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Microbiological Investigation of Local Native Clays and Samples from the Scripps Ceramic Studio

Kelly Fuller

Microbiological Investigation of Local Native Clays and Samples from the Scripps Ceramic Studio

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Kelly Fuller

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Abstract

This study explores the relationship between microorganisms and clay using samples currently being utilized in the Lincoln Ceramics Studio at Scripps College. Clay science spans disciplines, from geology and soil science to industrial material development and artistic practices. Although biological processes have been thought to effect clay properties such as plasticity and malleability, the interplay between microorganisms and clay minerals has not been thoroughly investigated in the scientific community. Drawing from diverse disciplines, this research investigates the microbial ecology of clay bodies to unveil potential innovations in ceramics production. In this experiment, colony-forming unit (CFU) assays were performed in both processed and native samples to determine the population of microbes. All samples were found to harbor microbes, confirming clay's function as a habitat for microorganisms. Despite efforts to uncover insights into the aging process of clay, statistical analyses between samples yielded non-significant results due to the limited number of replicates. The relationship between clay and biological processes remains elusive and further studies are necessary to determine the mechanisms involved in clay aging. As a pilot study, the experimental design and preliminary data can be used as an example for future art and science students. Clay continues to be one of the most important resources in the world, and as the field of microbiology broadens, so too will our understanding of the links between microorganisms and ceramics.

Introduction

Scientific research subject of clay is an expanding field, especially in physical and chemical sciences including geology and soil science. Advancements in clay science have practical implementation in material development for artistic and industrial fields, from fine art to refractory bricks. Although clay is considered an inorganic material, the interactions occurring between clay minerals and microorganisms is a co-evolving system, much of which is currently unknown. (Fomina & Skorochod, 2020) Investigating the impact of microorganisms within ceramic clay bodies can enable innovations by ceramicists and clay engineers, while simultaneously deepening our appreciation for the intricate ecological processes that contribute to the formation and transformation of this ancient and versatile material. Understanding and manipulating the microecology of ceramic clay bodies requires coordinated efforts across disciplines, in both scientific and artistic communities. Continued research of ceramic materials in the microbiological field has broad implications for the understanding of clay as a natural resource and the influence of biological activity on ceramic characteristics.

The development of ceramics coincided with the creation of kilns, which facilitate the transformation of dried clay to a hardened state. Referred to as a bisque firing, this process creates resilient objects that can be used for numerous applications such as safe storage for resources, a writing and record-keeping medium, and building materials like bricks. (Misra & Misra, 2022) Modern industrial development depends on clay resources to support public works and commercial demand with products such as building materials, sanitaryware, and biomedical prosthetics, among other applications. (Reinosa et al., 2022) Although clay chemistry and physics have been researched extensively, the impact of microbes on clay's properties has yet to explored significantly. As the field of microbiology broadens, the study of clay will benefit from using new lab techniques, including molecular and genetic testing. Experimental designs utilizing clay are continuously increasing, furthering our understanding of one of the most important resources in the world.

The term “clay” commonly refers to a naturally occurring fine-grained earth (< 4μm) particles composed primarily of minerals. When combined with an appropriate water content, the clay is generally plastic and will harden when dried and fired. Clay minerals, known as aluminium phyllosilicates, (e.g. kaolin, $Al_2Si_2O_5(OH)_4$) have a distinct crystalline structure that allows for movement of water molecules and other compounds. (Borrego-Sánchez & Sainz-Díaz, 2022) When dried, the surface area of the minerals are greatly reduced, creating a high capacity for swelling and shrinking, that becomes even more pronounced when fired at high temperatures. Transformation and movement of clay minerals effects soil composition and ceramic qualities, seen most prominently in native clay, harvested directly from the ground from local sites. The composition and structure of the clay effects the growth and proliferation of microorganisms in both natural and manufactured clay.

Clay formation

Clay is a natural resource generated through the decomposition and weathering of the earth's feldspathic crust. Clay is abundant on Earth, both as a raw material in soil, and compressed into shale, the most common sedimentary rock. The process by which clay soils form is caused by the weathering, erosion, and transportation process. Coarse-grained minerals, such as quartz and feldspar sand soils, tend to deposit in higher velocity waters than do finer grained minerals, such as feldspar or mica silt soils. (Galán & Ferrell, 2013) Clay deposition often involves water transport, where heavier granules settle at the bottom of high velocity rivers and the most fine-grained particles remain suspended until they are deposited in some of the lowest velocity environments, like swamps, deep lakes, and meandering rivers. Clay soils are linked to specific depositional environments, with unique source rocks of varying mineral composition. (Conrad, 1987) Each of these environments will create minor variations in the clay soils mineral composition and physical properties, which in turn effect ceramic characteristics such as color and density.

The decomposition of the Earth's crust through physical and chemical weathering transforms the rock into aluminium phyllosilicates with variable amounts of trace minerals, makes up the material known as clay. Deposited minerals, mostly feldspar, are then transformed through hydrolysis, a process that eliminates soluble components, leaving behind aluminum oxide and silicon dioxide. Clay minerals can absorb large amounts of water within their lattices without losing structural integrity and dissolving into solution. (Aboudi Mana et al., 2017) The atomic structure of clay consists of polyhedra, of which the vertices are occupied by oxygen surrounding silicon (Si) or aluminum (Al) atoms. The structure of these clay minerals creates interlayered space, which comprises up to 90% of the minerals total surface, accessible to water molecules. (Morari Do Nascimento, 2021) Clay minerals are able to hold large amounts of water within the lattices acting as a lubricant and allowing for movement of the particles and creation of intricate ceramic objects.

As clay minerals mix with water, they give rise to the typical plastic material commonly associated with ceramics. The purest form of natural clay, known as kaolin, used as a base for many clay bodies. (Norton, 1991) Natural clays can be categorized into primary and secondary clays. Primary clays are extracted from their original weathering sites and exhibit low plasticity, necessitating additives for workability. Typically, primary clays are white, coarse-grained, and contain minimal impurities; most commonly mined primary clay is within the kaolin group. In contrast, secondary clays undergo transportation by wind and water from their origin, accumulating impurities, such as iron oxide, and have finer particles. (Conrad, 1987) Various clay bodies from around the world have differences in the mineral content and can be engineered to maximize qualities such as strength, color, and plasticity. As the Earth's natural erosion processes continually replenish the rock supply, the cycle of clay formation persists, highlighting clay as an exceptionally sustainable and renewable resource.

Clay is commonly categorized into fat and lean categories, with high and moderate plasticity respectively. (Andrade et al., 2011) The physical properties that distinguish the categories depends on plasticity and water content. Fat clays are able to be molded and shaped more easily, and do not lose strength with the addition of large quantities of water, compared to lean clays that can only absorb small amounts. (Mijnendonckx et al., 2019) Both fat and lean clays are used in ceramics, often mixed together to create an ideal clay body. For example, ball clay is consider a fat clay and often added to increase plasticity and chemical bonding. In contrast, kaolin is a lean clay which restricts shrinkage in fabricated objects. (Conrad, 1987) Both lean and fat make up local soil matrices, and have effects on the soil's ability to absorb water. While water content is a widely accepted soil quality measure, few studies have determined the extent of microbial interactions with lean and fat clays, leaving a significant gap in our understanding of soil and clay dynamics.

Microbiology of clay soils

Soil is one of the valuable and abundant resources on Earth, allowing food growth and carbon cycling. The most fertile soil is made of inorganic sand and clay, as well as organic material, known as humus, formed by the decomposition of plant material by microorganisms. Clay minerals interact with these microorganisms, providing habitat structure through aggregate formation with humus. Fungi, bacteria and archaea all have been found in clay samples, and have been suggested to play a role in clay genesis. (Fomina & Skorochod, 2020) Microbes are fundamental drivers of nutrient cycling, decomposition, and soil structure formation. Specifically, the metabolism of microorganisms found in the soil matrix assist in the degradation and transformation of clay minerals, assisting in the cycling of global minerals. (Li et al., 2019) Of particular importance to ceramic clay are biogeochemically active microbes which assist with the dissolution of silicates.

Although interactions between clay minerals and microbes have not been widely characterized, previous research has found microbe cells concentrations ranging from 10^3 to 10^9 cells/cm^3 which can contain hundreds of species of microorganisms. (Sokolova, 2011) These microorganisms accept ions and soluble complexes on mineral surfaces as dissolution occurs, and assist in the transformation of minerals. (Cardoso et al., 2023) Their role in the dissolution of silicates is driven primarily by lichen, a complex system of photosynthetic microorganisms and fungi, which allows for other microbial colonization. (Banfield et al., 1999) The extent of the relationship of clay minerals with other microbes, such as bacteria, is an area of research that must be investigated further to create a complete mechanistic understanding of clay genesis.

While most clay coexists and even supports microbiological growth, there are notable exceptions with antimicrobial properties, even against antibiotic resistant pathogens. The most commonly known antimicrobial clay mineral is montmorillonite (MMT); while found in various parts of the world the most abundant deposits are located in France, and used in small amounts in ceramic recipes. (Kang et al., 2024) Antimicrobial processes of MMT are related to the the reduction of trace elements and their uptake by the cells, resulting in cell damage and even death. The role of clay minerals is to buffer the aqueous pH and oxidation state to conditions that promote Fe2+ solubility, increasing bactericidal effects. (Cardoso et al., 2023; Williams, 2019) Continued engineering of MMT and other antimicrobial clays will allow for advances of clay science into the biomedical sphere.

While much of the microbial interactions with clay minerals is currently uncharacterized, microbes are ubiquitous in clay environments. As of 2024, the overall biodiversity of ceramic-dwelling microorganisms includes 70 bacterial taxa, 97 cyanobacteria, 65 algae, 49 fungi and 9 lichens. (Fomina & Skorochod, 2020) With continued microbiological research, these numbers will increase along with our understanding of interactions between microbes and clay minerals. Although the extent of microbial effects on clay genesis and ceramic properties remains largely unknown, seasoned potters have heralded mold as a good quality for ceramic clay, thought to improve plasticity and workability. Through continued interdisciplinary study and technological innovation, the intricate relationship between clay minerals and microbial communities may pave the way for novel approaches in a multitude of fields from agriculture, environmental remediation, healthcare, and of course, ceramics.

Clay in ceramics

The earliest use of clay by humans was during the late Paleolithic era, more than 20,000 years ago, and has since grown into a branching industry across the globe with cultural, technological, and artistic applications. All of the first ceramic objects were earthenware, either sun-dried or fired below 1000° and varied mineralogically according to the land from which it was mined. (Norton, 1991) Earthenware in our modern context is characterized by its porous nature and fragility, as the low-firing process and clay bodies do not allow for a water tight surface without glaze. However, even early ceramic firing processes allow for the production of permanent utilitarian and artistic objects, classed by the temperature at which they are fired. (Davidge, 1979) The development of new clay bodies and high-firing techniques gave rise to stoneware and porcelain which were paramount to the proliferation of ceramics.

The first major ceramic developments occurred in China around 600CE with the first introduction of high temperature kilns, capable of reaching up to 1350°C, allowing for a stronger and watertight material. Chinese ceramics were the highest quality of wares, with the production of strong porcelain and beautiful craftsmanship. (*Brief History of Ceramics and Glass*, n.d.) International trade and use of these objects sparked innovation across the globe, allowing for the rich history of ceramic arts; from Japanese tea bowls to Greek amphoras, the impact of historical scientific and artistic exchange cannot be overstated. As industrialization shaped the modern world in the 18th century, ceramic production has contributed to the growth of many technologically advanced fields.

Ceramic traditions and techniques vary by location, especially the fabrication of clay bodies considering the mining of raw materials and local production. (Norton, 1991) Scripps College Ceramics has a variety of powdered materials, most of which are industrially processed clay powder purchased from Laguna Clay Co. located in City of Industry City, CA. The recipe used in my experiment was the same used in the Lincoln Ceramic Studio, a mixture of fire clay, Gold Art, grog, talc, and ball clay. Fire clay is the main ingredient, known for its stability at high temperatures and use in the production of pipes and sanitaryware. Gold Art is selectively mined in Southern Ohio and commonly used in clay mixes for its plasticity and wide firing range (Hansen, n.d.). Grog is a pulverized mix of fired clay used to reduce shrinkage and add structural strength to wet clay. Talc acts as a flux, used to lower the melting point of other constituents allowing for vitrification at lower temperatures. Ball clay is general term for a variety of secondary clays with high absorption rates and easy workability (Hamer & Hamer, 1991). When all ingredients are mixed together with water, the result is a homogenous clay body that is used by beginner and advanced students.

An important practice in the ceramic studio is the reclaiming and recycling of clay. In this experiment, reclaim clay was used in the non-sterile ceramic sample as representative of this common ceramic process. It is possible the reclaim clay is a site of microbial activity, and might have effects on the overall microbe population. While the firing process kills microbes, and the development of antibacterial glazes has made fired ceramics resistant to microbial activity, it is the important forming process that depends on ample malleability for shaping and molding.

Plasticity and malleability

The workability of clay is very important to ceramic artists and professionals as it describes the ease with which clay can be shaped, molded, and manipulated into various forms. Understanding how to control and enhance plasticity allows engineers and manufacturers to optimize processing, ensuring that clay-based materials meet specific performance standards.

This in turn makes clay an invaluable medium for industrial applications and artistic endeavors. Understanding the physical qualities contributing to clay's ability to be sculpted and retain its shape is crucial for harnessing its potential in diverse applications, ranging from traditional and experimental pottery to cutting-edge industrial manufacturing.

Previous research has been done to characterize clay malleability, with plasticity being the main focus of data collection. Plasticity is the physical property of clay bodies and their ability to form a new shape without deformation or returning to its original shape though elasticity. Plasticity is determined by particle size, shape, and the water content within the clay matrix. (Andrade et al., 2011) The morphology of the clay minerals changes with available moisture, as the plate-like particles slide over each other using water as lubricant, allowing for shaping of the material. As water content is increased, clay malleability increases, however other properties such as dry strength and shrinkage are negatively impacted, causing clay objects to crack and break. Some clays are plastic because the flat surface of the clay particles has the opposite charge to the edge of the same particle, allowing for conductivity to attract water. Lean and fat clays effect water adhesion and overall workability and shrinkage.

Clay bodies are formulated to accommodate the functional requirements of the maker. Considerations such as shrinkage, firing temperature toughness, resistance to cracking, and malleability are all determinants when changing clay recipes. Adjustments in clay composition can have strong effects on the resulting clay consistency and sculpted object characteristics. (Askarinejad et al., 2021) While strength and toughness are expected of industrial ceramics, plasticity and malleability are important factors for both commercial and artistic ceramists. Aging of clay is a common technique used by potters as a way of changing clay consistency and increasing workability.

Aging of ceramic clay

Experimenting with clay is very common in the ceramic studio, both in the endless forms that can be created and the making of the clay body itself. Although there are common recipes utilized by ceramic practitioners, changes in aging can have major effects on the malleability and feel of the clay. Aging, also known as maturation or ripening, is a process that involves allowing the clay particles to rest and undergo gradual transformations over time created by physical, chemical, and biological changes. During this period, the clay particles continue to absorb water and align themselves, enhancing plasticity and reducing the likelihood of cracking during forming.

The mechanism of aging clay is unknown, with possible answers in the electro-chemical changes over time or the result of action by biological factors. (Gaidzinski et al., 2011) The process of aging clay is essential for achieving optimal workability and unlocking the full potential of the material in creating exquisite pottery pieces. The aging of clay in ceramics is a critical process that influences the workability and final characteristics of the finished pottery. Due to the sheer volume of clay required at Scripps College in the Lincoln Ceramics Studio to support both undergraduate and graduate students, it is difficult to maintain aged clay. Clay is used in a matter of weeks and remade multiple times throughout the semester, using both fresh materials and reclaim clay. In this pilot experiment, I hope to investigate the impacts of biological factors on short-term aging of clay from a microbiological perspective.

Materials and Methods

Sample Collection

Ceramic clay samples were collected from the Lincoln Ceramics Studio at Scripps College, ensuring a typical representation of clay being used by undergraduate and graduate students for ceramic sculpture. Recipe provided by Professor Adam Davis, using materials from Laguna Clay Co. and reusing reclaimed clay. Sterile samples were made with autoclaved clay powders in the same ratio as the clay made in the ceramics studio and aseptically mixed using sterilized water in the lab, and stored in sanitized containers. Samples used for CFU assays were wrapped in parafilm and aluminum foil to reduce water loss during the aging process and left in the microbiology lab.

Image 1: Mixing ceramic clay at Lincoln Ceramic Studio using reclaim clay and fresh clay powder

Native sample was collected from the area surrounding the Live Oak Dam in Claremont, CA located at the end of Webb Canyon Road, located approximately ten minutes away from Scripps campus. Various clay deposits are found in the foothills of the San Gabriel Mountains, and are available for public use. (Los Angeles Department of Public Works (LADPW), 2008) Collected and processed in conjunction with fellow Scripps student Corinne Stevens, as part of her thesis for the intercollegiate Classics Department at the Claremont Colleges. Raw soil was processed similarly to ancient Greek methods and mixed with local ball clay from Mission Clay Products. Native samples were wrapped in parafilm and aluminum foil to reduce water loss and stored with other ceramic samples in the lab.

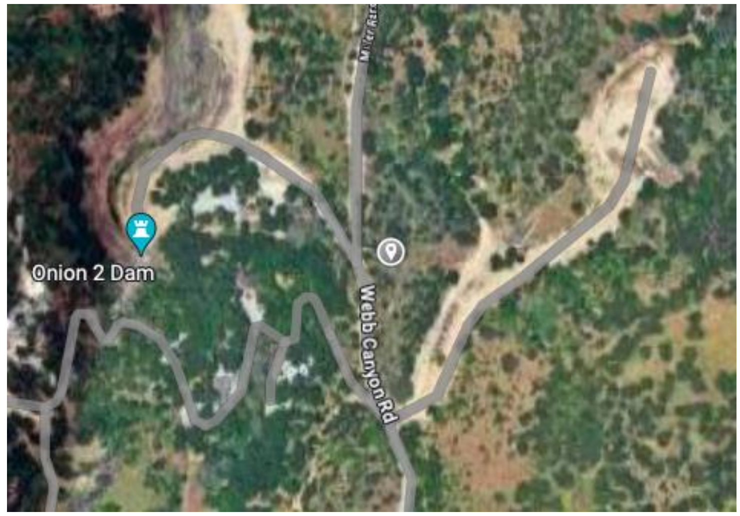

Image 2: Native clay harvesting site off Webb Canyon Road in Claremont, CA

Colony Forming Units (CFU) Assay

The colony forming unit (CFU) assay is a measure of viable colonogenic cell numbers reported in CFU per gram. The number of CFU/g is an indication of abundance cells that remain viable enough to proliferate and form small colonies in a particular sample.

1. **Serial Dilution:** Serial dilutions were prepared using water to create dilutions ranging from 10^{-1} to 10^{-8}. This step is crucial for obtaining countable CFUs, ensuring that the original microbial load is adequately diluted for accurate quantification.
2. **Inoculation and Incubation:** Aliquots from each dilution were inoculated onto non-selective agar plates using the spread plate method. Non-selective media was chosen to encourage the growth of all microbial groups present in the sample. Inoculated plates were then incubated at room temperature for the expected microbial communities to proliferate over a one-week period.
3. **Colony Counting:** Following the incubation period, colonies were counted on each plate. Colonies were differentiated based on morphological characteristics, such as size, color,

and shape. Duplicate plates were used to ensure viable plates to be using for colony counting. Final colony counts were used to determine CFU/g.

4. **Calculation of Colony Forming Units (CFUs):** CFUs were calculated based on the dilution factor and the number of colonies observed on the plates. The formula CFU/ml = (Number of Colonies Counted) × (Dilution Factor) was employed to determine the concentration of viable microorganisms in the original sample.
5. **Data Analysis:** Statistical analysis, such as t-tests and ANOVA tests, were performed to provide a comprehensive overview of the microbial population in the ceramic clay samples.

Malleability and Plasticity Tests

Using wet samples kept in the lab, the coil method was used to assess the plasticity of clay to determine its suitability for various forming techniques. Commonly used in ceramics studios, the coil method allows for qualitative data that directly effects the ceramists creative process. Initially, a sample of clay is wedged to ensure homogeneity and then rolled into coils of consistent diameter and wrapped around a coil template. The plasticity of the clay is evaluated based on the ease with which these coils can be manipulated without cracking or collapsing. This method relies on the tactile and visual feedback and the personal preferences of clay feel, allowing ceramicists to gauge the clay's malleability and cohesion as they coil it. The coil method is used while harvesting of clay and determining if the clay should be reclaimed; ceramicists can precisely assess and compare the plasticity of different clay samples, aiding in the selection of materials best suited for specific ceramic applications.

Dilatometer (DIL)

Tim Decker of Laguna Clay Co. in City of Industry, CA performed the relevant protocol using a model 1410B Orton Horizontal Dilatometer and provided comparative graphs. During a standard dilatometer test, both reversible and irreversible alterations in length, descriptive of expansion and shrinkage, are recorded throughout heating and cooling cycles. The results provide insights into changes in ceramic material as a function of temperature, including the precise points where reactions occur inducing expansion or contraction.

A fired clay coil is placed between the end of the sample holder and the end of the movable probe rod. The furnace is placed over the test sample and heated according to a user defined thermal cycle.. The probe rod transmits the amount of sample movement to the electronic displacement sensor (LVDT) which is located outside of the heated chamber. Even during shrinkage, the probe rod outside the furnace remains under load to maintain constant contact with the sample as the LVDT generates an electronic signal corresponding to the change in sample length and continuously sends that signal to the Orton process controller. The process controller calculates and saves the length change data along with the sample temperature. The results of dilatometers generally include data of temperatures and expansion lengths, shown on graph as a function of increasing temperature.

Results

As a pilot study, this experiment should be used as an example experimental design for future studies. The statistical analyses, including t-tests and ANOVA, conducted in this study failed to yield significant results primarily due to the inadequate number of replicates. Insufficient replicates diminish the statistical power of the tests, rendering them unable to detect meaningful differences or relationships within the data. (Konold & Fan, 2010) In the case of t-tests, the small sample size limits the ability to accurately assess the significance of differences between two groups. Similarly, ANOVA requires a sufficient number of replicates to reliably detect variations among multiple groups. Without an adequate number of replicates, the variability within and between groups cannot be adequately assessed, leading to non-significant results. Thus, the lack of replicates undermines the reliability and interpretability of the statistical analyses, highlighting the importance of ensuring adequate sample sizes for robust scientific conclusions.

Colony Forming Units Analysis

The CFU assay was performed on Lincoln Ceramic Studio clay samples over the course of three weeks. The native sample was tested over a course of three weeks, however due to a large amount of microbes only data Week 3 was used, as they were the only viable plates. The sterile sample was tested directly after combining clay powders with water, and tested alongside the ceramic sample over the course of two weeks. Due to the lack of replicates and non-viable samples, no significance can be drawn from these tests.

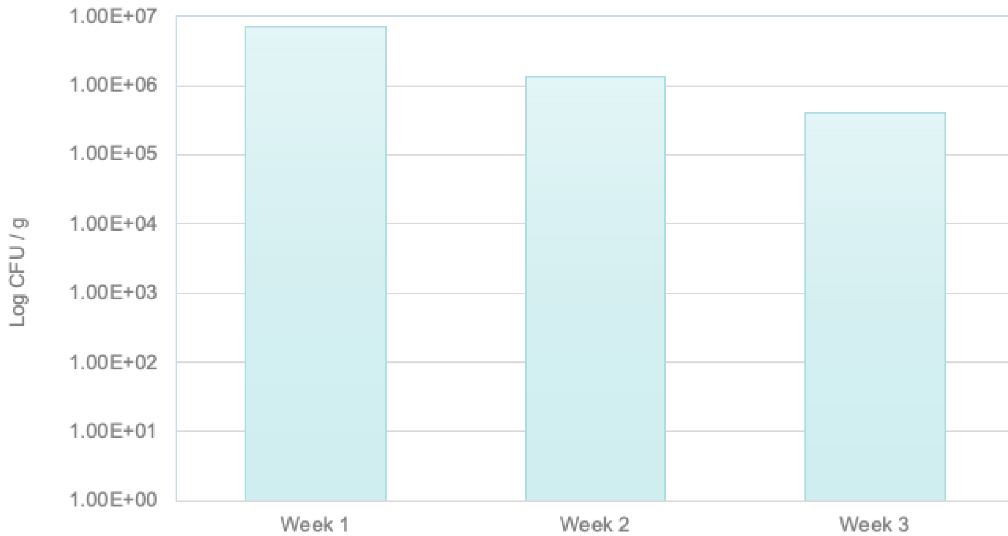

Figure 1: The effect on aging on log colony forming units per gram on non-sterile ceramic clay sample over a period of three weeks.
Result: Not significant

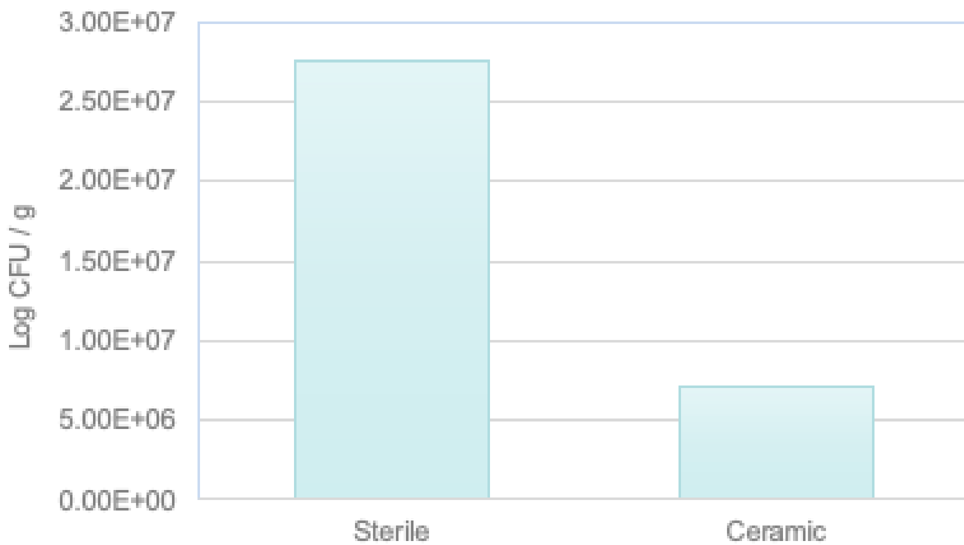

Figure 2: Comparison of log colony forming units per gram between sterile and non-sterile ceramic samples after two weeks.
Result: Not significant

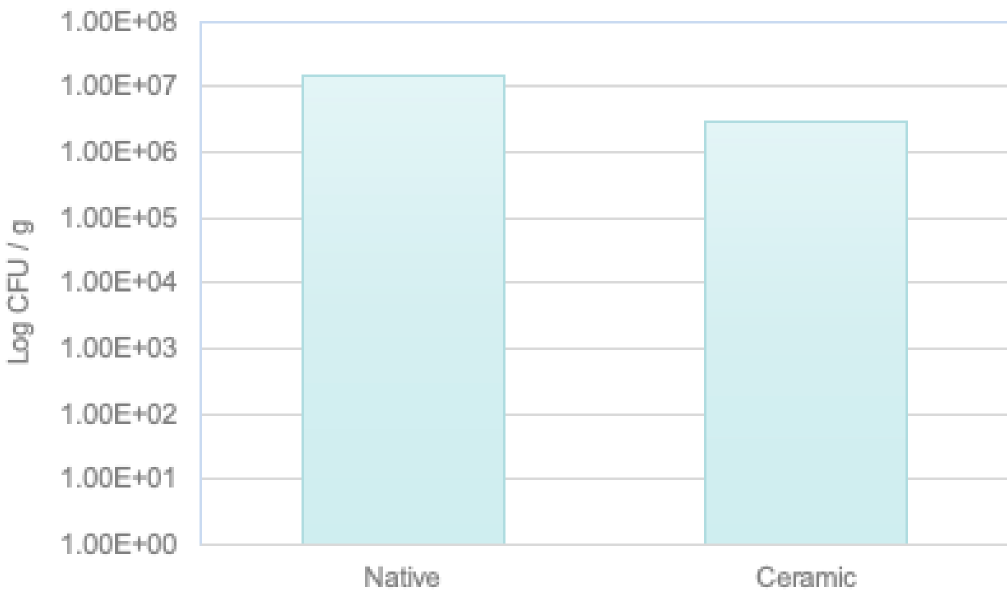

Figure 3: Comparison of log colony forming units per gram between native and non-sterile ceramic samples after two weeks.
Result: Not significant

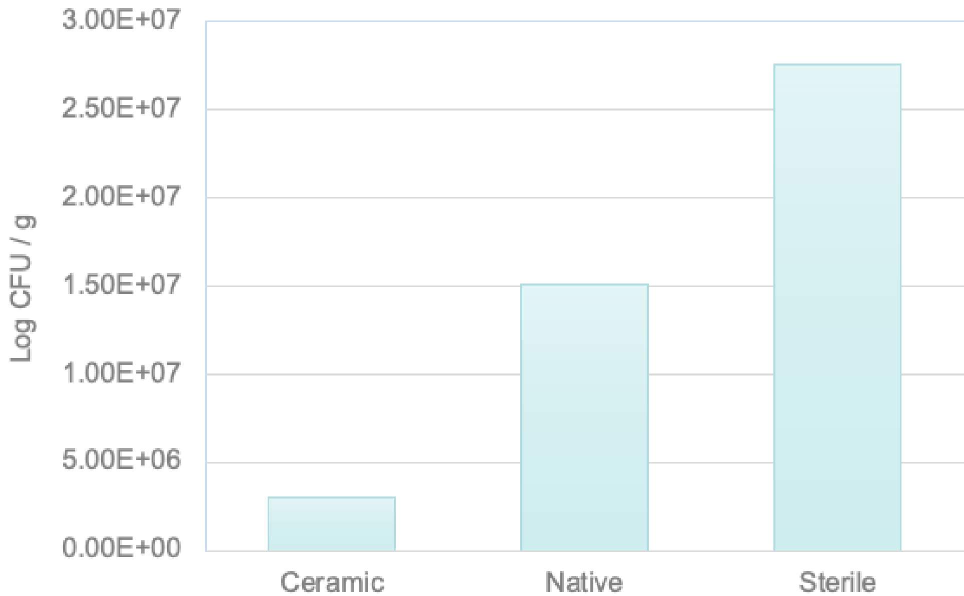

Figure 4: Comparison of log colony forming units per gram between all samples, sterile and non-sterile processed clay and native clay samples after two weeks.
Result: Not significant

Dilatometer Results

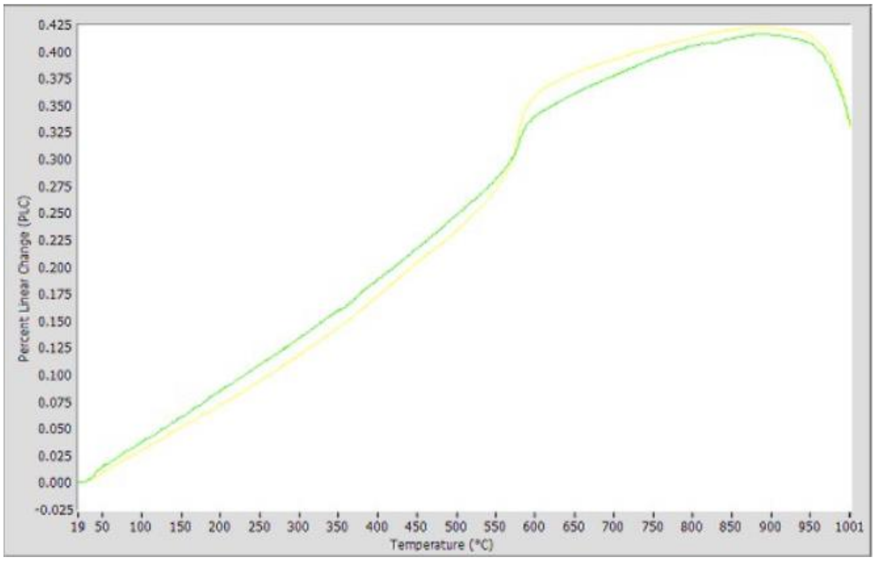

Figure 5: Comparison of percent linear change (PLC) versus temperature of native and ceramic samples. Green line is processed ceramic sample. Yellow line is native clay sample.

Coil Test Observations

Clay samples were rolled in a potter's coil test and observed for cracking. The non-sterile ceramic sample displayed noticeable cracking during the first week of observation. The second week, the non-sterile sample did not crack when coiled around the template. Similarly, in the third week, the ceramic sample remained intact without any new cracks forming. This sustained stability contrasts sharply with its performance in the first week, indicating a possible adaptation or strengthening over time. In contrast to the ceramic sample, the native sample showed no signs of cracking throughout all three weeks of observation. This suggests that the native material possesses inherent resilience or properties that prevent the formation of cracks even under similar conditions to those experienced by the ceramic sample in the first week.

Discussion

This experiment analyzed the clay used in the Lincoln Ceramics Studio at Scripps College to explore the role microbiological studies has on current sculptural materials. While this experiment did not result in statically significant data, the qualitative observations of microbe growth and tactile changes during coil tests provided a good starting point for future research, especially in interdisciplinary microbiology courses such as *Microbes and Art*. Therefore, determining the effects biological processes have on the malleability of clay, remains an important avenue for understanding the importance of material science.

Sterile clay materials do not inhibit microbe growth

The proliferation of microbes occurs despite the use of sterile ingredients, aseptic preparation techniques and storage in the lab environment. Although the CFU assay performed directly after the sterile sample was made in the lab did not result in a viable population count (as there was no detectable growth), continued testing revealed microbial population growth occurred over time. Through serial dilution techniques over 27 million organism were observed within the clay sample after just one week. This exponential growth highlights the dynamic nature of microbial colonization within ceramic habitats, suggesting complex interplay between clay minerals and microbial ecology. These microbiological results show a relationship between clay minerals as a habitat for population growth and ecology of microorganisms in a ceramic context.

Aged clay decreases microbiological activity

Previous research has suggested clay minerals can both reduce and increase the length of the lag-phase, which is the phase of microbial growth delay occurring immediately after inoculation of the microorganisms and required for microbial adaptation to the new growth conditions before proceeding to the active exponential growth. (Fomina & Skorochod, 2020) It is suggested that the longer more microorganisms are adapted to the new environment the shorter the lag-phase. It is possible the microbial community present in the sample with reclaim clay may start the exponential growth phase missing the lag phase. Such might be the also case with clay aged over a prolonged period. Further testing, especially additional replicates, will be necessary to determine a typical bacterial growth phases of clay from the Lincoln Ceramic Studio at Scripps College.

Native clay contains more microbes

The native sample collected from the local clay pit on Webb Canyon Road had more microorganisms than the processed ceramic sample made in the ceramic studio with a combination of clay powder and reclaimed clay. This discrepancy may be attributed to several factors inherent to natural environments that are not present when making clay bodies with processed materials. Firstly, native samples encompass a diverse array of microhabitats and niches, providing ample opportunities for microbial growth and proliferation. These environments offer a rich source of nutrients, organic matter, and microclimatic conditions conducive to microbial growth. (Vos et al., 2013) Additionally, native samples may contain a larger pre-established microbial community sourced from surrounding soils, air, and water sources, facilitating the rapid establishment of microbial populations within the clay matrix.

Future studies could explore other clay deposits in the area to compare microbial populations along with qualitative comparisons.

Conclusions and future studies

The greatest result of my thesis is the development of a pathway for future Keck Science students to explore interdisciplinary research integrating ceramics and biology. Artists associated with ceramics at Scripps College have made an impact on contemporary ceramics, and will continue to challenge the bounds of this versatile material. Continued collaborations between the Art and Science departments have the potential to further our understanding of clay as an adaptable medium within the larger context of biological ecology. The connections between microbes and art are just beginning to be understood, and this study reveals the presence of microbes and possible applications on clay workability, which could create new avenues for material experimentation.

Future studies can span across Keck Science departments including microbiology, molecular biology, and biochemistry. Within microbiology, continued analysis of CFUs are necessary to determine the significance of aging on microbial communities. In addition, isolation and identification of the specific microbe species present in the clay used at Scripps College, is another approach to further investigation. Interdisciplinary exploration will always be a fundamental process in understanding our relationship to the materials we use to not only advance our society technologically, but to express creative interpretations of the world.

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My thesis would not have been possible without the exceptional support of my peers and professors throughout the research and analysis process. I extend my deepest gratitude to the Scripps College and Keck Science community for fostering an open and innovative environment, allowing for connections between art and science education.

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Finally, I am especially grateful to my friend and colleague, Corinne Stevens, for providing the native sample included in the experimental study and working tirelessly with me in and out of the studio. Motivating me to develop and execute native clay comparisons, her

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