a geologically distinct intervening metamorphic aureole.

The Cockscomb batholith, situated inland from the Alabama site, also marks the high point on the landscape. Numerous rivers and stream drain the upland area, forming steep courses, transporting eroded material picked up along the way and depositing it on an extensive alluvial plain. Not surprisingly, the exact composition of the sediments, in terms of the rocks and minerals they contain, reflects contributions from the specific land area different rivers and stream travel through. Accordingly the rock and mineral grain component of associated natural clays will be mineralogically different. Additional observable differences between natural clays relate to soil genesis and depositional history and processes, reflecting the specific environmental context within which they formed. For example ones that form in a high energy environment like a river bank will have different soil-formation-related features than those that form in a low energy land-locked locality.

Taken together this variation is an ideal situation for a petrographic study of pottery, as it permits identification of ceramic bodies made using natural clays and tempering materials deriving from different geographic localities, based on a range of characteristics and features. A summary of relevant geological information has been included as APPENDIX 1.

**Observations Concerning clay samples**

The petrographic characteristics of the clay samples are summarized in Section 2. General observations of note include the following:

- All of the clay samples are micaceous (loads of tiny muscovite & biotite)
- There is significant variation in rock and mineral assemblages and soil-related features that occur in clays found at different localities within the study area. For example, SCP 11, which was taken from a location north site of the archaeological site is comparatively coarse textured, the mineral assemblage has a green schist component and it contains soil fragments and metamorphic rock fragments. In comparison, CP 14, which derives from a stream depostis situated south west of the archaeological site, is comparatively rich in quartz (contains a greater quantity of quartz inclusions proportionately) and contains very few rock fragments. SCP13 is an example of further textural and mineralogical differences betwwen the clay samples, containing

comparatively abundant larger-sized grains, fragments of gnessic metamorphic rock and abundant highly altered alkali feldspar.

- The clay samples are significantly different from pottery in terms of their textural characteristics and the quantity of rock and mineral clasts present. This may suggest that the natural clays used for pottery may have been processed to remove unwanted rock content.
- None of the clay samples are identical to the natural clay-component of any of the pottery sampled. The implication is that the evidence at hand suggest that none of pottery sampled was made from natural clays derived from these specific geographic localities. However, natural clays may have been processed, which is in keeping with observed mineralogical similarity among the clay samples, in general and specific pottery samples, with the textural differences resulting from processing.
- Clay sample SCP9 is petrogrpahically consistent with the daub sample (SCP8), an may have in fact been the source of the clay used to make this building material.

**General Observations concerning the pottery samples**

Detailed Petrographic descriptions of the pottery thin sections are presented in Section 3. Of the six sherds analysed, four are geologically inconsistent with the local clay samples. Significant mineralogical differences suggest that these pottery vessels were made elsewhere. As each of these four fabrics is also unique in its own right, they can be interpreted as deriving from different geographic localities.

***Non-local Pottery***

**SCP 3** contains fragments of phyllite and schist indicating a connection to metamorphosed sedimentary parent rocks fo the Santa Rosa Group. Additionally, rounded and frayed stubs of biotite are abundant in this sample, and it contains these distinctive, well-rounded iron-rich nodules. The fabric is 'sandy-textured', comparatively well-sorted, and the rock and mineral fragments tend to be rounded, akin to a 'well-worked sand'. Taken together these characteristics link this fabric to sediment deposits deriving ultimately from iron-rich sandstones and metamorphosed sedimentary rocks. These are only exposed at specific localities in the Maya Mountains area.

**SCP 4** is tempered with grog and carbonate rock and is therefore a technological outlier within the sample set. Particularly significant is the compositional characteristics of the grog fragments. The clay matrix in at least some of the grog fragments is mineralogically and texturally distinct from the surround ceramic body, and visually and compositionally similar to examples of carbonate-tempered pottery from the Belize Valley, from which carbonate is removed ('burnt out') during firing (see Jordan et al. n.d.). Distinctive characteristics include this fabric are the presence of fine-textured polycrystalline quartz and the use of dolomitic limestone as temper. A local provenance cannot be ruled out completely based on the mineralogy of the clay component alone, being consistent with the geology of the local area. However, the choice of tempering materials and the compositional characteristics of the grog inclusions indicate not only distinctive tempering practice, but the use of grog that the derived from a vessel that was most likely made elsewhere, possibly the Belize Valley. The use of grog and crushed carbonate rock together as tempering materials is a prevalent practice in Northern Belize starting in the Terminal Classic period (Howie 2012). This practice is not known occur outside this area, based on the current petrographic data available, and has not as of yet been observed in the Belize Valley in later time periods.

**SCP5** contains rock and mineral clasts that derive ultimately from an alkali igneous rock parentage and it is rich in muscovite mica. Conspicuous characteristics that clearly differentiate this fabric from all of the other samples are the rarity of biotite and  the specific types of feldspar it contains. Taken together, this fabric is more with the geology of the Hummingbird Batholith area, situated to the north, than the Cockscomb batholith.

**SCP 7**  contains fragments of devitrified volcanoclastic rock, linking it to the Bladen Formation, which is situated on the southern fringe of the Cockscomb batholith. The  rock and mineral fragments in this fabric, including the volcanoclastic component, tend to be rounded, suggesting the presence of a sand, possibility an added tempering material, and/or and the clay derived from a deposited situated on the coastal plain.

***Local Pottery***

**SCP 1 and SP6** are not only consistent with the geology of the local area, but share important similarities to the bildking material samples. These include: the prevalence and co-occurrence of muscovite, the sample feldspar assemblage, especially the presence of highly altered alkali feldspar, and textually and mineralogially similar fine fraction and the oranish to reddish brown colour of the micromass (clay matrix). T

**SPC 1** - This fabric can be characterized as a poorly sorted, sandy-textured, immature clay containing abundant muscovite and biotite, and a smaller quantity of quartz, feldspar and few igneous and metamorphic rock fragments, tempered with crushed igneous rock.  The igneous rock temper occurs as very angular to subangular rock fragments and derived terminal grades and mineral fragments. Larger-sized rock and mineral fragments are unevenly distributed across the thin section and exhibit shattered edges indicative of mechanical crushing. The presence of temper gives the fabric a bimodal appearance.

The igneous rock temper is a two-mica granite mineralogically consistent with the Cockscomb batholith. The rock and mineral component of the clay overlaps in mineralogically with the temper indicating that it too derives from the local area  containing transported material derived ultimately from Cockscomb granite, and thus that it too derived from the local area. Metamorphic rock fragments represent transported materials derived from the metamorphic aureole surrounding the main batholith. The occurrence of comparatively rounded grains of quartz s and feldspar alongside subangular to angular grains suggests the clay contains a mixture of older and younger transported material (multiple depositional episodes). The tendency towards comparative angular grains and the presence of rock fragments indicated a immature, possibly  land-based deposit.

**SCP 6 -** This fabric can be characterized as a comparatively well-sorted, sandy-textured, clay containing abundant muscovite, quartz and feldspar, tempered with crushed igneous rock (granite). The igneous rock temper occurs as very angular to subangular rock fragments and derived terminal grades and mineral fragments. Larger-sized rock and mineral fragments are unevenly distributed across the thin section. The presence of temper gives the fabric a bimodal appearance.

The igneous rock temper is a two-mica granite mineralogically consistent with the Cockscomb batholith. The rock and mineral component of the clay overlaps in mineralogically with the temper indicating that it too derives from the local area, containing transported material derived ultimately from Cockscomb granite, and thus that it too derived from the local area. The tendency towards comparative angular grains and the presence of soil fragments indicates a immature, land-based deposit.

**General Observations concerning building materials**

**SCP8** - SCP8 is a sample of daub. it is petrographically identical to clay sample SCP9, in all respects, expect for the presence of material that can best be described as masonry debris. Clay sample SCP 9 was collected from an area across the stream from the archaeological site. Both SCP 9 and the daub sample can be characterized as fine-textured, micaceous, silty clays devoid of larger rock and mineral fragments. But unlike the clay sample, SCP8 contains 'swirls' of very small, angular mineral fragments that have shattered edges. This is consistent with mechanical crushing and suggests that this is likely masonry debris, which might have been intentionally or incidentally incorporated into the wet mixture before it was applied to the building. The daub sample documents the use of a natural clay with very specific textural characteristics for a specific purpose, and this clay, although known and used, was not used in pottery production.

**SCP2** - SCP2 is a sample from a work surface. It documents the use of natural clayey soil with very different characteristics. By contrast this raw material is sandy-textured and contains abundant, large-sized rock and mineral clast and soil fragments. A distinctive characteristic is the presence of clay accumulation features. it is unclear if these are postdepostional features or a compositional characteristic of the natural clay itself.

## Section 2 – Petrographic characteristics of SCRAP clay samples

| | SCP9 | SCP10 | SCP11 |
|---|---|---|---|
| | **well-sorted, silty delta clay?** | **immature, clay-rich** | **mature, quartz-rich/soil fragments** |
| **Textural and Physical Characteristics** | | | |
| **coarse fraction: fine fraction (<10µ)** | 30:70 | 50:50 | +50:50 |
| **general characteristics of groundmass** | delta clay with distinctive "streaky" birefringence; clay-rich but silty; brown/golden-brown; prevalent mica | delta component; silty; brown/golden brown, golden orange; prevalent mica (muscovite and biotite) | delta component; silty; brown/dark greyish brown; prevalent mica, muscovite predominant |
| **inclusion packing** | open-spaced | single-spaced | close-spaced |
| **inclusion sorting** | very well sorted | poorly sorted | very poorly sorted |
| **Characteristics of Inclusions** | | | |
| **roundness** | very angular; rarely sub-angular | very angular to round; predominant sub-angular | very angular to sub-rounded; predominant sub-angular |
| **Size( mm) largest of all/ range of 98%** | 1.140/<0.023 very coarse sand to medium silt; large = feldspar, small = quartz | 5.772/<0.023 granule to medium silt; large = rock frag., small = mica | 3.454/<0.023 granule to medium silt; large = quartz (strongly undulose) |
| **mode size (mm)** | 0.047 coarse silt; rare grains> 0.163 quartz and feldspar | 0.116 fine sand; micas | 0.047 coarse silt |
| **Composition of Inclusions (mineralogy and *relative proportion)** | | | |
| **quartz** | common; mostly monocrystalline/some polycrystalline; very angular to angular (rare), equant; large = 0.744 mm (poly) coarse sand | common; monocrystalline and polycrystalline; very angular to sub-angular; equant to elongated; large = 2.772 mm granule (poly) | common; monocrystalline and polycrystalline (mono = terminal grade/frags from rocks); large = 3.727 mm granule (poly) |
| **feldspar** | common; seriticized, microcline, alkali; very angular to angular, equant to elongated; large = 1.140 very coarse sand | common; very angular to sub-angular; equant to elongated; large = 2.559 mm granule | very few; highly altered with oxides in cracks/cleavages, elongated, sub-rounded; completely seriticized, sub-rounded, equant; large = 0.455 mm medium sand |
| **muscovite** | frequent; laths; large = 0.279 mm medium sand; mode = 0.070 fine sand | frequent; large = 0.605 mm coarse sand | dominant; laths and crystal "masses"; light brown mica with metamorphic texture |
| **biotite** | frequent; laths; large = 0.279 mm medium sand; mode = 0.070 fine sand | frequent; large = 0.465 mm medium sand | few; angular to sub-angular laths, some frayed; large = 0.455 mm medium sand |
| **rock fragments** | | few; metamorphosed igneous: seriticized feldspar + quartz, quartz + chlorite, feldspar + quartz+ muscovite, cracking w/ secondary mineral formation; metamorphic rocks with gneissic textures and recrystallization; sub-angular to sub-rounded, large = 5.772 mm granule, small = 0.233 mm fine sand | very few; metamorphic rock fragments: feldspar + muscovite (gneissic), muscovite + quartz, feldspar (microcline and plagioclase) ossilatory zoning + mica, sub-angular to sub-rounded,elongtated |
| **other inclusions** | | | 1) tourmaline (?): rare, triangular, green/brown w/ chemical zoning<br>2) chlorite (?): very rare, blueish green/greyish, 0.0855 mm very fine sand |
| **Naturally occurring Soil Features (pedofeatures)** | | | |
| **Textural Concentration Features** | few – iron-rich segregations | rare – segregations, impregnations | few; soil frags/iron-rich sedimentary rocks, mode = 0.636 mm;<br>dark brown clay frags, equant to elongated, rounded, clear to sharp |
| **Amorphous Concentration Features (% field of view/type)** | 2%/nodules; dark reddish brown to black; equant; sharp; mode = 0.047 mm | 1-2%/nodules; brownish black/black, equant, sharp, mode = 0.6363 mm; iron-rich concretions containing equant/elongated, sub-rounded mineral frags, large = 1.768 mm | reddish/brownish black nodules, high opacity, rounded/equant, <0.186 mm |
| **Comment** | silty; coarse-very coasre sand sized clasts are very rare | minerals derive from rocks and are terminal grades/frags, contains older sediments | light brown muscovite are masses w/ metamorphic frags; quartz rich = mature, sub-rounded grains; contains older sediments |

*frequent = 30-50%; common = 15-30%; few = 5-15%; very few = 2-5%; rare = 0.5-2%; very rare = <0.5%

| | SCP12 | SCP13 | SCP14 |
|---|---|---|---|
| | **immature, inclusion-rich** | **intermediate, rich in large metamorphic clasts** | **mature, quartz-rich, soil fragments** |
| **Textural and Physical Characteristics** | | | |
| **coarse fraction: fine fraction (<10µm)** | >70:20 | 40:60 | +50:50 |
| **general characteristics of groundmass** | sandy/silty clay; brown/dark greyish brown; prevalent mica, primarily biotite | coarse sandy/silty; dark brown/dark orange brown/dark greyish brown; large muscovite frags | sandy/silty; brown/dark brown/dark greyish brown; visibly less mica, silt-sized, predominantly muscovite |
| **inclusion packing** | close-spaced | single-spaced | close-spaced |
| **inclusion sorting** | poorly sorted | very poorly sorted | poorly sorted |
| **Characteristics of Inclusions** | | | |
| **roundness** | very angular to sub-angular; mostly angular | angular to rounded; most sub-angular to sub-rounded | very angular to sub-angular |
| **Size( mm) largest of all/ range of 98%** | 2.591/<0.023 granule to medium silt; large = polycrystalline quartz | 4.561/<0.023 granule to medium silt; large = polycrystalline quartz | 3.136/<0.023granule to medium silt; large = polycrystalline quartz |
| **mode size (mm)** | 0.163 fine sand | 0.233 fine sand | 0.116 fine sand (quartz); 0.047 coarse silt (mica) |
| **Composition of Inclusions (mineralogy and *relative proportion)** | | | |
| **quartz** | common; very angular to sub-rounded; equant (mono & poly); undulose to strongly undulose; large = 2.591 mm granule | few; angular to sub-angular; equant to elongated; monocrystalline and polycrystalline; mono = terminal grades, poly = granular & crenulated; large = 4.561 (poly) | frequent; monocrystalline and polycrystalline/crenulated; strongly undulose; very angular to angular; equant to elongated; poly w/ oxids in cracks; large 3.136 granule |
| **feldspar** | common; microcline, alkali, plagioclase, altered w/ granular intergrowths, seriticized; very angular to sub-rounded, equant to elongated; large = 1.651 mm very coarse sand | common; sub-angular to sub-rounded; equant; seriticized: large = 1.5 mm very coarse sand; alkali: large = 2.727 mm granule; altered secondary mineral formation in cracks | prevalent; plagioclase (sub-angular); highly altered alkali (sub-rounded); seriticized (sub-rounded); microcline (sub-angular) |
| **muscovite** | frequent; laths and needles; large = 0.651 mm coarse sand | few; angular to sub-angular laths; angular to round elongated masses; kinked and wavy; large = 1.682 mm very coarse sand | frequent; needles; large = 0.372 mm medium sand |
| **biotite** | common; laths and needles, frayed; large = 0.651 mm medium sand | common; angular to sub-rounded; altered laths; frayed laths; stubby needlelike laths; large = 0.727 mm coarse sand | very few; stubby needles, laths; mode = 0.070 mm very fine sand |
| **amphibole** | very rare; equant; strongly pleochroic; chemical zoning; large = 0.09 mm very fine sand | very rare; equant; strongly pleochroic; chemical zoning; large 0.093 mm very fine sand | very rare; equant; strongly pleochroic; chemical zoning; large = 0.2545 mm medium sand |
| **rock fragments** | few/very few; metamorphic rocks, metamorphosed granite; muscovite + quartz + feldspar (microcline); quartz + muscovite + feldspar ("granular"); muscovite + feldspar; large = 1.070 mm very coarse sand | common; gneissic metamorphic rocks: granular quartz+ feldspar + muscovite; granular quartz + muscovite; seriticized feldspar + muscovite; alkali feldspar + granular quartz w/ secondary mineral formation; large = 3.5 mm granule | very rare; metamorphic, metagranite; quartz + muscovite; quartz + feldspar; sub-angular; equant to elongated |
| **other inclusions** | charred plant matter: very rare | schist (?): very rare (1 piece); elongated, sub-angular | 1) chlorite (?): blue-green; cubic?; XP = greenish grey; strongly pleochroic (blue) ; large = 0.116 mm fine sand; 3$^{rd}$ order birefringe; 2) unknown (?): non-pleochroic; dark green; large = 2.954 mm granule, small = 0.093 mm very fine sand<br>3) garnet |
| **Naturally occurring Soil Features (pedofeatures)** | | | |
| **Textural Concentration Features** | none | none | 1) very large soil fragments; iron-rich areas, shrink voids; 2) clay accumulation frags |
| **Amorphous Concentration Features (% field of view/type)** | 2% nodules; high opacity; brownish black; equant; rounded to amorphous; sharp to clear | 2% nodules; high opacity; brownish black; equant; rounded to amorphous; sharp to clear; large = 0.1818 mm; mode = 0.0182 | 7% nodules; high opacity; brownish black; equant; rounded to amorphous; sharp to clear; derive from clay accumulations or feldspars |
| **Comment** | some inclusions w/oxide crusts; quartz shapes reflect crenulated crystals; no mica masses, altered biotite (dark brown/black) | some grains have iron oxidation on exterior (seriticized feldspars): contains older sediments, | inclusions show alteration on edges; quartz with staurolite inclusions, contains older sediments |
| *frequent = 30-50% common = 15-30% few = 5-15% very few = 2-5% rare = 0.5-2% very rare = <0.5% | | | |

## Section 3 – Petrographic Descriptions

***Pottery Samples***

**Cockscomb- granite tempered Fabric #1**

**Sample No:** SCP 1

**Related Geological Sample**: no specific match

I Microstructure

(a) ***Voids**:* few voids (5-10% of total field of view), predominantly meso- and macro channels and meso- to macrovughs. Larger rock and mineral clasts are surrounded by channel-like shrink voids.
(b) ***c/f related distribution:*** A single-spaced to close-spaced, porphyric related distribution.
(c) ***Preferred orientation**:* A moderately developed preferred orientation of inclusions and voids parallel to sub-parallel (c. 45˚) to the vessel margins.

II Groundmass

(d) ***Homogeneity:*** there is variation within this fabric with respect to the distribution of larger-sized rock fragments. The finer grains are distributed evenly, as are voids, and colour and optical activity of the micromass (clay matrix) are homogenous throughout..
(e) ***Micromass:*** optically very active with a strial B-fabric. Colour: PPL(x40) = reddish brown; XP(x40) = dark orangish brown.
(f) ***Inclusions:*** The size distribution of inclusions ranges from 0.009mm – 4.54mm, and is bimodal, with an upper mode comprised exclusively of coarse-sand- to pebble- sized, angular to sub rounded fragments of igneous rock and derived mineral fragments (mode size = c. 0.95mm); and a lower size mode comprising fine-silt to medium-sand-sized, very angular to sub-rounded mineral inclusions and fragments (mode size = c. 0.009mm). Inclusions are very poorly sorted and equant to elongated. Inclusions associated with the clay component are predominantly needle-like laths of mica and subangular to subrounded mineral grains, whilst the igneous rock and associated mineral fragments (representing added temper) are angular to subangular

**Relative abundance (% proportion of field of view) of coarse fraction, fine fraction and voids**
coarse fraction = >10µ (upper limit of the micromass) $c:f:v_{10\mu}$ = 45:45:10
coarse fraction = >0.5mm (coarse sand/medium sand boundary) $c:f:v_{0.5mm}$ = 10:80:10

**Coarse Inclusions (>0.5mm**)
**Common (15-30%):** MONOCRYSTALLINE AND POLYCRYSTALLINE QUARTZ – predominantly very angular to angular and occasionally rounded to subrounded. Grains are non-undulose to slightly undulose. Very angular to angular inclusions are terminal grades and mineral fragments derived from (meta)igneous rock (added as temper), whereas rounded to subroundeded inclusions are associated with the clay component. Size = 1.67mm to 0.5mm.
FELDSPAR – microcline ('tartan' twinning), highly altered alkali feldspar (simple twinning), plagioclase (multiple twinning), and rare intergrowths of microcline and alkali feldspar or plagioclase (<1%); subangular to subrounded; equant to elongated. Subangular inclusions are terminal grades and mineral fragments deriving from (meta) igneous rock (added as temper). Subrounded inclusions are associated with the clay component and tend to be equant. Size = 2.14mm to 0.5mm.

MUSCOVITE – very angular to angular needle-like grains and laths and stubby rounded laths. Size = 0.53mm to 0.5mm.
BIOTITE – very angular to angular needle-like grains and laths and stubby rounded laths. Rounded laths exhibit fraying and splitting along cleavage planes, indicating a sedimentary origin. Size = 0.74mm to 0.5mm.
IGNEOUS ROCK FRAGMENTS (granite) – predominantly very angular to angular and rarely subangular; equant to elongated. Exact mineral composition of individual fragments varies (muscovite + microcline, intergrowths of microcline and plagioclase + muscovite +intergrowths of biotite and muscovite, quartz + alkali feldspar, quartz + biotite) and indicate that the parent rock is a 'two mica granite' composed of quartz, alkali and plagioclase feldspar, muscovite and biotite. Size = 4.54mm – 0.5mm .
**Very Rare (<0.5%)** METAMORPHIC ROCK FRAGMENT - subangular, elongated grain of metamorphose granite composed of strained quartz + granular feldspar + muscovite + tourmaline(?) Size =1.95mm.

**Fine Inclusions (<0.5 mm)**
**Frequent (30-50%):** MUSCOVITE – very angular needle-like grain and laths.
**Common (15-30%):** BIOTITE – very angular laths.
MONOCRYSTALLINE AND POLYCRYSTALLINE QUARTZ – very angular to rounded; equant to elongated. Grains are both non-undulatory and exhibit varying degrees of undulose extinction.
FELDSPAR – microcline ('tartan' twinning), highly altered alkali feldspar (simple twinning), plagioclase (multiple twinning); subangular to subrounded; equant to elongated.
**Very Rare (<0.5%)** PHYLLITE – subrounded; elongated

III Textural Concentration Features (Tcf)

None

IV Amorphous Concentration Features (Acf)

1) **Fe-rich impregnations** - rare (1% of total field of view) - areas of impregnated matrix and groundmass (areas comprising clay and inclusions) that are less optically active and characterized by high optical density owing to high concentrations of Fe compounds. Morphology is generally ovoid to irregular and boundaries are diffuse to merging. Colour: PPL and XP = dark orangish brown to dark reddish brown
2) **'Sinuous' Fe-rich impregnation** – very rare (only one) – a discrete, sinuous area of impregnated matrix and groundmass (areas comprising clay and inclusions) that is less optically active and characterized by high optical density owing to high concentrations of Fe compounds. It has a very well-developed preferred orientation parallel to vessel margins. Boundaries are diffuse to merging. Colour: PPL (x40) = dark brown. XP(x40) = dark orangish-brown.
3) **– Fe/Mn nodules** – few (10% of total filed of view) – These are discrete spherical to elongated growths and 'fragments' that have high optical density and sharp to clear boundaries. In some cases angularity suggests they might be highly chemically altered mineral fragments as opposed to fragments of nodules. Colour: PPL and XP – brownish black. Mode Size = 0.02mm.

IV COMMENT

***Paste Technology -*** This fabric can be characterized as a poorly sorted, sandy-textured, immature clay containing abundant muscovite and biotite, and a smaller quantity of quartz, feldspar and few igneous and metamorphic rock fragments, tempered with crushed igneous rock. The igneous rock temper occurs as very angular to subangular rock fragments and derived terminal grades and mineral fragments. Larger-sized rock and mineral fragments are unevenly distributed across the thin section and exhibit shattered edges indicative of mechanical crushing. The presence of temper gives the fabric a bimodal appearance.

***Provenance*** - consistent with the geology of the local area
The igneous rock temper is a two-mica granite mineralogically consistent with the Cockscomb batholith. The rock and mineral component of the clay overlaps in mineralogically with the temper indicating that it too derives from the local area containing transported material derived ultimately from Cockscomb granite, and thus that it too derived from the local area. Metamorphic rock fragments represent transported materials derived from the metamorphic aureole surrounding the main batholith. The occurrence of comparatively rounded grains of quartz s and feldspar alongside subangular to angular grains suggests the clay contains a mixture of older and younger transported material (multiple depositional episodes). The tendency towards comparative angular grains and the presence of rock fragments indicated a immature, possibly land-based deposit.

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**Sandy, untempered fabric**

**Sample No:** SCP 3

**Related Geological Sample**: no specific match

I Microstructure

(a) ***Voids**:* common voids (15% of total field of view), predominantly meso- and macro channels and meso- to macrovughs. Frayed biotite fragments and spherical nodules are commonly surrounded by a channel-like shrink void.
(b) ***c/f related distribution:*** A single-spaced to open-spaced, porphyric related distribution.
(c) ***Preferred orientation**:* A well-developed preferred orientation voids parallel to the vessel margins. The orientation of inclusions is less well-developed, but generally parallel to sub-parallel (c. 45˚) to the vessel margins.

II Groundmass

(d) ***Homogeneity:** homogenous throughout* with respect to the distribution of voids and inclusions, as well as the colour and optical activity of the micromass (clay matrix).
(e) ***Micromass:*** optically very active with a unistrial b-frabic, sub-parallel with the vessel walls. Colour: PPL(x40) = brown; XP(x40) = yellowish brown.
(f) ***Inclusions:*** The size distribution of inclusions ranges from 0.009mm – 1.364mm, and is unimodal, with a mode size of medium sand. The large majority of inclusions (98%) are smaller than 1.14mm (very coarse sand), and tend toward the sand-sized range. Inclusions are moderately sorted, predominantly rounded to subrounded and range from equant to elongated. The prevalent frayed biotite stubs are commonly subangular to angular.

**Relative abundance (% proportion of field of view) of coarse fraction, fine fraction and voids**
coarse fraction = >10µ (upper limit of the micromass) $c:f:v_{10\mu}$ = 40:45:15
coarse fraction = >0.5mm (coarse silt/very fine sand boundary) $c:f:v_{0.5mm}$ = 30:55:15

**Coarse Inclusions (>0.0625mm**)
**Common (15-30%):** MONOCRYSTALLINE QUARTZ– predominantly angular to subrounded and occasionally very angular. Grains are predominantly non-undulose to and occasionally slightly undulose. Size = 1.36mm to 0.0625mm.
FELDSPAR – predominantly microcline ('tartan' twinning), highly altered alkali feldspar (simple twinning) and occasionally plagioclase. A few grains exhibit perthtic textures; subangular to subrounded; predominantly equant and occasionally elongated. Size = 0.65mm to 0.0625mm.
MUSCOVITE – subangular laths. Size = 0.0.56mm to 0.0625mm.
BIOTITE – subangular to subrounded laths and frayed laths, many of which exhibit splitting along cleavage planes, indicating a sedimentary origin. Size = 0.1.363mm to 0.0625mm.
**Few (5-15%):** IGNEOUS ROCK FRAGMENTS (granite) – subangular to subrounded; equant to elongated. Exact mineral composition of individual fragments varies (alkali feldspar + biotite, plagioclase + quartz, alkali feldspar + muscovite) and indicate that the parent rock is a 'two mica granite' composed of quartz, alkali feldspar, plagioclase feldspar, muscovite and biotite. Size = 0.45mm to 0.0625mm.
**Rare (0.5-2%):** METAMORPHIC ROCK FRAGMENTS – subrounded, equant to elongated grains composed of strained quart + feldspar + muscovite. Size =0.74mm.
PHYLLITE – subrounded, elongated grains composed predominantly of biotite and quartz. Size = 1.22mm to 0.0625mm.
MUDSTONE – subrounded, elongated grains, dark brown in colour (dark reddish brown in XP). Size = 0.62 to 0.0625mm.
FINE-TEXTURED SANDSTONE – subrounded, equant. Size = 0.32mm to 0.0625mm
**Very Rare (<0.5%) -** POLYCRYSTALLINE QUARTZ
ZIRCON – angular triangular prismatic crystal. Size = 0.045mm.

**Fine Inclusions (<0.5 mm)**
**Frequent (30-50%):** MONOCRYSTALLINE QUARTZ; FELDSPAR
**Common (15-30%):** BIOTITE
**Few (5-15%):** MUSCOVITE
**Very Rare (<0.5%):**- AMPHIBOLE

III Textural Concentration Features (Tcf)

None

IV Amorphous Concentration Features (Acf)

**1) Fe-rich impregnations** - rare (1% of total field of view) - areas of impregnated matrix and groundmass (areas comprising clay and inclusions) that are less optically active and characterized by high optical density owing to high concentrations of Fe compounds. Morphology is generally ovoid to irregular and boundaries are diffuse to merging.

2) **– Fe/Mn nodules** – few (7% of total field of view) – These are discrete spherical to irregular-shaped growths that have high optical density and clear to diffuse boundaries. Colour: PPL and XP – brownish black. Mode Size = 0.02mm.

3) **Rounded to ovoid Fe-rich inclusions** – rare (1% of total field of view) - These are discrete spherical, ovoid and 'sausage-like' inclusions that have high optical density and sharp to clear boundaries. They are commonly surrounded by a channel void. Colour: PPL and XP = brownish black. Size = 0.47mm to 0.047mm

IV COMMENT

***Paste Technology***

This fabric can be characterized as moderately sorted, sandy-textured, immature clay containing abundant inclusions of quartz, feldspar, frayed biotite, muscovite, a small quantity of sedimentary and metamorphic rock clasts and rare zircon grains. As rock and mineral clasts are evenly distributed throughout, with a unimodal size distribution, and the different grain types are of similar size and roundedness, there is no compelling evidence of the presence of a tempering material. However, some clasts have oxide or clay coatings, suggesting a sedimentary origin. Additionally, conspicuous stubby biotite baths are commonly frayed – also indicative of a sedimentary origin. It is possible, therefore, that some of the clasts represent a sand that was intentionally added to modify the textural and/or behavioural properties of the clay. The discrete spherical, ovoid and 'sausage-like' inclusions are distinctive and clearly differentiate this fabric from the others analyzed.

***Provenance*** - consistent with the geology of the local area

The mineralogy of the coarse fraction of the clay, with feldspar, quartz, biotite and muscovite present, indicates that the parent rock was a two-mica granite, the dominant rock type forming the Cockscomb batholith. The sandstone, mudstone and phyllite clasts are consistent with the Santa Rosa Group formation, which flanks the batholith on all sides. The metamorphic rock fragments derive from the intervening metamorphic aureole. The presence of transported material derived from at least three areas dominated by different rock formations, suggests a clay derived from a watershed (creek and stream system that traverses multiple rock formations), on the coastal plain.

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**Grog-tempered fabric**

**Sample No:** SCP 4

**Related Geological Sample**: no specific match

I Microstructure

(a) ***Voids****:* Common (20% of total field of view)

forming-related voids - few (5% of total field of view), predominantly meso- channels and vughs..

carbonate 'ghosts'**-** common (15% of total field of view) - voids with very angular to angular margins resulting from the removal of carbonate rock and mineral fragments that were originally present. Morphologies reflect predominantly angular to subangular discrete grains of carbonate and multi-mineralic mosaics. Some are rhombic, suggesting that the original rock may have been a dolomitic limestone. Some have dark brown hypocoatings. These voids are present in both the groundmass and the grog inclusions. The size of the voids ranges from 0.16mm (mosaic ghost) to 0.23mm (discrete grain ghost), with a mode size of 0.16mm ).

plant-material-related - very rare – thin, channel-like voids with rounded margins and bordered by dark brown hypocoatings. The morphology reflects a grassy plant material.

(b) ***c/f related distribution:*** A n open-spaced, porphyric related distribution.

(c) ***Preferred orientation****:* A random orientation of inclusions and voids.

II Groundmass

(d) ***Homogeneity:*** there is variation within this fabric with respect to the distribution of carbonate ghosts and inclusions; with some clustering of both, and matrix dominated areas containing comparative little of both. Colour and optical activity is homogenous throughout.

(e) ***Micromass:*** optically active with a crystallitic and striated B-fabric. Colour: PPL(x40) = light greyish brown; XP(x40) = greyish yellow.

(f) ***Inclusions:*** The size distribution of inclusions ranges from 0.009mm – 4.54mm, and is bimodal, with an upper mode comprising nearly exclusively coarse-sand- to granule- sized, angular to subangular fragments of grog (one feldspar fragment is present); and a lower size mode comprising silt- to medium sand-sized, subangular to rounded mineral inclusions and fragments (mode size = c. 0.009mm). The mineral inclusions are well-sorted and generally equant.

**Relative abundance (% proportion of field of view) of coarse fraction, fine fraction and voids**

coarse fraction = >10µ (upper limit of the micromass) $c:f:v_{10\mu}$ = 30:50:20

coarse fraction = >0.5mm (coarse sand/medium sand boundary) $c:f:v_{0.5mm}$ = 5:75:20

**Coarse Inclusions (>0.5mm**)

**Predominant(>70%):** GROG – angular to subangular, equant to elongated fragments. The groundmass contains sparse inclusions of quartz, muscovite and possible feldspar. The presence of calcite ghosts indicate that the parent pottery contained carbonate. Void morphologies suggest that this carbonate material was angular to very angular, coarse-sand-sized inclusions of sparry calcite. Size = 2.36mm to 0.5mm.

**Few (5-15%):** MONOCRYSTALLINE AND POLYCRYSTALLINE QUARTZ – subangular to subrounded; equant to elongated. The monocrystalline grains are exhibit undulose extinction. Polycrystalline grains are fine-textured. Size = 0.57mm to 0.5mm.

**Very Rare (<0.5%):** ALKALI FELDSPAR – one subangular, elongated grain, which as an oxide coating. Size = 2.36mm.

BURNT PLANT MATTER – woody plant material exhibiting a cellular structure. Size = 0.59mm.

**Fine Inclusions (<0.5 mm)**

**Dominant (50-70%):** MUSCOVITE – very angular needle-like grains and laths.

**Common (15-30%):** MONOCRYSTALLINE AND POLYCRYSTALLINE QUARTZ – very angular to rounded; generally equant. Moncrystalline grains appear to be terminal grades of the polycrystalline grains. Grains are both non-undulatory and undulose.

**Few (5-15%):** BIOTITE – very angular laths.

varying degrees of undulose extinction.

FELDSPAR – microcline ('tartan' twinning), highly altered alkali feldspar (simple twinning), plagioclase (multiple twinning); subangular to subrounded; equant to elongated.

**Very Few (<0.5%):** GROG – angular to subangular, equant to elongated.

III Textural Concentration Features (Tcf)

**Clay Pellets** – rare (1% of total field of view – These are compositionally the same as the surrounding matrix in terms of textural characteristics and inclusion content , and are generally ovoid, with one example having a 'pinched' appearance. This deformation is evidence of plasticity and presence of absorbed water. One large example (size = 2.2mm ) is partly surrounded by a channel void.

IV Amorphous Concentration Features (Acf)

3) **– Fe/Mn nodules** – few (10% of total field of view) – These are discrete spherical to elongated growths that have high optical density and sharp to clear boundaries. PPL and XP – brownish black. Mode Size = 0.03mm.

IV COMMENT

***Paste Technology -*** This fabric can be characterized as a well sorted, clay containing abundant muscovite and quartz, tempered with grog and crushed carbonate rock. Both clay-based body and the grog temper originally contained carbonate inclusions, as indicated by the presence of calcite ghosts. These ghosts are generally angular and unevenly distributed throughout the thin section, suggesting that they represent a carbonate temper that was present in the original ceramic body. The presence of rhombic voids suggests that the parent rock might have been a dolomitic limestone. Compositionally, the grog differs from of the surrounding clay matrix, suggesting it derives from a ceramic body made from different raw material ingredients.

This fabric contains relatively few voids related to vessel forming, especially channel voids. This suggests that a different forming technique was employed to make this vessel

***Provenance*** - possibly local clay, non-local tempering practice and grog
The mineral assemblage is generally consistent with the local geology, derived ultimately from granitic parent rock. However, unlike other fabrics in the sample set, feldspar is rare. The grog temper is visually and compositionally similar to examples of carbonate-tempered pottery from the Belize Valley, from which carbonate was removed ('burnt out') during firing (see Jordan et al. n.d.). Distinctive characteristics include this fabric are the presence of fine-textured polycrystalline quartz and the use of dolomitic limestone as temper. A local provenance cannot be ruled out completely based on the mineralogy of the clay component alone, being consistent with the geology of the local area. However, the choice of tempering materials and the compositional characteristics of the grog inclusions indicate not only distinctive tempering practice, but the use of grog that the derived from a vessel that was most likely made elsewhere, possibly the Belize Valley. The use of grog and crushed carbonate rock together as tempering materials is a prevalent practice in Northern Belize starting in the Terminal Classic period (Howie 2012). This practice is not known occur outside this area, based on the current petrographic data available, and has not as of yet been observed in the Belize Valley in later time periods.

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**Cockscomb- granite-rich Fabric**
**Sample No:** SCP 5

**Related Geological Sample**: no specific match

I Microstructure

(a) ***Voids**:* common voids (10-20% of total field of view), predominantly meso- and macro channels and meso- to macrovughs. Some larger rock and mineral clasts are partly surrounded by channel-like shrink void.
(b) ***c/f related distribution:*** A close-spaced, porphyric related distribution.
(c) ***Preferred orientation**:* A well- developed preferred orientation of voids parallel to sub-parallel (c. 45˚) to the vessel margins. The orientation of inclusions is similar but less well-developed.

II Groundmass

(d) ***Homogeneity:*** homogenous throughout with respect to the distribution of voids and inclusions. The colour of the clay matrix is darker at the margins of the vessel.
(e) ***Micromass:*** optically very active with a crystallitic, monostriated B-fabric. Colour: PPL(x40) = brown with dark brown margins; XP(x40) = dark brown with dark orangish brown margins.
(f) ***Inclusions:*** The size distribution of inclusions ranges from 0.009mm – 2.94mm, and is unimodal, with a mode grain size of fine sand. The large majority of inclusions (98%) are smaller than 1.45mm (very coarse sand), with abundant terminal grades of polycrystalline quartz in the fine sand-sized range. Inclusions are poorly sorted, range from subangular to well rounded and are equant to elongated. The rounded to well rounded inclusions tend to be fine sand-sized inclusions of quartz and feldspar (alkali and plagioclase).

**Relative abundance (% proportion of field of view) of coarse fraction, fine fraction and voids**
coarse fraction = >10µ (upper limit of the micromass) $c{:}f{:}v_{10\mu}$ = 30:50:20
coarse fraction = >0.5mm (coarse sand/medium sand boundary) $c{:}f{:}v_{0.5mm}$ = 25:55:20

**Coarse Inclusions (>0.5mm**)
**Dominant (50-70%):** MONOCRYSTALLINE AND POLYCRYSTALLINE QUARTZ – subangular to subrounded. Grains are non-undulose and undulose. The polycrystalline grains are composed of crystals with a mode size of 0.32mm and have crenulated boundaries. The discrete grains appear to be terminal grades of the polycrystalline clasts. Size = 1.45mm to 0.5mm.
**Common (15-30%):** FELDSPAR – altered microcline ('tartan' twinning), alkali feldspar (simple twinning), plagioclase (multiple twinning) and perthite; dominantly subangular to subrounded, equant to elongated, but smaller grains are generally subrounded to rounded. Size = 2.45mm to 0.5mm.
**Few (5-15%):** MUSCOVITE – very angular to angular needle-like grains and laths and stubby rounded laths. Size = 0.5mm.
BIOTITE – dominantly light brown in PPL; very angular to angular needle-like grains and laths and stubby rounded laths. Rounded laths exhibit fraying and splitting along cleavage planes, indicating a sedimentary origin. Size = 0.5mm.
**Very Few (<0.5%):** IGNEOUS AND METAMORPHOSED IGNEOUS ROCK FRAGMENTS (granite) – subangular to subrounded; equant to elongated. Exact mineral composition of individual fragments varies (quartz + alkali feldspar, microcline + perthite + quartz). The parent rock is a 'two mica granite' composed of quartz, alkali feldspar, perthite, muscovite and light brown biotite. Size = 2.36mm – 0.5mm .

**Fine Inclusions (<0.5 mm)**

**Frequent (30-50%):** BIOTITE – very angular laths. Abundant light brown laths and fewer, highly altered, black laths.

MUSCOVITE – very angular needle-like grain and laths.

MONOCRYSTALLINE AND POLYCRYSTALLINE QUARTZ – subangular to rounded; equant to elongated. Grains are both non-undulatory and exhibit varying degrees of undulose extinction.

**Common (15-30%):** FELDSPAR – plagioclase and microcline; subangular to rounded; equant to elongated.

III Textural Concentration Features (Tcf)

None

IV Amorphous Concentration Features (Acf)

**Fe/Mn nodules** – **rare** (2% of total field of view) – These are discrete spherical growths that have high optical density and sharp to clear boundaries. PPL and XP – brownish black to black (close to margins). Mode ssize = 0.16mm.

IV COMMENT

***Paste Technology -*** This fabric can be characterized as a poorly sorted, sandy-textured clay containing abundant quartz, microcline, perthite and muscovite, and a small quantity of igneous and metamorphic rock fragments. Angular rock and mineral fragments are comparatively infrequent, inclusions are evenly distributed across the thin section, the size distribution of inclusions is unimodal and none of the rock and mineral grains exhibit shattered edges indicative of mechanical crushing. Accordingly, there is no compelling evidence to indicate the presence of a temper and certainly not a crushed rock temper.

Mineralogically distinctive characteristics of this fabric include: the dominant feldspars present-microcline and perthite, the prevalence of muscovite, the comparative infrequency of brown biotite and prevalence, instead, of light brown mica. .

***Provenance*** - inconsistent with the geology of the local area

The mineralogy of the coarse fraction of the clay, with microcline and perthite as the dominant feldspar minerals, abundant muscovite and distinctive light brown mica, indicates that the parent rock was a granite rich in light brown mica and muscovite and containing abundant microcline and feldspars with perthitic textures. Granites with this composition are not characteristic of the Cockscomb batholith. Rather they are typical of the Hummingbird Batholith, situated further to the north. The mineralogy of this fabric, therefore, is consistent with the geology of the area surrounding the Hummingbird batholith. The presence of discrete grains of both undulose quartz derived from metamorphosed igneous rock and plutonic quartz, and the presence of both igneous and metamorphic rock fragments are also consistent with the more complex metamorphic history of the Hummingbird rock formations. Also significant is the co-occurrence of highly altered, black biotite, unaltered grains and frayed, stubby laths, indicating a mixture of older and younger transported material. The occurrence of both comparatively angular and rounded grains also suggests this. This mixing of older and younger sediments suggests that the clay derives from a watershed.

**Cockscomb- granite tempered Fabric #2**

**Sample No:** SCP 6

**Related Geological Sample**: no specific match

I Microstructure

(a) ***Voids**:* few voids (7% of total field of view), predominantly macrovughs. Soil fragments are partly surrounded by channel-like shrink voids.
(b) ***c/f related distribution:*** A single-spaced, porphyric related distribution.
(c) ***Preferred orientation**:* Inclusions and voids generally exhibit a well-developed preferred orientation parallel to the vessel margins except for the larger-sized inclusion, which are randomly oriented.

II Groundmass

(d) ***Homogeneity:*** there is variation within this fabric with respect to the distribution of larger-sized rock fragments, which tend to cluster. The finer grains are distributed evenly, as are voids, and colour and optical activity of the micromass (clay matrix) is homogenous throughout.
(e) ***Micromass:*** optically active with a monostriated B-fabric. Colour: PPL(x40) = orangish brown; XP(x40) = brownish orange.
(f) ***Inclusions:*** The size distribution of inclusions ranges from 0.009mm – 2.04mm, and is bimodal, with an upper mode comprised exclusively of medium to coarse sand-sized, very angular to sub angular igneous rock and derived mineral fragments and soil fragments. The lower size mode consists of very angular to rounded mineral grains with a mode size of very fine sand (0.09mm). Inclusions are equant to elongated and generally poorly sorted, but the lower mode is well-sorted. Inclusions associated with the clay component are predominantly needle-like laths of mica and subangular to subrounded mineral grains, whilst the igneous rock and associated mineral fragments (representing added temper) are very angular to subangular

**Relative abundance (% proportion of field of view) of coarse fraction, fine fraction and voids**
coarse fraction = >10µ (upper limit of the micromass) $c:f:v_{10\mu}$ = 35:55:10
coarse fraction = >0.25mm (medium sand/fine sand boundary) $c:f:v_{0.5mm}$ = 20:70:10

**Coarse Inclusions (>0.25mm**)
**Frequent (30-50%):** MUSCOVITE – very angular to angular needle-like grains and laths and stubby rounded laths, commonly frayed. Size = 0.53mm to 0.5mm.
**Common (15-30%):** MONOCRYSTALLINE AND POLYCRYSTALLINE QUARTZ – predominantly very angular to subangular; equant to elongated. Grains are generally non-undulose and only occassioanlly have undulose extinction. Very angular to angular inclusions are terminal grades and mineral fragments derived from igneous and metamorphosed igneous rock (added as temper). The polycrystalline quartz is composed of comparatively large crystals. Size = 1.54mm to 0.25mm.
FELDSPAR – microcline ('tartan' twinning), alkkali feldspar (simple twinning) and perthite; subangular to subrounded; equant to elongated. Subangular inclusions are terminal grades and mineral fragments deriving from (meta) igneous rock (added as temper). Subrounded inclusions are associated with the clay component and tend to be equant. Size = 1.44mm to 02.5mm.

**Very Few (2-5%)** BIOTITE – subangular to subrounded laths and frayed laths, many of which exhibit splitting along cleavage planes, indicating a sedimentary origin. Size = 0.1.363mm to 0.0625mm.

**Very Rare (<0.5%)** IGNEOUS ROCK FRAGMENTS (granite) – angular; equant to elongated. Exact mineral composition of individual fragments varies (quartz + alkali microcline, muscovite + microcline, intergrowth of muscovite +biotite) and indicates the parent rock is a 'two mica granite' composed of quartz, alkal feldspar, muscovite and biotite. Size = 0.59mm – 0.25mm .

**Fine Inclusions (<0.5 mm)**

**Frequent (30-50%):** MUSCOVITE – very angular needle-like grain and laths.

MONOCRYSTALLINE AND POLYCRYSTALLINE QUARTZ – very angular to rounded; equant to elongated. Grains are both non-undulatory and exhibit varying degrees of undulose extinction.

**Common (15-30%):** FELDSPAR – microcline ('tartan' twinning), highly altered alkali feldspar (simple twinning), plagioclase (multiple twinning); subangular to subrounded; equant to elongated.

**Few (5-15%):** BIOTITE – very angular laths (altered, black biotite and brown biotite)

**Very Rare (<0.5%):** ZIRCON; **A**MPHIBOLE; UNIDENTIFIED GREEN MINERAL (epidote?)

III Textural Concentration Features (Tcf)

**Soil fragments** - rare (2% of total field of view) – These are 'clumps' of impregnated matrix and groundmass (areas comprising clay and inclusions) that are characterized by high optical density owing to high concentrations of Fe compounds. They are discordant with the surrounding matrix, morphology is generally ovoid to irregular and boundaries are sharp to merging. One example is deformed, indicating plasticity, and thus presence of absorbed water. They are commonly at least partly surrounded by a channel-like shrink void. Colour: PPL and XP = dark reddish brown

IV Amorphous Concentration Features (Acf)

**Fe nodules** – few (5% of total field of view) – These are discrete spherical to elongated growths and 'fragments' that have high optical density and sharp to clear boundaries Colour: PPL and XP – dark reddish brown. Mode size = 0.02mm.

IV COMMENT

***Paste Technology -*** This fabric can be characterized as a comparatively well-sorted, sandy-textured, clay containing abundant muscovite, quartz and feldspar, tempered with crushed igneous rock (granite). The igneous rock temper occurs as very angular to subangular rock fragments and derived terminal grades and mineral fragments. Larger-sized rock and mineral fragments are unevenly distributed across the thin section. The presence of temper gives the fabric a bimodal appearance.

***Provenance*** - consistent with the geology of the local area

The igneous rock temper is a two-mica granite mineralogically consistent with the Cockscomb batholith. The rock and mineral component of the clay overlaps in mineralogically with the temper indicating that it too derives from the local area, containing transported material derived ultimately from Cockscomb granite, and thus that it too derived from the local area. The tendency towards comparative angular grains and the presence of soil fragments indicates a immature, land-based deposit.

**Bladen Formation-related Fabric**

**Sample No:** SCP 7
**Related Geological Sample**: no specific match
I Microstructure

(a) ***Voids****:* common voids (25% of total field of view), predominantly meso- and macro channels and meso- to macrovughs. Some larger rock and mineral clasts are partly surrounded by channel-like shrink void.
(b) ***c/f related distribution:*** A single-to double-spaced, porphyric related distribution.
(c) ***Preferred orientation****:* A well- developed preferred orientation of voids parallel to the vessel margins. The orientation of inclusions is similar but less well-developed.

II Groundmass

(d) ***Homogeneity:*** homogenous throughout with respect to the distribution of voids and inclusions. The colour of the clay matrix is darker at the vessel's lip.
(e) ***Micromass:*** optically very active except at the lip, where is only slightly optically active. B-fabric is monstriated to unistrial. Colour: PPL(x40) = brown grading into dark brown at the lip; XP(x40) = orangish brown grading into dark brown at the lip.
(f) ***Inclusions:*** The size distribution of inclusions ranges from 0.009mm – 3.27mm, and is unimodal, with a mode size of fine sand. The large majority of inclusions (98%) are smaller than 2.18mm (very coarse sand), with abundant biotite, quartz and feldspar in the fine sand-sized range. Inclusions are very poorly sorted, range from subangular to rounded and are equant to elongated. The rounded inclusions are predominantly volcanoclastic rock fragments.

**Relative abundance (% proportion of field of view) of coarse fraction, fine fraction and voids**
coarse fraction = >10µ (upper limit of the micromass) $c:f:v_{10\mu}$ = 30:50:20
coarse fraction = >0.5mm (medium sand/fine sand boundary) $c:f:v_{0.25mm}$ = 25:50:25

**Coarse Inclusions (>0.25mm**)
**Frequent (30-50%):** MONOCRYSTALLINE AND POLYCRYSTALLINE QUARTZ – subangular to subrounded. Grains are predominantly non-undulose The discrete grains appear to be terminal grades of the polycrystalline clasts. Size = 1.5mm to 0.25mm.
**Common (15-30%):** FELDSPAR – altered microcline ('tartan' twinning), alkali feldspar (simple twinning) and plagioclase (multiple twinning); subangular to subrounded, equant to elongated. Size =1.55mm to 0.25mm.
**Common (15-30%):** BIOTITE – angular needle-like grains and laths and stubby rounded laths. Rounded laths exhibit fraying and splitting along cleavage planes, indicating a sedimentary origin. Size = 1.27mm - 0.25mm.
**Very few (<0.5%):** VOLCANOCLASITIC ROCK FRAGMENTS - rhyolite and rock fragments composed of crystals of quartz, biotite, feldspar and muscovite (<1.14mm) set in a matrix of volcanic glass. The glassy matrix ranges from altered (yellow in PPL) to heavily oxidized (reddish brown in PPL). Subrounded to rounded; predominantly equant.

MUSCOVITE – predominantly stubby subrounded laths. Size = 0.5mm
IGNEOUS ROCK FRAGMENTS (granite) – subangular to subrounded; equant to elongated. Exact mineral composition of individual fragments varies (quartz + biotite, feldspar + quartz, muscovite+ feldspar). The parent rock is a biotite rich, 'two mica granite'. Size = 1.55 – 0.25mm .

**Fine Inclusions (<0.5 mm)**
**Frequent (30-50%):** BIOTITE
**Common (15-30%):** VOLCANOCLASITIC ROCK FRAGMENTS; QUARTZ; FELDSPAR
**Very few (<0.5%):** RHYOLITE
**Very Rare (<0.5%):** TOURMALINE

III Textural Concentration Features (Tcf)

None

IV Amorphous Concentration Features (Acf)

**Fe nodules** – few (5% of total field of view) – These are discrete spherical to ovoid growths that have high optical density and sharp to clear boundaries. Colour: PPL and XP – black to reddish black and orangish brown. Mode Size = 0.02mm.

IV COMMENT

***Paste Technology -*** This fabric can be characterized as a poorly sorted, sandy clay containing both granitic and volcanoclastic rock and derived mineral fragments, tempered with sand containing a similar range of rock and mineral grains. The presence of a sand temper is suggested by the co-occurrence of both rounded and subangular grains of the same rocks and minerals, and the presence of clay and oxide coatings on the roundeded grains, especially those of larger size. miner mgrcoatingins eral the inclsions of the same tclasts. clastssisting mposed on with a similar rock and mineral assemblage. aleticg a wide rancomparatively well-sorted, sandy-textured, clay containing abundant muscovite, quartz and feldspar, tempered with crushed igneous rock (granite). The igneous rock temper occurs as very angular to subangular rock fragments and derived terminal grades and mineral fragments. Larger-sized rock and mineral fragments are unevenly distributed across the thin section. The presence of temper gives the fabric a bimodal appearance.

***Provenance*** - non-local – inconsistent with the geology of the local area
This fabric contains volcanoclastic rock fragments. These rocks are restricted to the Bladen Formation, which skirts the southern edge of the Cockscomb batholith. Also present are igneous rock fragments and derived mineral grains derived from the Cockscomb batholith. The presence of transported material derived from both these formations, suggests a clay derived from a watershed (creek and stream system that traverses multiple rock formations), on the coastal plain. The presence of sand temper with an overlapping mineralogy supports this interpretation.

## Appendix I - Geological Summary

**Hydrology**
Major nearby watersheds near the site of Alabama are South Stann Creek (north of Alabama) and Swasey Branch (southwest of Alabama) . These watersheds transport material from source. Moving away from parent formations, more recently transported material becomes mixed with older, previously deposited sediments source. The course fraction (above silt-sized) of these older sediments would be expected to be comparatively quartz-rich, contain far less to no rock clasts and composed of sub-rounded to rounded grains with clay or oxide coatings on their surface. All clay-rich sediments deposited along waterways would be expected to contain abundant muscovite and biotite, given the parent formations are granites/metagranite containing muscovite and biotite. Biotite in particular, occurs as frayed, rounded to subrounded 'stubs'. As muscovite is more resistance than biotite to chemical alteration and dissolution, it would be expected that clay-rich sediments would contain predominantly muscovite further away from parent formations. These platy minerals tend to break up into tiny needle-like blades during transport. Because they are light and small in size, they 'float' in moving water and are deposited as generally silt-sized particles , as water flow slows (becomes 'sluggish') at lower elevations. Consequently, delta deposits are rich in these tiny inclusions and larger-sized mineral and rock fragments are comparatively rare, having been deposited further upstream – deposition of larger-sized material depends on slope gradient, water velocity and the weight of clasts. Clasts are deposited when slope gradient and velocity are insufficient to carry them, given their weight.

**Characteristics and Differences among Relevant Geological Formations**

**1)** Cockscomb-Sapote Granites

**Bateson and Hall 1977**

- Two-mica granite: biotite > muscovite
- Muscovite – occurs as scattered cleavage fragments
- Biotite – dark-brown, pleochroic
    - abundant/minute needle-like inclusions – rutile
        - arranged parallel to edges of hexagonal crystals
- Feldspars: perthite; some microcline and orthoclase; smaller crystals of plagioclase
    - Plagioclase: Carlsbad/albite twinning, composition near oligoclase-andesine boundary
        - Many plagioclase crystals have clear outer rim of albite
        - Alteration common – crystals ID only by outline, replaced by white mica
    - Poikilitic relationships between plagioclase and microcline/perthite
- Quartz in large pools and sufficiently abundant for rocks to be called granite
- Accessory/alteration minerals associated with clusters of biotite
    - Apatite (euhedral crystals) and zircons at center of pleochroic haloes in biotite
    - Biotite altered to chloritic minerals w/ associated clusters of brown epidote near faults/crush zones
    - Clinozoisite forms in veins, associated with clumps of mafic minerals
    - Monazite rare accessory – heavy mineral concentrates from Sapote Granite

**Kesler et al. 1974**

- Coarsely porphyritic modal granodiorites: euhedral to subhedral oligoclase laths in matrix of anhedral quartz, alkali feldspar, biotite, and muscovite
- Hornblende in anhedral masses; pyroxene partially altered to biotite

**Shipley 1976**

- Average granite composition: 40% quartz, 25% microcline, 15% plagioclase, 20% biotite; minor muscovite and accessory minerals
- Alteration: chloritization and seriticization; no veining
- Uniform in texture and mineralogy across batholith

**2) Hummingbird-Mullins River Granites**

**Bateson and Hall 1977**

- Similar to other granites but more basic marginal facies
- Quartz as groups of interstitial grains rather than large pools (Cockscomb/Mountain Pine Ridge [MPR])
    - Smaller proportion of rock than in other batholiths
- Normal accessory minerals: apatite, zircon, magnetite
- Granite lower in silica and total alkalies, richer in alumina and total iron than MPR
- Rock becomes more granodioritic/dioritic near intrusive margin
- Rare garnet in granites/metamorphosed country rock contamination from original sediments
- Pomona/False Creek/Mullins River granites show basification

**Kesler et al 1974**

- Muscovite quartz monzonite to biotite granite
- Gneissic textures with xenoblastic feldspars in allotriomorphic granular groundmass of quartz/mica – cataclastic deformation
- Undeformed: medium- to coarse-grained hypidiomorphic granular rocks
    - large subhedral plagioclase; perthite; interstitial quartz
- One true granite matching MPR signatures found in Mullins River sample

**Shipley 1976**

- At least four different rock types w/ distinctive textures and mineralogies
    - Two areas of Muscovite Granite: 10% muscovite, 30% quartz, 40% microcline, 15% plagioclase, 5% biotite
        - Areas separated by SRG metasediments and another granitic phase
        - Big Eddy Creek and Wagner Creek (north of Hummingbird Hwy)
    - Quartz Monzonite: Equal parts euhedral plagioclase and microcline, selectively seriticized plagioclase; lesser amounts quartz and biotite
        - Along Hummingbird Hwy from Middlesex westward
    - Granodiorite: 50% plagioclase, 25% quartz, 15% microcline, 10% biotite; hypidiomorphic-granular, medium grained, gneissic texture along margins
        - North of Pomona and along Mullins River

**3) Metasediments around Alabama (Santa Rosa Group - SRG) – generalized, not specific to locality**

- Alabama is located near SRG unconformity
    - Dominantly banded central argillites and southern argillites flanking Bladen
    - Pocket of arenites near (~10 km?) Alabama
- Arenaceous rocks show few effects of regional metamorphism

    - Quartzites, sandstones, greywackes, conglomerates
    - Matrices show development of sericite and chlorite
    - Welding/suturing of adjacent quartz grains in some examples – near intrusive granites
- Argillaceous rocks – make up most of SRG, show effects of regional and thermal metamorphism
    - Grey or black w/ fine sedimentary banding, BUT some massive bedding
    - Bulk of granular material quartz set in sericite/chlorite/iron oxides matrix
    - Thermal effects near granites superimposed: development of biotite, andalusite/chiastolite, staurolite, and occasionally garnet
        - General recrystallization and not infrequent marked schistosity
- Limestone – dark bands associated with argillaceous rocks
    - Bands composed of crinoids, some bivalves, and corals (near Trio Branch)
    - Unit north of Cockscomb: disoriented crinoidal fragments and some w/o identifiable organic remains
        - Thin interbeds of shale and mudstone
        - Quartz grains included in some limestone units
        - Associated with well-sorted orthoquartzites w/ appreciable carbonate in matrix
- Metamorphism
    - Widespread low-grade regional metamorphism of SRG sediments
        - Younger Cretaceous sediments/intrusive granites unaffected
        - Characteristics – sericitic mica, chlorite, iron oxides
        - Sericitic mica (minute laths) and amorphous chlorite significant part of fine matrix
        - Interstices b/w quartz grains packed with chlorite and sericite in coarse sediments
        - Mica flakes larger in argillaceous rocks – preferred orientation produces phyllitic cleavage
        - Chlorite – occurs as irregular/pale-green/slightly pleochroic amorphous masses
        - Quartz still identifiable as clastic grains w/ little or no recrystallization
        - Occasional detrital zircons and tourmalines also retain clastic characteristics
        - Iron oxide dust (hematite) scattered throughout many rocks
            - Tendency to alignment when under greater degree of pressure
        - Better-sorted sandstones – sericite blades/chlorite/iron molded around clastic grains
        - Calcite in limestones recrystallized – interlocking new grains
            - Small laths of sericite common when limestone contained clay fraction
    - Thermal metamorphism near granites – rarely exceeds andalusite grade
        - Andalusite/chiastolite most common metamorphic minerals w/in aureole
            - Common in argillaceous rocks, less common in arenaceous beds
        - Fabric of arenaceous rocks recrystallized to produce hornfels
            - Matrices contain sericite/chlorite/iron dust
            - Andalusite/chiastolite remain as felted mat of white-mica flakes
        - Very common around eastern granites – less common around MPR
        - Garnets common around Silk Grass Creek and possibly elsewhere (**closer to Mayflower than Alabama**)
            - Small metamorphic garnets in narrow aureole in tributaries of South Branch and North Stann Creek (**more Hummingbird related)**
        - Staurolite in fine-grained sandstone from Silk Grass Creek

    - Tourmaline – present in regionally metamorphosed sediments from detrital origins
        - Aureole rocks contain pale brown/pleochroic/euhedral tourmaline formed contemporaneously w/other metamorphic minerals
            - Boron pneumatolysis (gaseous form of hydrothermal interaction) Explains lack of cored/zoned appearance in thermal metamorphosed tourmalines
    - Shearing effects around fault zone locally alter sediments – fine-grained sediments converted to lustrous phyllites and schists
- Heavy mineral concentrates
    - Granites: zircon, ilmenite, magnetite, cassiterite, tourmaline; some monazite
        - Cockscomb granite: rare tiny flakes of gold
    - SRG sedimentary rocks: ubiquitous well-rounded pinkish zircons; ilmenite, magnetite
    - Thermal aureole rocks: andalusite, chiastolite, epidote; occasional garnet

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