

Application of Palaeodermatoglyphic Analytical Methods to Assess Age and
Biological Sex of Potter(s) from a Pre-Contact Late Woodland Period Vessel

by

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Abstract

The objectives of this research is the application and critique of analytical methods that have been developed in the dactylographic and dermatoglyphic literature to determine the biological sex and age of the potter(s) involved in the production of a Late Woodland vessel from the boreal forest region in Northwestern Ontario.

Age was determined from mean ridge breadth. The modified regression equation used in Fowler et al. (2019) was chosen for this analysis. The comparative data set for the aging model consisted of mean ridge breadth data from Laing (2021). Biological sex determination used mean ridge density. The Acree method, counting ridges in 25mm² area was used, modified using Gungadin's (2007) approach as needed; measuring in 6.25 mm² areas and adjusting. A bespoke model based upon fingerprints from North American Indigenous groups was used to interpret ridge density measurements (Stinson 2004). Measurements were corrected to account for shrinkage of the clay material during the drying and firing process. A shrinkage test was conducted using regional clays. The corrections used were 6% and 12%.

The results of this research show that most ridge skin impressions of the vessel were made by an adolescent or adult female. There were two anomalies impressed during the decoration stage of manufacture suggesting a late adolescent or adult male. Despite earlier assumptions that pre-contact Indigenous pottery was made by women (Syms 1977; Taylor-Hollings 2017, p.110; Bales 1997), this analysis show males could have been involved in production.

Moreover, this study critiques these methods, identifying issues that can affect the results obtained using the models. Some issues such as shrinkage are already factored into the models. The issue of the effect of curvature on fingerprint impressions, however, is not considered in these analytical models.

This research is valuable since it provides insight into past populations where there may be no other means of investigation. This research is further significant since it is the first analysis of pre-contact epidermal prints in this region. Currently, there is no data that can be used to infer the age and sex of potters in pre-contact boreal forest hunter-gatherer societies in Canada.

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Definitions

Term	Definition
Female(s); Woman/Women	An individual or individuals who are biologically females. It does not refer to one's gender identity or expression.
Male(s); or Man/Men	An individual or individuals who are biologically male. It does not refer to one's gender identity or expression.
Sex	An individual's biological sex.

Chapter I. Introduction

Dactylography, the study of fingerprints, and dermatoglyphics, the study of all features of ridged skin, have long been used in forensic research (Cole 2004). Despite the long-known presence of human ridge skin impressions on ancient artifacts (Faulds 1880; Åstrom 1980), the methods used in the study of ridge skin are not regularly conducted in the study of archaeological objects. However, given the impressionable nature of clay, such analyses can prove particularly useful in the study of ceramic artifacts providing useful insight into the organization of ceramic production.

This thesis project applies palaeodermatoglyphic analytical methods to assess the age and sex of the potter(s) involved in the production of a reconstructed ceramic vessel from a pre-contact boreal forest hunter-gatherer group in Canada. The ceramic vessel that was studied was surface collected by Brad Hyslop along the shores of Lac Seul in Northwestern Ontario.

The primary goal of this research is to apply and critique the analytical methods that have been developed in the dactylographic and dermatoglyphic literature to determine the age and sex of the potter(s) involved in the production of a Late Woodland vessel. Ridge breadth measurements will be used to make age identifications and ridge density will be used to make sex determinations. Throughout the literature, many different measurement techniques and analytical models have been proposed. This research applies a regression equation model to interpret age from ridge breadth measurements (Fowler et al. 2019) and a bespoke model based upon fingerprints from North American Indigenous groups to interpret ridge density measurements (Stinson 2004).

An unfortunate reality is that the fingerprints found on ceramic artifacts are often partial since impressions on ceramics, whether fingerprints, tool marks, or other sources, are often wiped off during production. This project develops and applies an impression quality analytic framework, to sort these data and create a more accurate data set of sufficient quality for analysis. This will be used to identify outliers and prevent the inclusion of measurements of impressions from sources other than epidermal ridge skin.

This framework also takes into account “smudged” fingerprint impressions. The wetness and plasticity of clay changes throughout the manufacturing process. Clay bodies lose plasticity as the clay dries and this in turn affects the quality of the resulting impression. The firmness, or consistency, of the clay plays a role in the clarity of a print (Cummins 1942). Fingerprints in wet clay may “smudge” and not leave discernible ridges and furrows; thus limiting the measurable value of the impression. However, even if the print does not have defined epidermal ridges, the finger indentations can still provide useful information. These indentations can be used specifically for anthropometric analyses (Králík & Nejman 2007); though, this type of analysis is out of the scope of this project.

The clay material also shrinks as it dries and loses its plasticity. This means that the measurements gathered from the impressions of sufficient quality must be corrected to account for this shrinkage. Multiple corrections will be applied. This is because, as Fowler et al. (2019) note, shrinkage varies depending on the quality of the clay itself and any inclusions or added temper used in pottery production. To determine the appropriate corrections, a shrinkage test was conducted using clay from the Lac Seul location as well as other clays derived from glacial till bedrock.

Once modified for shrinkage, the appropriately scaled data will be compared to reference data sets in order to make age and sex determinations. Unfortunately, there is no relevant published dermatoglyphic research for Indigenous populations in this region in Canada. The data sets to be used for comparison are being compiled as part of the broader Ancient Prints Project directed by Dr. K. Fowler. The aging model is based on ridge breadth data from Laing's research (2021). For ridge density, data obtained from this thesis research will be compared to fingerprints from North American Indigenous groups data sourced from Stinson's (2004) PhD thesis.

Although the purpose of this thesis is to test and apply a methodological framework to the study of a reconstructed ceramic vessel, the information gathered has further value. These data can be used in conjunction with other analyses to provide insight into the ceramic production and the division of labour within pre-contact boreal forest hunter-gatherer group. Even though one single vessel is studied here, it is still significant because no other data exist to infer the age and sex of potters in pre-contact boreal forest hunter-gatherer societies in Canada.

Chapter II. Literature Review

Dactylography and Dermatoglyphics

The study of fingerprints, dactylography, originated in 1880 with Henry Faulds' "On the skin-furrows of the hand." Dactylography developed in the field of forensics for the purpose of individual authentication and identification, eventually creating a criminal record database (Cole 2004). In order to make such identifications, researchers developed various ways to organize and classify prints, from looking at fingerprint patterns to matching minutiae (Cole 2004).

Dermatoglyphics is more specifically the study of fingerprint ridges, the patterns and measurements. Ridge measurements, density and breadth, have been correlated with various individual characteristics throughout the literature. Ridge density measurements have been used to identify biological sex (Acree 1999), estimate stature (Brazelle et al. 2017), and infer ethnic origin (Kanchan et al. 2013; Gutiérrez-Redomero et al. 2011). In addition to age, the correlation between ridge breadth and weight, stature, and BMI has also been examined (Mundorff et al. 2014).

Even though fingerprint analyses were initially developed for forensic purposes, it has more recently migrated to other fields of research, including archaeology. In forensics, the use was limited to identification and demographic characteristics. However, archaeologists can use this research in conjunction with other analyses in order to make broader interpretations of past demographic and culture groups as a whole. For example, using sex and age determined from fingerprint analyses, archaeologists have been able to offer hypotheses regarding the

manufacturing process of pottery, the division of labour (Kanter et al. 2019), the mobility of potters (Rockwell 1970), and individual experience level (Kamp 2001).

Forensic Methodology: Sex Determination

Ridge density refers to the number of ridges in a defined area. The dermatoglyphic literature empirically demonstrates that fingerprint ridge density is in fact a sexually dimorphic characteristic (Ohler & Cummins 1942; Acree 1999; Krishan, et al. 2013; Kanchan et al. 2013; Kapoor & Badiye 2015). It is accepted throughout the literature that females have a higher ridge density than males, given their finer, less coarse, ridges.

However, the identification of an individual's sex from epidermal ridge densities is based in probability. There will always be overlapping values shared by both males and females. Density values vary on an individual level, based on the locus of the defined area of measurement on the finger or hand (Krishan et al. 2013) as well as globally across geographic populations (Acree 1999). Some studies suggest that ridge density increases moving from the proximal to the distal portion of the finger (Krishan, et al. 2013). This, in turn, suggests that the highest predictive value for sex would come from a distal area (Krishan, et al. 2013). Moreover, if the prints being measured are partial, it may not be possible to determine which finger, or which region of the finger, is represented.

Unfortunately, there is a lack of uniformity in ridge density measurement methods in the literature, which, affects the comparative value of the research. The lack of standardization in methodology, has led to some researchers to acquire ridge density values that are quite different than others. Gutiérrez-Redomero et al. (2014) believe the root of this issue is the lack

of standardization in two areas: 1) the method of acquiring the print, and 2) the areas where counting should take place. Gutiérrez-Redomero et al.'s research did exemplify this lack of uniformity as the resulting values stand out from other literature.

Ridge Density Measurement Techniques

The first technique used in determining ridge density is simply counting the number of ridges per cm^2 (Ohler & Cummins 1942). Acree found that the same results could be obtained if a smaller line length or area was used. The first systematic methodology began with Acree (1999) counting the number of ridges in a single square 25 mm^2 , which he placed on the top radial side of the core of the fingerprint. Later researchers adopted and modified Acree's method for the purposes of their own analyses, such as adjusting the size of the area being examined and examining different areas of the finger.

Researchers tend to examine ridge count in three main areas of the finger – radial, ulnar, proximal – instead of simply one (Ahmed & Osman 2016; Krishan et al. 2013; Gutiérrez-Redomero et al. 2008). Dhall and Kapoor (2016) went further and examined five regions on a finger 1) radial; 2) upper radial; 3) ulnar; 4) upper ulnar and; 5) proximal (Dhall & Kapoor 2016, p.424). In determining the region to study, Kapoor and Badiye (2015) took a different approach. They studied two 25mm^2 areas, but determined the locations of the areas by 1) drawing two bisecting line, 2) placing the intersection of the lines at the print's core, and 3) placing the two 25mm^2 measurement areas on the left and right of the line (Kapoor & Badiye 2015, p.24). These techniques have been further used for making comparisons between different fingers and applying ridge density methods to palm impressions (Kanchan et al. 2013).

This study uses the Acree method, defining a 25mm² area within which the number of ridges is counted. Since the impressions found on this particular vessel are primarily partial, Gungadin's (2007) approach will be followed by making measures in 6.25 mm² areas and then later adjusting these to a 25mm² area so all values are from the same unit of area.

Population Variation

Acree (1999) empirically showed that there was both a difference in the ridge densities of males and females and that there is a difference amongst populations of differing descent; his case study specifically focused on individuals of European and African descent. Others followed this observation and examined variation in ridge density amongst geographically different populations. Since then, researchers have analysed a wide variety of populations, including, but not limited to Sudanese (Ahmed & Osman 2016); Indian (Dhall & Kapoor 2016; Gangadin 2007; Kapoor & Badiye 2015; Kaur & Garg 2011; Krishan et al. 2013; Kumar et al. 2013; Nithin et al. 2011); Turkish (Oktem et al. 2015); Thai (Nanakorn & Kutanan 2012; Soanboon et al. 2016; Suthiprapha et al. 2010); Chinese (Nayak et al. 2010); Malaysian (Nayak et al. 2010); Spanish (Gutiérrez-Redomero et al. 2008); and Egyptian populations (Eshak et al. 2013). Even though the comparative value of these data sets is impacted by the lack of standardization, cross-population comparisons can still be made.

For instance, Gutiérrez-Redomero et al (2011) compared the results of a sample of the Mataco-Mataguayo peoples from Bolivia, Argentina and Paraguay to a previously researched Spanish population (Gutiérrez-Redomero et al. 2008). The Mataco-Mataguayo males and females had higher ulnar and proximal epidermal ridge densities than the Spanish population,

with no statistical difference in the radial region (Gutiérrez-Redomero et al. 2008, p.497). Knowing that ridge densities vary across populations, Gutiérrez-Redomero et al (2013) proposed that ridge density could be used to “facilitate discrimination between the populations” (Gutiérrez-Redomero et al. 2013, p.599). They used the same methodology as they would for fingerprints but instead of making comparisons between sex, they sought to distinguish the different populations. They proposed a discrimination threshold to ascertain whether the print was most likely from a male of South American origin or one of Spanish origin (Gutiérrez-Redomero et al. 2013, p.596).

In another avenue of investigation, researchers have compared their respective analyses to studies of populations with similar biological history. Brazelle et al. (2017) did this in their analysis of the relationship of ridge density and stature in African American males, but found significantly different results when compared to Acree’s (1999) findings. This is possibly due to the differences in measurement techniques, or more likely, due to their differing sample populations. Moreover, the age range of Brazelle et al.’s (2017) sample population was substantially wider.

Many have theorized as to why such cross-population differences exist. It has been suggested that it is due to the genetic origins of different populations, developmental differences, and resulting variation in body size and stature (Kanchan et al. 2013; Gutiérrez-Redomero et al 2011). In modern populations, discrete variation is complicated by increasing globalization and population intermingling.

In this research I will consider population variation by using a reference data set from measurements of handprints taken of historically Indigenous North American populations in

order to increase accuracy. Stinson (2004) collected these data from full ink handprints of peoples from across North America housed in the James V. Neel Collection. This collection was subsequently moved to the National Anthropology Archives at the Smithsonian where it has not been accessioned and is not available for study. Stinson only used measurements from the fingerprints of Southwestern populations in her study, and did not include Athabaskan speaking populations in her analysis. There is presently no published data set for populations in the area of research or optimal for examining Late Woodland Indigenous populations inhabiting the boreal forest or adjacent plains regions over the past 1,300 years. It is an imperfect situation. However, Stinson's data set is the most relevant available data in terms of population affinity and geographic proximity.

Forensic Methodology: Age Determination

Mean ridge breadth is a predicator of an individual's age (Králík & Novotný 2003). Ridge breadth increases with age until maturity is achieved (Králík & Novotný 2003). Mean ridge breadth is calculated by determining the number of ridge-furrow pairs along the distance of a line (Králík & Novotný 2003). Although some predictions about age can be made, some uncertainty remains. More specifically, there is an overlap between adolescent individuals during puberty and adults (Králík & Novotný 2003). The adolescent growth period varies between females and males as well as through time. In modern populations, the initiation of puberty is usually 8 years of age for females and is complete at 16 years. For males, initiation is around 11 years and is complete at 17 or 18 years (Lewis 2022). In preindustrial populations, puberty development can start later and last longer. Lewis et al. (2016) and Lewis (2022)

estimated that puberty stages span 10 to 25 years for males and females during the Roman, Medieval and Post-Medieval Periods in England. Likewise, in Upper Palaeolithic populations, puberty can begin after 11 years and be complete between 17-22 years (Lewis et al. 2025). When considering the overlap in ridge breadth values between adolescents and adults, it is necessary to account for sex-based differences in growth and maturation: females can exhibit adult value mean ridge breadths at an earlier age than males. This is likely because females reach puberty and mature one to two years earlier than males (Králík & Novotný 2003; Lewis 2022).

In addition to age, ridge breadth has been associated with other biological factors. Králík and Novotný (2003) outline how the length of hands, the width of wrists, the breadth of the hand, and the breadth of an individual's distal finger bones can affect the mean ridge breadth. As well, similar to ridge density, mean ridge breadth also varies amongst different regions on a finger (Míquez et al. 2016). Importantly, the media on which the fingerprints are preserved also affects ridge breadth (as with ridge density), especially in the case of ceramics where there is shrinkage due to the drying and firing process (Králík & Novotný 2003). This will be accounted for and corrected in this research. For these reasons, Fowler et al. (2019, 2020) advocated for the classification of age estimates from mean ridge breadth values into three categories: children (prepubescent), adolescent/adult, and adult, based upon the highest probabilities (>80%) that individual measurements belong to each category relative to a reference sample from modern populations. This type of categorical classification will be used for this study. These categories will be defined using Laing's (2021) data set for mean ridge breadth.

Ridge Breadth Measurement Techniques

Over the years researchers have proposed a variety of techniques to measure ridge breadth, but, like ridge density, there is no universal technique. The techniques fall into two groups: 1) individually measuring each ridge-furrow pair and then calculating the mean; and 2) measuring multiple ridge-furrow pairs at one time and then dividing by the number of pairs by the distance measured (Kamp et al., 1999). Going further, Míquez et al. (2016) divided the prints into three regions for measurement, distal, lateral, and proximal. They compared the measurements from each region and used the averages for each finger for their analysis.

In their experimental research, Králík and Novotný (2003) followed Kamp (1999) and took multiple measurements for each single fingerprint to get the mean ridge breadth for each print. They specifically measured “the width of a bundle of ridges on the longest possible section perpendicular to the stream of ridges and counted the number of involved ridges” (Králík & Novotný 2003, p.16) and then calculated the mean ridge breadth for the individual, or creator, by using the values of all of the fingerprints on the ceramic piece. This approach was based on the understanding that there is only one individual associated with each object made in the ceramic studio (Králík & Novotný 2003). This same assumption cannot be made for archaeological objects. It needs to be demonstrated whether all epidermal print impressions could belong to the same individual because ridge breadth varies based on the region of the finger (Míqueze al. 2016).

A variety of models have been proposed for the analysis of ridge breadth measurements and several regression equations have been proposed to convert mean ridge breadth values to age. Míquez et al. (2016) used logarithmic regressions for their determinations of age. Králík

and Novotný (2003) found that the mean ridge breadth should be an independent variable. They determined that equations using mean ridge breadth as a dependent variable were not good predictors. In Králík and Novotný's (2003) test of four regression equations, they found that a modified version of Kamp et al.'s linear regression worked as well as the equation from their data (PM 1) if they modified it using a correction of 7.5% for shrinkage.

$$\text{KA: } y = 614 \cdot x - 112 \text{ (} y - \text{age in months, } x - \text{MRB in mm)}$$

KAmoD: modified according to shrinkage rate of 7.5%, the mean ridge breadth values were multiplied by 1.08108

$$\text{KAmoD: } y = 614 \cdot 1.08108 \cdot x - 112 \text{ (} y - \text{age in months, } x - \text{MRB in mm)}$$

$$\text{PM 1: } y = 52.18087 \cdot x - 7.89682 \text{ (} y - \text{age in years, } x - \text{MRB in mm)}$$

This adjustment was required because the epidermal ridge impressions used by Králík and Novotný sample was from fired vessels, not from ink or digital fingerprint impressions.

In Fowler et al. (2019), the argument was that KAmoD and PM 1 could only take into account 7.5% shrinkage. Fowler et al. introduced a variation to the KA regressions equation to account for higher or lower shrinkage rates. This variation was designed to calculate age in months from unmodified fingerprints based on the original Kamp et al. equation that did not include an adjustment for shrinkage (as with the KAmoD and PM1 equations). The age in months for an MRB value was then multiplied to account for a percentage of shrinkage (increasing the value), and then multiplied y – the age in months – by 0.0833334 to arrive at age in years. That is the KAmoD2 equation:

KAmod2: $y = ((614 \cdot x - 112) \cdot 0.02 \text{ or } 0.06) \cdot 0.0833334$ (y – age in years, x – MRB in mm).

This formula took the observed MRB value for epidermal prints on the object, calculated an age estimate in months, and scaled the MRB value and derived age estimate up by 2% and 6% to account for shrinkage experienced by the particular ceramics under study from the Bronze Age Levant. This research will follow that of Kamp as well and will use the KAmod2 regression equation.

Archaeological Application

The use of fingerprinting is steadily developing in archaeology. Epidermal print data can provide useful information about the individual person including their age (Åström 2007), sex (Acree 1999), handedness (Moran 2007), stature (Brazelle et al. 2017), ethnic origin (Kanchan et al. 2013), weight, stature, and BMI (Mundorff et al. 2014). In a broader sense, these data have aided archaeologists in gaining insight into the larger population or culture as a whole. Of particular relevance to this research, is the interpretation of demographic data in terms of the production of ceramic wares.

Researchers have used dermatoglyphic data on age and sex obtained from fingerprint analyses to discuss the production process of ceramics (Lichtenberger & Moran 2018), the division of labour in ceramic production (Kantner et al. 2019; Fowler et al 2020), and gender roles (Stinson 2004). Furthermore, shifts in these trends can provide useful cultural information, such as the division of labour over time (Kantner 2019), shifts in the division of labour during urbanization and the rise of states (Sanders 2015).

An example of using dermatoglyphic to formulate a detailed hypothesis regarding the production of ceramics is Arp's (2002) research on Sumerian tablets. Arp analysed fingerprints found on Sumerian tablets from the Ur III Dynasty in order to identify the technique that was used by the scribe to support the tablet whilst they made the impressions (Arp 2002). His research on the Sumerian tablets resulted in a conclusion contrary to the widespread assumption, that scribes in the Ur III Dynasty held their tablets by their palms. He was able to determine this as the prints were located along the edges of the tablets.

Researchers have also been interested in how the craft of ceramics was learned in specific populations (Fowler et al. 2019; Fowler et al. 2020; Kamp 2001). The stage in the learning process corresponds to the manufacturer's experience level (Kamp 2001). Kamp (2001) also made qualitative and quantitative assessments of the characteristics of the pot to make her conclusions; complexity of the ceramic, how well it was finished, the uniformity in thickness, for example (Kamp 2001).

In a broader sense, information regarding the age and sex has been used to comment on the socio-economic and political state. Sanders (2015) correlates the shift in division of labour to the rise of state and urbanization. Rockwell (1970) proposed the use of these techniques to tracing mobility of potters as well as identifying a specific potter.

Over time, changes in recording technology has made the study of fingerprints in archaeology more prevalent. Rockwell's (1970) early study relied on coating the fingerprint on the artifact with graphite, lifting the impression off using tape, and applying it to a white card in order to render a fingerprint image for analysis. Four decades later, Bennison-Chapman's (2018) research uses Reflectance Transformation Imaging technology to enhance the surfaces

of artifacts for analysis. In part, this change in imaging technology helps resolve complications caused by conservation efforts. For instance, Králík et al. (2002) noted how the varnish used for conservation led to difficulties in photographing the fingerprint. These technological advances in fingerprint capture provides opportunity and insight into the ceramic ware manufacture and production processes, especially where no other evidence is available.

Chapter III. Methods and Methodology

Sample and Cultural Context

Based upon ethnographic analogy, there is a widely held assumption that pottery was a women's craft in North American Indigenous populations (Syms 1977; Taylor-Hollings 2017, p.110; Bales 1997). Some researchers have suggested this is possibly due to the women's association with food production (Bales 1997; Rice 1999), while others tie women's involvement in the craft to traditional cultural beliefs and mythos (Bales 1997). However, more evidence is gradually showing that men also had a role in ceramic production (Taylor-Hollings 2017, p.110; Syms 1977). Research such as this can be used to provide a set of expectations, or hypotheses, about those involved in ceramic manufacturing and the divisions of labour of pre-contact Late Woodland boreal forest populations.

This study will examine a single reconstructed vessel (Figure 1) from Lac Seul located in the boreal forest of Northwestern Ontario (Figure 2). This vessel is peculiar and after consultation with different Indigenous ceramic experts, it does not fit into any one defined culture. The entirety of the exterior of the vessel is decorated, with linear and curvilinear motifs created with rocker stamping. Punctates are present on the exterior rim of the vessel (Figure 3), resulting in curved surfaces on the interior of the vessel (Figure 4). Figure 5 shows the impressions covering the body of the vessel. In profile, the vessel has a drop shoulder. The interior of the vessel is smoothed with a plain lip.

One hypothesis is that it is "blaurel," exhibiting a Laurel-like shape, marked coil breaks, and decorative features of both Blackduck and Laurel ceramics. This could place the vessel in

the Late Woodland Period. Another hypothesis is that it may be a late Laurel vessel, placing it within the Middle Woodland era. As this vessel was surface collected there no chronometric data for its recovery.

However, this vessel is similar to a sherd examined by Taylor-Hollings in her PhD thesis. She outlines Hyslop's proposal that the sherd belongs to a "Newly identified Plain Banded Stamp and Punctate Type from the Lac Seul Area," which is "similar to Blackduck Ware, but clearly different" (2017, p.119). This "type" was proposed by Hyslop as "a regional grouping of similar vessels for the Lac Seul area" (2017, p.120). She goes on to state that it is "definitely a Late Woodland" (2017, p.120) type. The more complete vessel in this study shares similar decorative features and is from the same site (EcJx-7) on Lac Seul, it will be considered here as a Late Woodland ceramic entity. Although classifying the vessel more precisely is not within the scope of this research, it can at least be situated amongst the populations inhabiting the network of rivers and lakes in Northwestern Ontario and Eastern Manitoba.

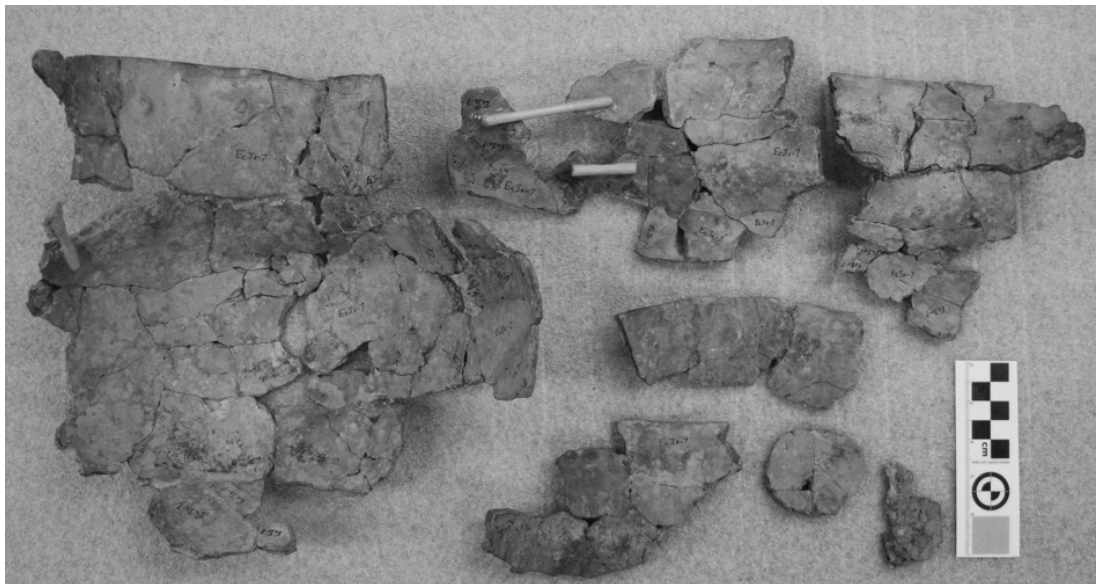


Figure 1. Interior of reconstructed ceramic vessel used for this study.



Figure 2. Location of Lac Seul, Ontario Canada. Obtained from Google Maps (Map data ©2025 Google).

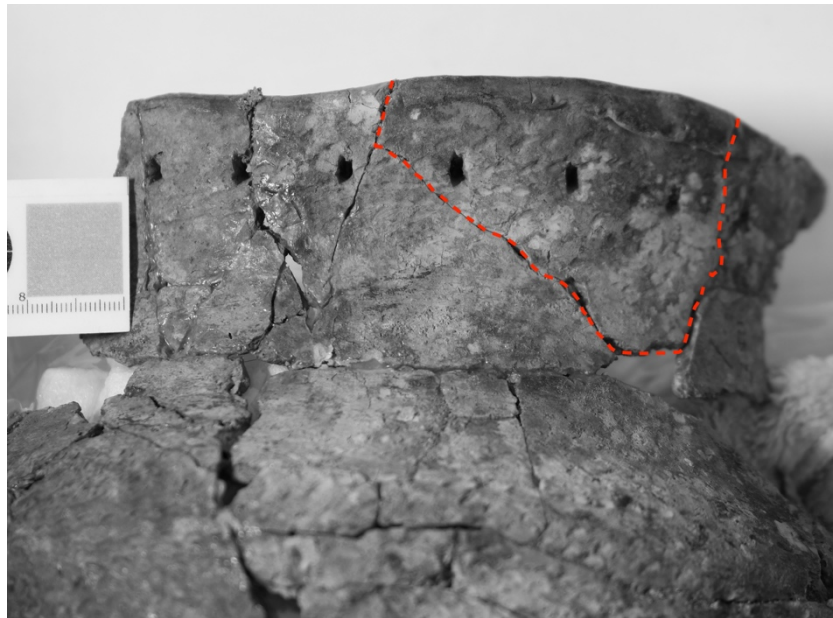


Figure 3. External view of vessel showing extensive decoration. Interior side of highlighted rim fragment shown in Figure 4.

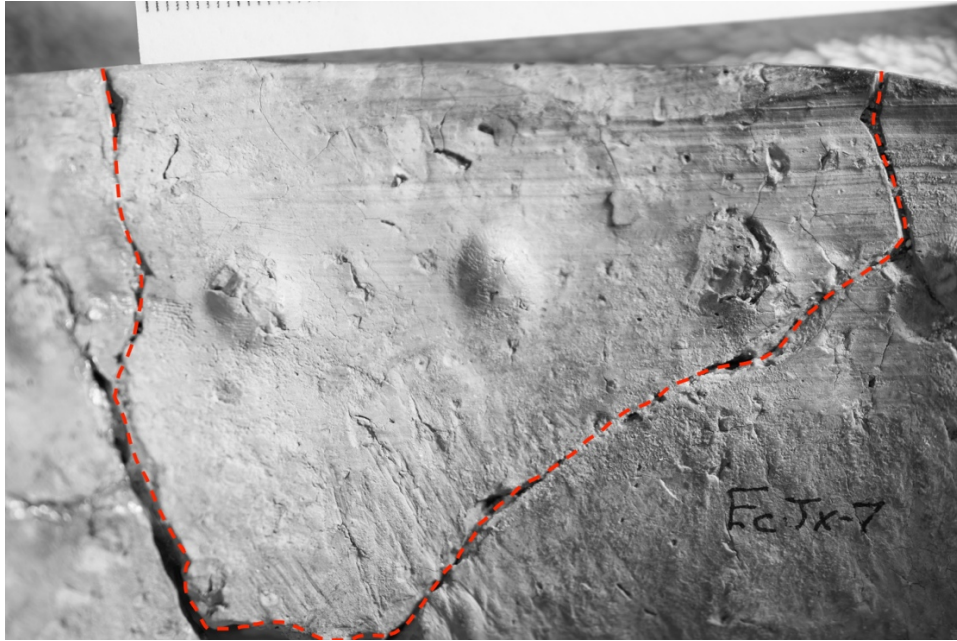


Figure 4. Interior view of rim fragment referenced in Figure 3. The interior view shows the raised curved surface opposite the punctates.



Figure 5. Close-up of pattern impressed around body of vessel.

The Late Woodland Period spans 1,250 to 250 B.P (Taylor-Hollings 2017). The ceramic cultures that define this period include Blackduck, Selkirk Composite, and other undifferentiated Woodland cultures (Taylor-Hollings 2017, p. 109). The ceramic vessel that will be studied has Blackduck features, albeit with some Laurel features as well. Even though, boreal forest regions are primarily Blackduck culture (Taylor-Hollings 2017, p. 109).

The predominantly coniferous boreal forest region addressed here extends across a broad part of the southwestern Canadian Shield from the upper Great Lakes westward to the Manitoba-Ontario border. It has a long history of permanent Indigenous settlement with seasonally shifting resource use involving highly mobile forager groups that utilized upland forests, lakes, and rivers (Hyslop & Colson 2017). Subsistence would have included small and large mammals, including moose, as well as an abundance of freshwater fish (Taylor-Hollings 2017).

The geographic area of primary interest is centred on Lac Seul, a very large inland lake that is characterized as the hub of a vast water-based transportation network that offered an optimal settlement location (Hyslop & Colson 2017). Archaeological evidence supports Lac Seul as being active in trading as artifacts made from non-local materials have been discovered in the area (Hyslop & Colson 2017, p.317).

Data Collection

Surface images were taken of both the interior and exterior of all of the fragments of each sherd of the vessel top down (Figure 6). Multiple images were taken of each fragment, flooding light from different angles. Since the impressions are not uniformly oriented, lighting

from different angles was necessary to capture the ridge impressions. The images were all then digitally enhanced in order to obtain a clearer image of the ridges and furrows. These enhancements included adjusting the exposure, contrast, highlights, shadows, saturation, and sharpness as needed.



Figure 6. Camera set-up used to capture impressions on the interior and exterior surfaces of the ceramic vessel.

The images were uploaded to the ImageJ computer program. Each print was photographed with a scale in mm to control the measurements. For ridge density, this research employed the Acree method of measurement. To calculate ridge density, an area of 25mm^2 or a lesser 6.25mm^2 is fixed over the maximum area of a print that has visible ridges and furrows (Figure 7):

$$\text{Ridge Density} = \text{Number of Ridges in a } 25 \text{ mm}^2 \text{ area (or lesser } 6.25\text{mm}^2 \text{ area)}$$

Since these prints are partial, the region of the finger generally cannot be identified, thus the area will be confined to the maximum area of the print.

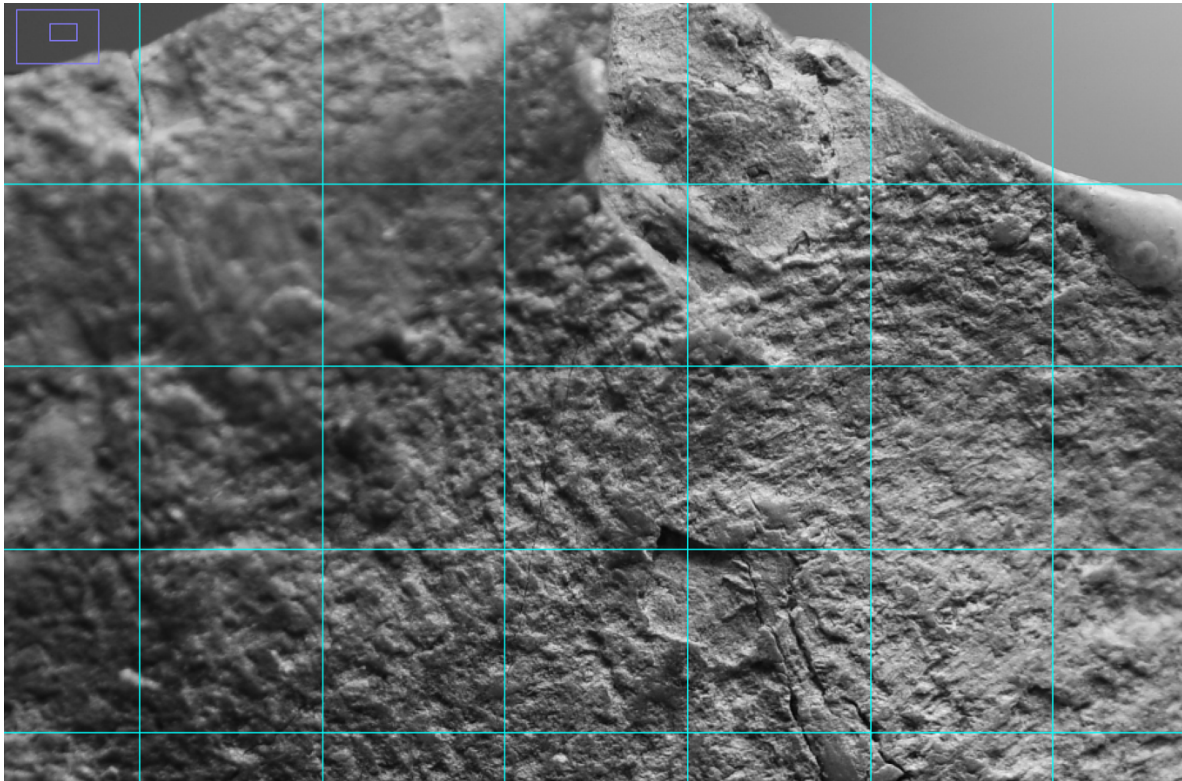


Figure 7. 6.25mm² grid overlay on an epidermal print found on the surface of Eclx-7 vessel sherd to determine ridge density using the ImageJ program.

To calculate the ridge breadth, the number of ridge furrow pairs is counted along the length of a line:

$$\text{Mean Ridge Breadth} = \text{Line Length} / \text{Number of Ridge-Furrow Pairs}$$

In order to improve accuracy multiple ridge breadth measurements were taken for each impression to arrive at a mean (Figure 8).

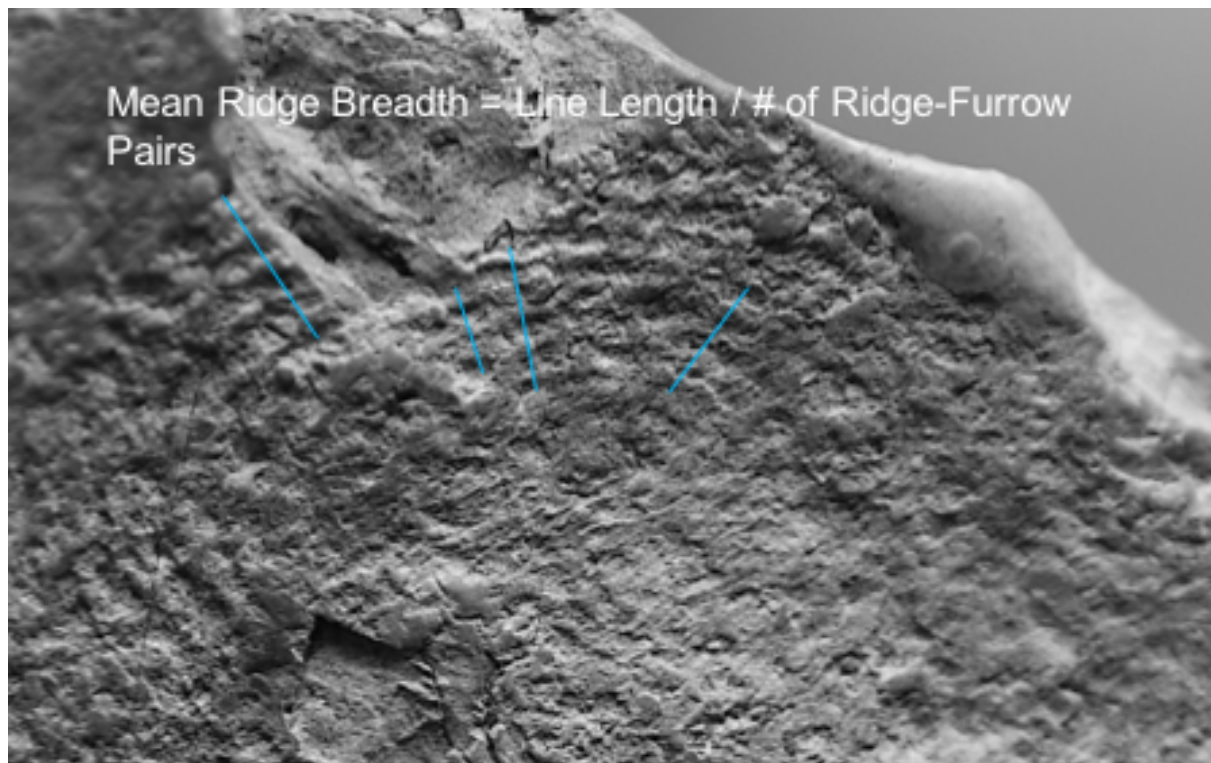


Figure 8. Sample Ridge Breadth measurement lines on an epidermal print found on surface of Eclx-7 vessel sherd to determine mean ridge density.

Impression Quality Analysis

Impressions on ceramics whether fingerprints, tool marks, or other sources are often wiped off during production. Fingerprints can be easily distinguished from impressions from another source by the presence of fingerprint identifiers (presence of ridges and furrows, ridge bifurcation, pores, core patterns) and biometric properties (the orientation of the print and where it is situated). Partial impressions can be still be analysed, depending on the quality of the impression. Since the majority of prints found on this ceramic vessel are partial, different

factors need to be taken into consideration so as to prevent the inclusion of measurements from impressions that are not fingerprints and to identify outliers.

The analysis applied the following developed framework to choose the sample population for ridge breadth analysis (Table 1).

Level	Category	Description
1	Excellent Quality	• Near-Complete Print • 10+ Measurable Ridge-Furrow Pairs • Fingerprint Identifiers Present
2	High Quality	• 8-10 Measurable Ridge-Furrow Pairs • Fingerprint Identifiers Present
3	Moderate Quality	• 5-7 Measurable Ridge-Furrow Pairs • Fingerprint Identifiers Present
4	Poor Quality	• 3-4 Measurable Ridge-Furrow Pairs • Fingerprint Identifiers Present
5	Smudged Print	• Fingerprint that has “smudged” due to clay wetness
6	Miscellaneous Impressions	• No Fingerprint Identifiers Present • Impression from an Alternate Source (i.e., not finger) • Examples: Tool Marks, Organic Materials, etc.

Table 1. Impression Quality Analysis Framework, developed to determine sample population based on quality of the fingerprint impression to prevent the inclusion of measurements from impressions that are not fingerprints and to identify outliers.

For the purpose of this study, fingerprints falling within Levels 1, 2 and 3 were used. Fingerprints were not used from Level 4 as there are too few ridges to conduct an accurate analysis. Level 5, smudged prints, were not used for the purposes of the analysis, but can still provide valuable information (outside the scope of this research) on anthropometrics. Level 6, miscellaneous impressions, likely from other sources, were recorded for thoroughness. Wipe marks were not included and they coat a significant portion of the interior of the vessel, erasing everything underneath. Examples of each level can be found at Figures 9 through 14.

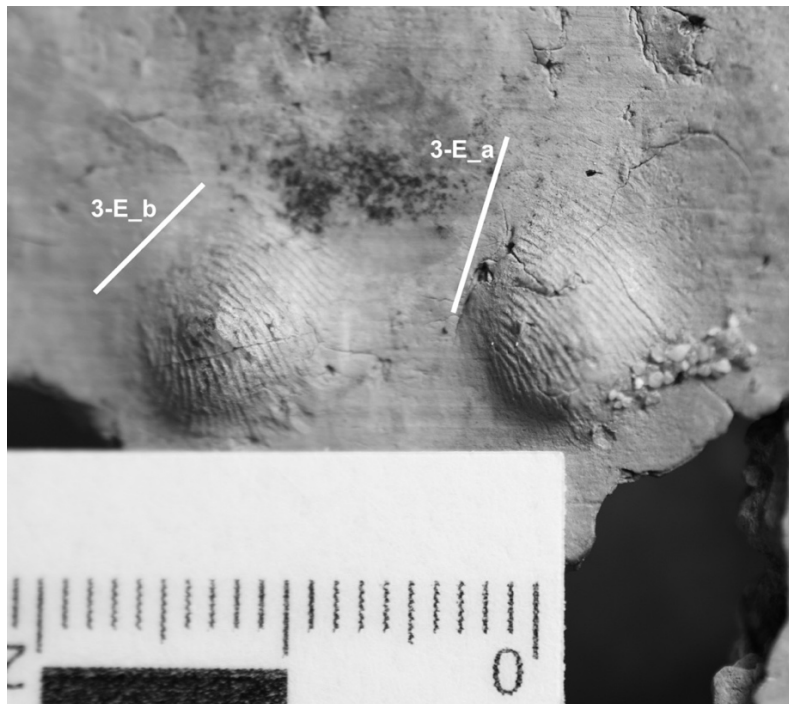


Figure 9. Examples of two Level 1 impressions under the Quality Analysis Framework.

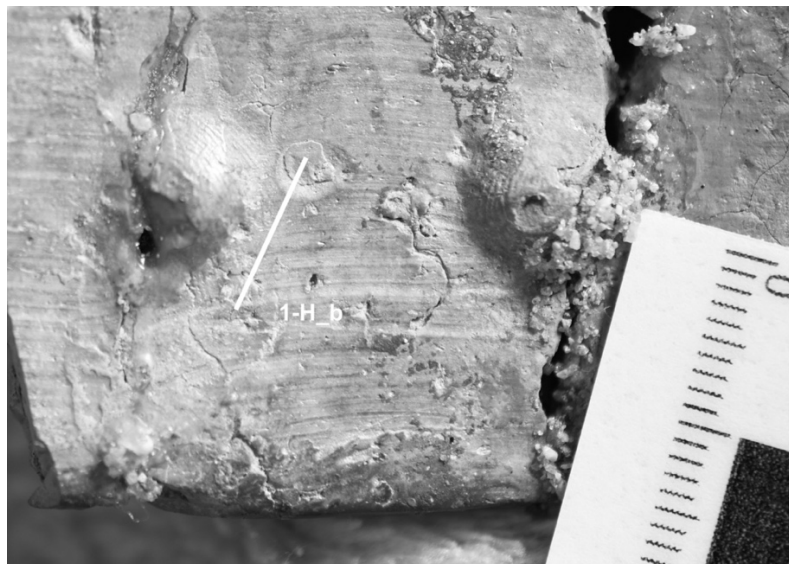


Figure 10. Example of a Level 2 impression under the Quality Analysis Framework.

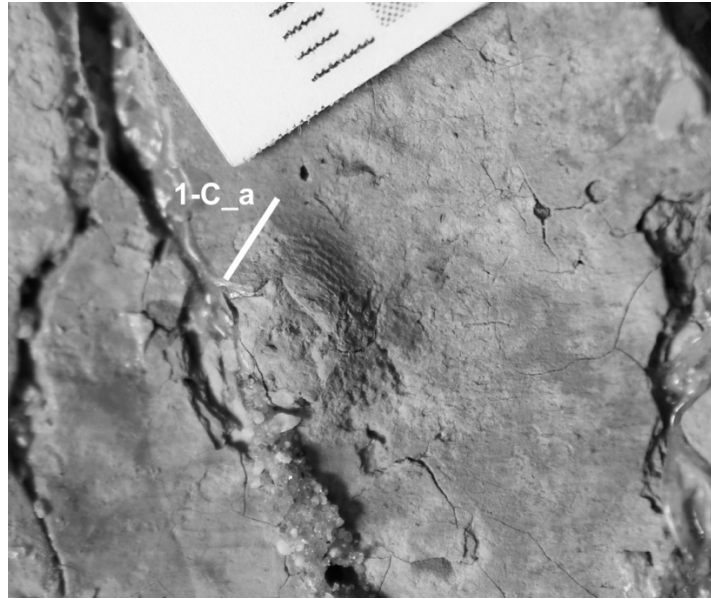


Figure 11. Example of a Level 3 impression under the Quality Analysis Framework.

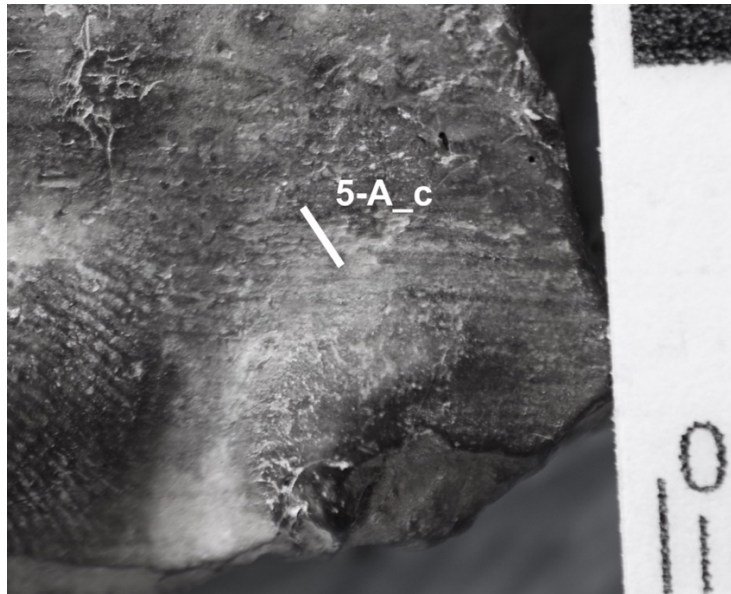


Figure 12. Example of a Level 4 impression under the Quality Analysis Framework.



Figure 13. Example of two Level 5 smudged fingerprints under the Quality Analysis Framework.

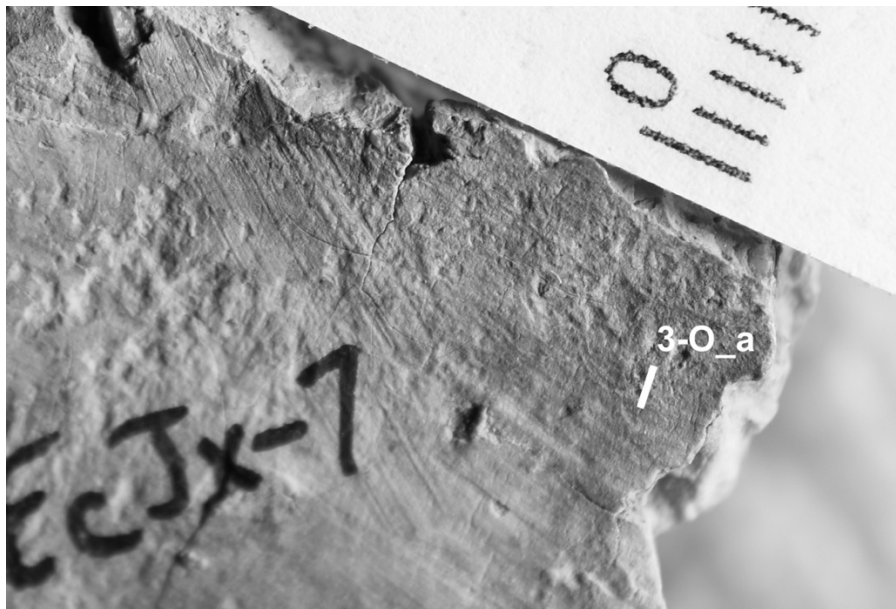


Figure 14. Example of a Level 6 impression under the Quality Analysis Framework (impression from another source).

The quality of the print directly conditions the ability to obtain measurements for analysis. Despite this, all ridge density measurements were used in this analysis. This is because it is more difficult to obtain ridge density measurements. First of all, the number of visible ridges that are needed for ridge density measurements are substantially higher than what is required for ridge breadth measurements. As a result, it may only be possible to take measurements of ridge breadth. This results with data from prints where both age and sex measurements are obtainable or only age measurements are obtainable. Another obstacle that may limit ridge density measurements, but permit ridge breadth measurements, is in the case of overlapping prints. An overlap of prints may make it impossible to obtain enough ridges for a density measurement, but there may be ample ridges for a ridge breadth measurement. Due to these limitations, all ridge density measurements will be used despite some having slightly lower preservation quality.

Shrinkage Factor

Clay is naturally subject to shrinkage during the drying and firing processes. The ceramic material shrinks due to moisture evaporation from the clay. The degree of shrinkage may be mediated by the addition of temper to the clay by the potter. In the context of dactylography, this means that the ridge breadth and density measures do not accurately reflect the size of the original epidermal impression, unless a correction factor is used. This, of course, adds another level of analytic complication.

Throughout the literature, different factors have been proposed. In their test of regression equations, Králik and Novotný (2003) used a single correction of 7.5% to account for

shrinkage. Fowler et al (2019) instead argued that clay shrinkage is variable as a result of the clays and density of mineral and rock inclusions in processed clay bodies that could be used for making pottery. Vessels serving different functions and even those produced using different batches of processed clays, can vary in shrinkage. This complexity may require a range of values, not a single value, to estimate the original size of the fingerprint impression. A combination of clay shrinkage experiments and petrographic research is the necessary to determine the appropriate shrinkage correction for any particular assemblage. In their study of the marl clays used at Tel es Safi (Fowler et al. 2019, 2020) and the rendzina and terra rosa clayey soils in the vicinity of Beth Shemesh (Fowler et al. 2022), Fowler et al. found that corrections of 2% and 6% were an appropriate adjustment for the shrinkage of these clays.

The range of corrections used in this analysis have been determined by a shrinkage test. Samples have been provided from Lac Seul and other clays sourced from weathered glacial till bedrock at other locations across the boreal forest, from Nutamik Lake in the south to Cross Lake in the north. Each sample was rehydrated and dried in order to determine an appropriate shrinkage range for raw, organic tempered, and grit tempered clays (see Fowler et al. 2019b).

The shrinkage experiment in this study took into consideration air drying and not firing. Previous study of clays derived from glacial till sources showed that the difference in linear shrinkage between dry and fired tiles and briquettes was negligible. Free hydroxyls, such as the moisture added to clay for the manufacture of ceramics, evaporates almost completely during air-drying process (Fowler et al. 2017, p. 110). The purpose of firing is to get rid of any water that is chemically bound (Fowler et al. 2017, p 111), which includes “pore water” in the pores and capillaries of a clay matrix, “inter-layer water” that exists between clay mineral layers, and

“surface-absorbed water” which “naturally absorbed by a dry or drying clay mass” (Fowler 2017, p.111). Fowler et al. note that this “surface-absorbed water” does not affect the shrinkage. The other types of chemically bound hydrols, “pore water” and “inter-layer water,” require significant and maintained firing temperatures in a highly controlled environment (Fowler et al. 2017, p.111). Even if these temperatures were able to be met and maintained with the pre-contact method of firing, the shrinkage is minimal (Fowler et al. 2017, p.111). Based on the air-drying experiment, corrections of 6% and 12% were chosen for the analysis of ridge breadth and ridge density, with the latter being the most extreme estimation based upon a grit-tempered (rock and mineral inclusions <2 mm in length) clay from a Boreal Forest glacial till bedrock sourced clay. The results of the shrinkage experiment can be found in Table 2 below.

	Lac Seul Clay	Other Glacial Till Bedrock Sourced Clays					
	No Temper	Grass Tempered		Grit Tempered		No Temper	
Average Observed Length (mm)	9.34	9.64	9.56	9.22	8.82	9.68	9.38
Percent Shrinkage (%)	6.6	3.6	4.4	7.8	11.8	3.2	6.2
	% Linear Dry Shrinkage = $100 * \{(\text{Actual length}^1 - \text{Observed length}) / \text{Actual length}\}$						

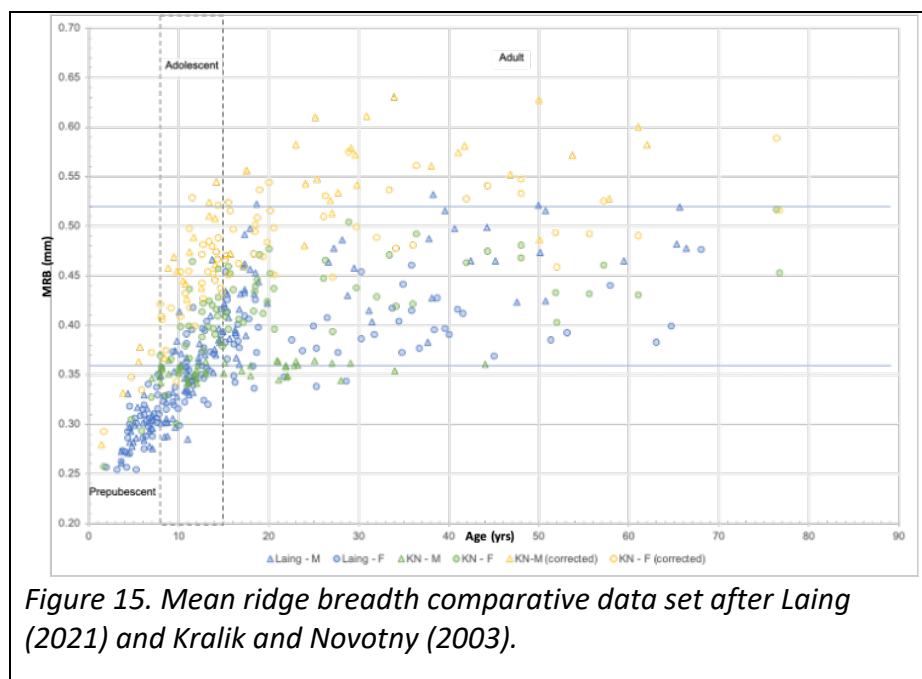
Table 2. Shrinkage test results from a Lac Seul untempered sample, and two grass, two grit, and two untempered samples from other clays derived from glacial till bedrock at other locations across the boreal forest, from Nutamik Lake in the south to Cross Lake in the north.

¹ Each sample has an initial length value of 10mm.

Comparative Data Sets

Once modified for shrinkage, the corrected (scaled) data will be compared to reference data sets in order to make appropriate age and sex determinations. For biological sex determinations, a geographically relevant population should be used as a comparative data set. This is because ridge density varies amongst populations due to the overall tendencies in stature and body mass, ridge breadth does not appear to be affected these same factors. As such, ridge density data sets had to be extrapolated from studies of populations most relevant to the population in the Late Woodland Lac Seul region. Age models can use data from any population.

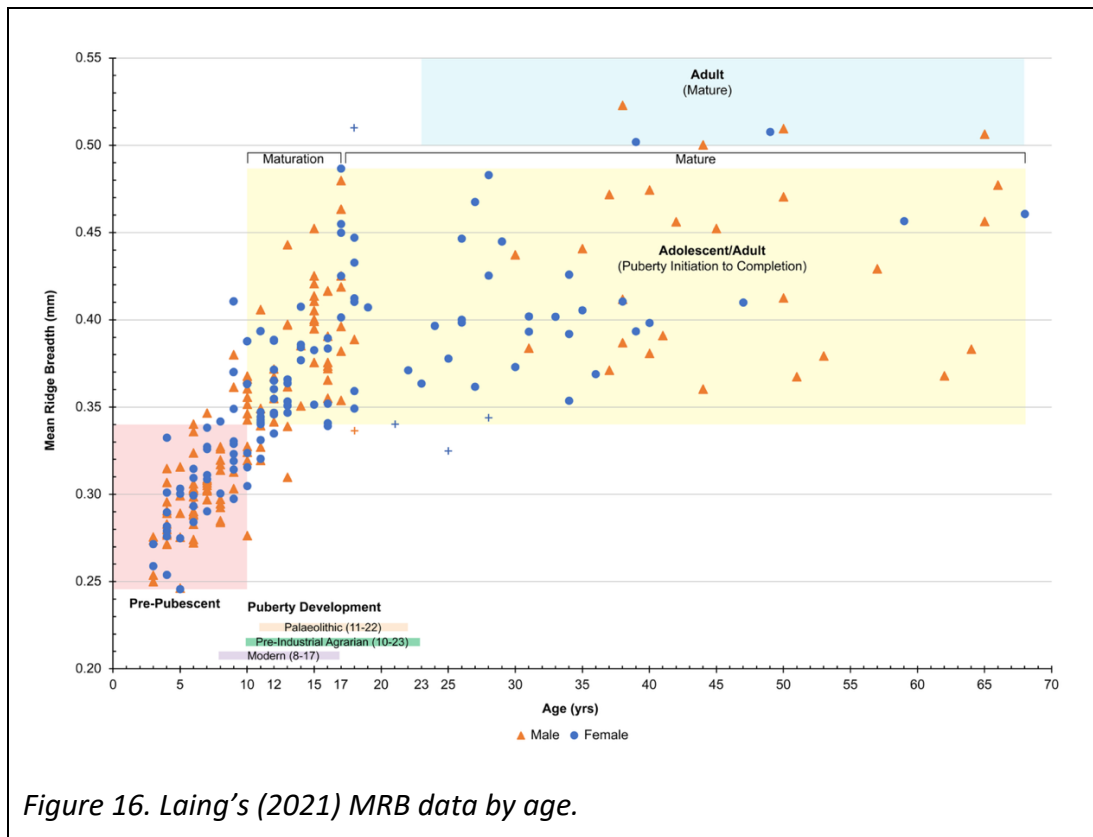
In choosing a comparative data set, this study looked to data sets compiled as part of the broader Ancient Prints Project directed by Dr. K. Fowler. Figure 15 below illustrates an aging model based on ridge breadth that includes data from, Králik and Novotný (2003) and Laing (2021).



The Králik and Novotný (2003) data sets were taken from prints impressed on objects made using commercial earthenware clay, the values were then “corrected” by an assumption or guess of a 7.5% correction to account for shrinkage of the clays, which is between 6-9%. This scaling affects the observation that only male prints will exceed 0.52 mm mean ridge breadth, instead a small proportion of female prints can exceed 0.52 mm mean ridge breadth. However, this is not supported by Laing's bespoke data set.

Contrary to Králik and Novotný's (2003), Laing's (2021) data set is obtained from inked prints. Because of this, the results do not need to be corrected for shrinkage. Based on the fact that the data does not need to be corrected and the fact Králik and Novotný's (2003) 7.5% shrinkage was not precise, Laing's (2021) data set will be used for comparison.

Laing's data helps clarify the relationship between mean ridge breadth and pubescent growth between 9 to 15 years of age. Values $<0.33\text{mm}$ always belong to prepubescent individuals, but those between 0.33 and 0.37 form a distinct group that have not yet experienced rapid growth relative to those in the same age cohort. Females are the indicator of this growth surge as they experience rapid growth and development of secondary sex characteristics before males. There is also a small adult group with exceedingly small mean ridge breadth. These may represent the mean ridge breadth of light, short, small-handed individuals (Ibegbu et al. 2015). Values greater than 0.50mm always belong to adults. Consequently, there are three age groups: Prepubescent (<0.33 MRB), Adult (>0.50 MRB), and an ambiguous Adolescent/Adult group (>0.32 to <0.50 MRB) because ridge breadth cannot be discriminated for adults and individuals in later stages of puberty development, see Figure 16.



To develop a ridge density comparative model, data obtained from this study will be compared to data extracted from Stinson's (2004) PhD thesis. Stinson measured the ridge density on 437 ink fingerprints (240 male, 197 female) from Indigenous peoples across the United States collected by Dr. James V. Neel sometime around the 1950s.

Stinson's data can be found in Table 3 and further illustrated in Figure 17. Based on these data, three different categories will be used for my analysis based on posterior probabilities for each sex at different mean ridge density values. 1) High female probability (F+) for probabilities of female >87%; 2) High male probability (M+) for probabilities of male >98%; and 3) Low male probability (M) where the probability of male 68% and probability of female 33%. This latter category is highlighted in Table 3. For the purpose of this study a fourth low

probability female (F) category is not warranted, since there really is not a low probability female category; after the low probability male range, the probability jumps to 87% female.

Mean RD/25mm ²	Male	Female	Total	N Males	N Females	Prob M	Prob F
7	0	0	0	0%	0%	0%	0%
8	2	0	2	1%	0%	100%	0%
9	46	0	46	19%	0%	100%	0%
10	92	0	92	38%	0%	100%	0%
11	65	1	66	27%	1%	98%	2%
12	27	13	40	11%	7%	68%	33%
13	7	46	53	3%	23%	13%	87%
14	1	68	69	0%	35%	1%	99%
15	0	51	51	0%	26%	0%	100%
16	0	14	14	0%	7%	0%	100%
17	0	4	4	0%	2%	0%	100%
18	0	0	0	0%	0%	0%	0%
Total Sample Size	240	197	437				

Table 3: Stinson's (2004) mean ridge density data set. Highlighted row indicates an ambiguous value with a lower probability of the ridge skin impression being male or female.

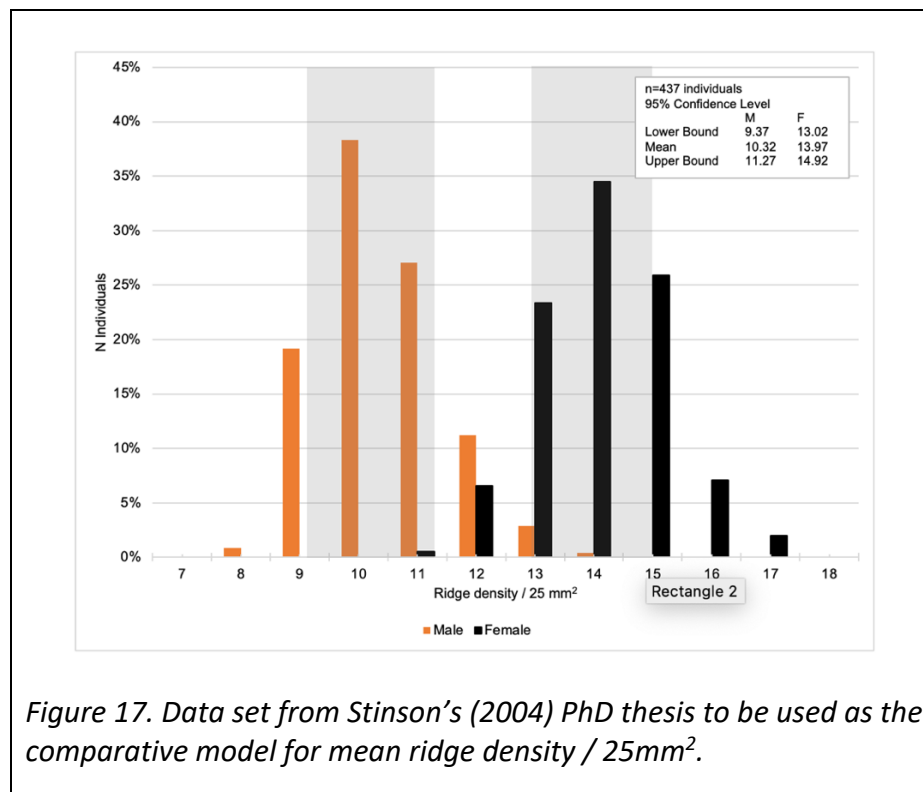


Figure 17. Data set from Stinson's (2004) PhD thesis to be used as the comparative model for mean ridge density / 25mm².

Chapter IV. Results and Analysis

Sample Selection and Size

Overall, a total of 121 impressions were identified and measured for this study. Images of each Impression can be found in Appendix B. When broken down by quality level, the totals are:

- Level 1: 7 prints;
- Level 2: 11 prints;
- Level 3: 8 prints;
- Level 4: 14 prints;
- Level 5: 6 prints; and
- Level 6: 75 impressions.

As previously mentioned, Levels 1 through 3 are used to take ridge breadth measurements.

Thus, the total data set for age determination is 26 fingerprints.

The data set used to measure ridge density for sex determination is determined differently. The majority of the prints imaged did not have sufficient ridges to be measurable. Since ridge density requires more visible ridges than for ridge breadth measurements, there were less opportunities to obtain ridge density measurements. Therefore, all ridge density measurements were used (21 prints in total), excluding only level 6 impressions since these were not made by fingers.

Sex Determination

When comparing my values to Stinson's (2004) in Table 3, almost the entirety of the prints on this vessel are high probability female (see Table 4). This result corresponds to the

expectation that Indigenous pottery making generally being considered as a ‘women’s craft’ (Syms 1977; Taylor-Hollings 2017, p.110; Bales 1997).

Impression	MRD 0% (25mm ²)	MRD 6%	MRD 12%	0% Sex	6% Sex	12% Sex
1-A_a	16	15	14	F+	F+	F+
1-D_c	16	15	14	F+	F+	F+
1-G_a	14	13	12	F+	F+	M
1-H_a	16	15	14	F+	F+	F+
1-H_b	19	18	17	F+	F+	F+
1-z._a	18	17	16	F+	F+	F+
2-B_b	18	17	16	F+	F+	F+
3-B_a	13	13	12	F+	M	M+
3-E_a	18	17	16	F+	F+	F+
3-E_b	17	16	15	F+	F+	F+
3-E_c	18	17	16	F+	F+	F+
3-F_a	18	17	16	F+	F+	F+
3-F_b	19	18	17	F+	F+	F+
4-A_b	16	15	14	F+	F+	F+
4-C_a	16	15	14	F+	F+	F+
4-G_b	18	17	16	F+	F+	F+
5-A_a	15	14	13	F+	F+	F+
5-A_b	18	17	16	F+	F+	F+
5-B_a	17	16	15	F+	F+	F+
5-B_b	17	16	15	F+	F+	F+
6-A_a	15	14	13	F+	F+	F+

Table 4: Lac Seul ceramic vessel Mean Ridge Density/25mm² at 0%, 6% and 12% shrinkage corrections using Stinson’s (2004) data set to determine biological sex probability. F+ = probability >87%; M+ = probability >98%; M = probability of male 68%/female 33%.

However, as highlighted in Table 4, there are two outliers. Upon applying the corrections for shrinkage, two fingerprints result in a degree of male probability, impressions 1-G_a and 1-B_a. Of the two, Impression 1-G_a has the lower probability of coming from a male. The male probability arises only at the extreme 12% shrinkage correction. Print 3-B_a, on the

other hand, has a higher probability of being male at the 6% and the 12% shrinkage correction. At this higher correction, when comparing to Stinson's (2004) in Table 3, the 11.73 mean ridge density correspond to a male probability >98%. The 6% shrinkage correction yielded a 12.53 MRD corresponding with a low male probability (M) with the probability of being male at 68% and the probability of being female at 33%.

The two outlier prints, 3-B_a (Figure 18) and 1-G_a (Figure 19) are visibly different in both ridge thickness and ridge breadth compared to rest of the sample. Figure 18 shows 3-B_a situated beside a print with a high female probability (3-E_a) even after the most extreme shrinkage corrections.

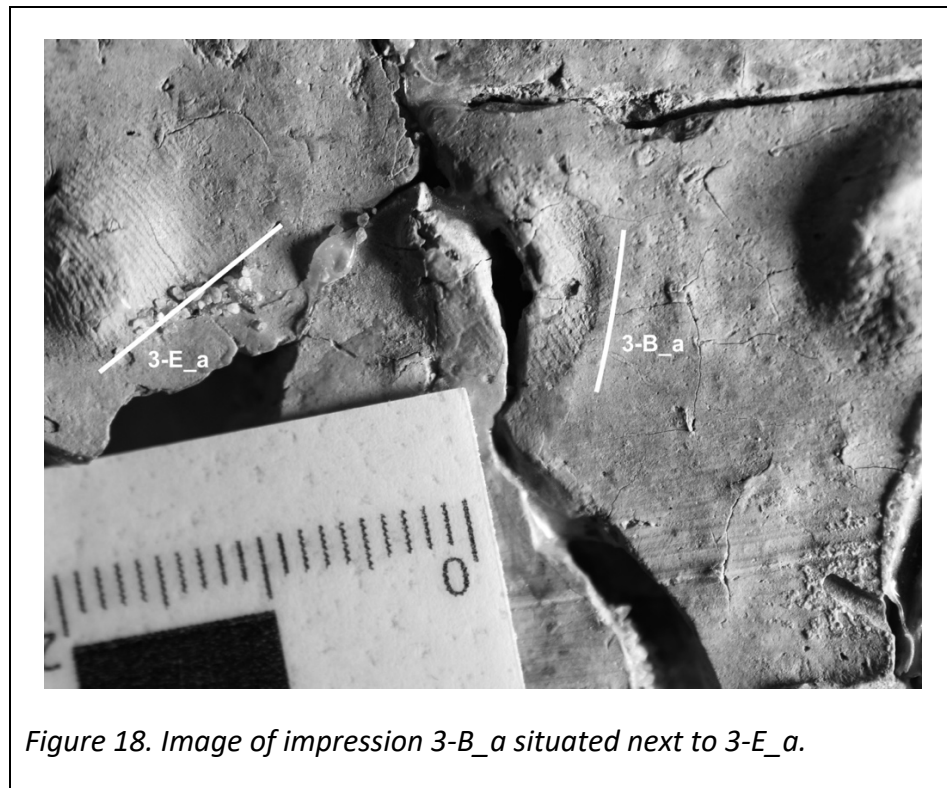


Figure 18. Image of impression 3-B_a situated next to 3-E_a.

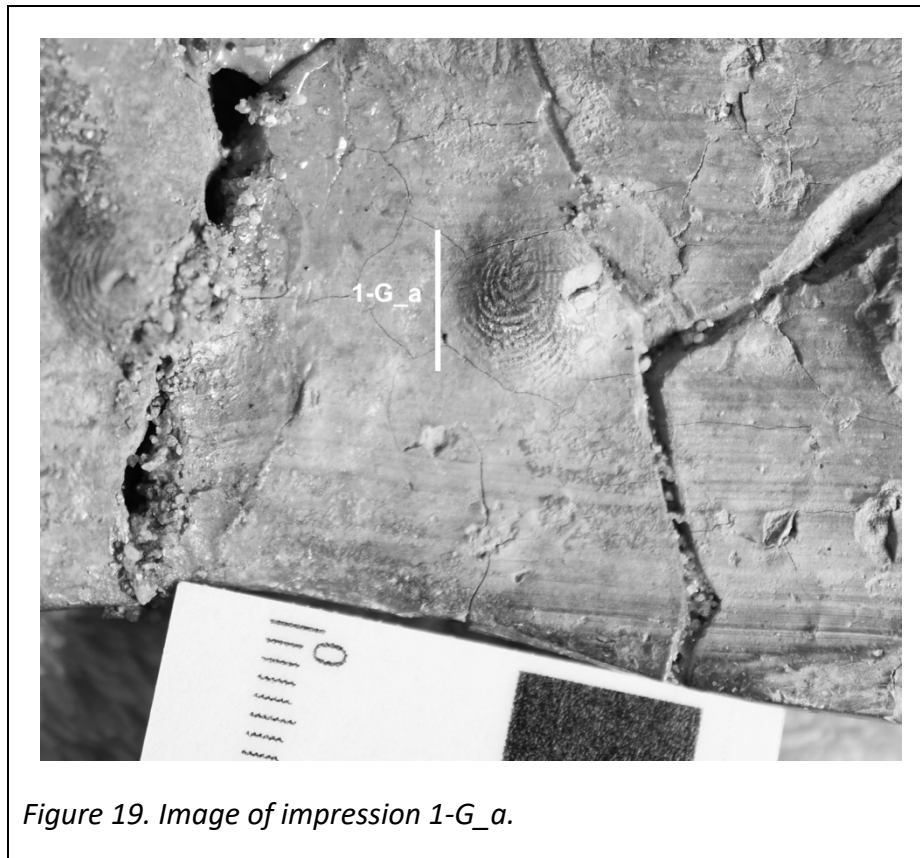


Figure 19. Image of impression 1-G_a.

What is interesting is that both of these potential male prints are located in the same region of the ceramic vessel, the interior rim. This part of the vessel is more heavily decorated with punctates around the perimeter of the pot. Each print is located behind a punctate. This pattern may provide insight into the process of manufacture. Could this possibly suggest that the decoration stage in manufacturing includes men? Considering that the male prints occur exclusively at this late stage of manufacture, they are rare, and are only placed on the interior boss created by the exterior punctate, the male imprints may represent more than just a male hand in manufacturing. The punctate can be made by one person. But here we possibly see an intention to have the vessel elaborated by both men and women. However, there could very well have been male prints earlier in the manufacturing process that were wiped away

intentionally or through use-wear. We also cannot ignore the fact that the manufacture of the vessel is not occurring in a vacuum outside individuals may have interfered for a variety of reasons. Further studies could be used to provide more insight into this anomaly.

Age Determination

The mean ridge breadth data results from this study can be found in Table 5. To reiterate, for comparison purposes, Laing's bespoke data set lays out the following criteria:

- 1) <0.33mm = pre-pubescent;
- 2) 0.32mm< and <0.50mm = ambiguous adolescent/adult identification;
- 3) only adult prints can be >0.50mm.

Impression	MRB (mm) 0%	Age (yrs) 0%	MRB 6%	Age 6%	MRB 12%	Age 12%
1-C_a	0.31844	6.96041	0.33755	7.93804	0.36379	9.28064
1-D_b	0.34493	8.31552	0.36562	9.37445	0.39405	10.82872
1-D_c	0.37318	9.76121	0.39557	10.90689	0.42632	12.48028
1-G_a	0.42335	12.32806	0.44875	13.62775	0.48363	15.41264
1-H_a	0.37189	9.69499	0.39420	10.83669	0.42485	12.40462
1-H_b	0.31961	7.01990	0.33878	8.00110	0.36512	9.34861
2-B_b	0.34877	8.51190	0.36969	9.58262	0.39843	11.05306
3-A_b	0.35611	8.88769	0.37748	9.98095	0.40682	11.48237
3-B_a	0.47689	15.06757	0.50550	16.53163	0.54480	18.54227
3-E_a	0.37484	9.84617	0.39733	10.99694	0.42822	12.57734
3-E_b	0.38333	10.28058	0.40633	11.45742	0.43792	13.07360
3-E_c	0.37514	9.86118	0.39765	11.01285	0.42856	12.59448
3-F_a	0.35765	8.96627	0.37911	10.06425	0.40858	11.57213
3-F_b	0.34017	8.07211	0.36058	9.11644	0.38861	10.55065
4-A_a	0.35396	8.77754	0.37520	9.86419	0.40436	11.35653
4-A_b	0.36819	9.50575	0.39028	10.63610	0.42062	12.18844
4-C_a	0.33286	7.69796	0.35283	8.71984	0.38026	10.12322
4-G_a	0.36372	9.27697	0.38554	10.39358	0.41551	11.92707
4-G_b	0.32723	7.40998	0.34686	8.41458	0.37383	9.79423
5-A_a	0.33941	8.03329	0.35978	9.07529	0.38775	10.50630
5-A_b	0.35146	8.64981	0.37255	9.72880	0.40151	11.21061
5-B_a	0.37533	9.87123	0.39785	11.02350	0.42878	12.60596
5-B_b	0.38302	10.26457	0.40600	11.44045	0.43756	13.05532
6-A_a	0.34074	8.10105	0.36118	9.14711	0.38926	10.58370
6-A_c	0.35433	8.79673	0.37559	9.88453	0.40479	11.37845
6-A_d	0.36950	9.57276	0.39167	10.70712	0.42212	12.26499

Table 5. Lac Seul MRB Data from quality assessment levels 1-3 and corresponding age in years.

When applying Laing's (2021) criteria to the Lac Seul results, the majority of the results fit within the ambiguous adolescent/adult group (Table 6).

Shrinkage Correction	Pre-Pubescent (<0.33mm)	Ambiguous Adolescent/Adult (>0.32mm, <0.50mm)	Adult (>0.50mm)
0%	2	24	0
6%	0	25	1
12%	0	25	1

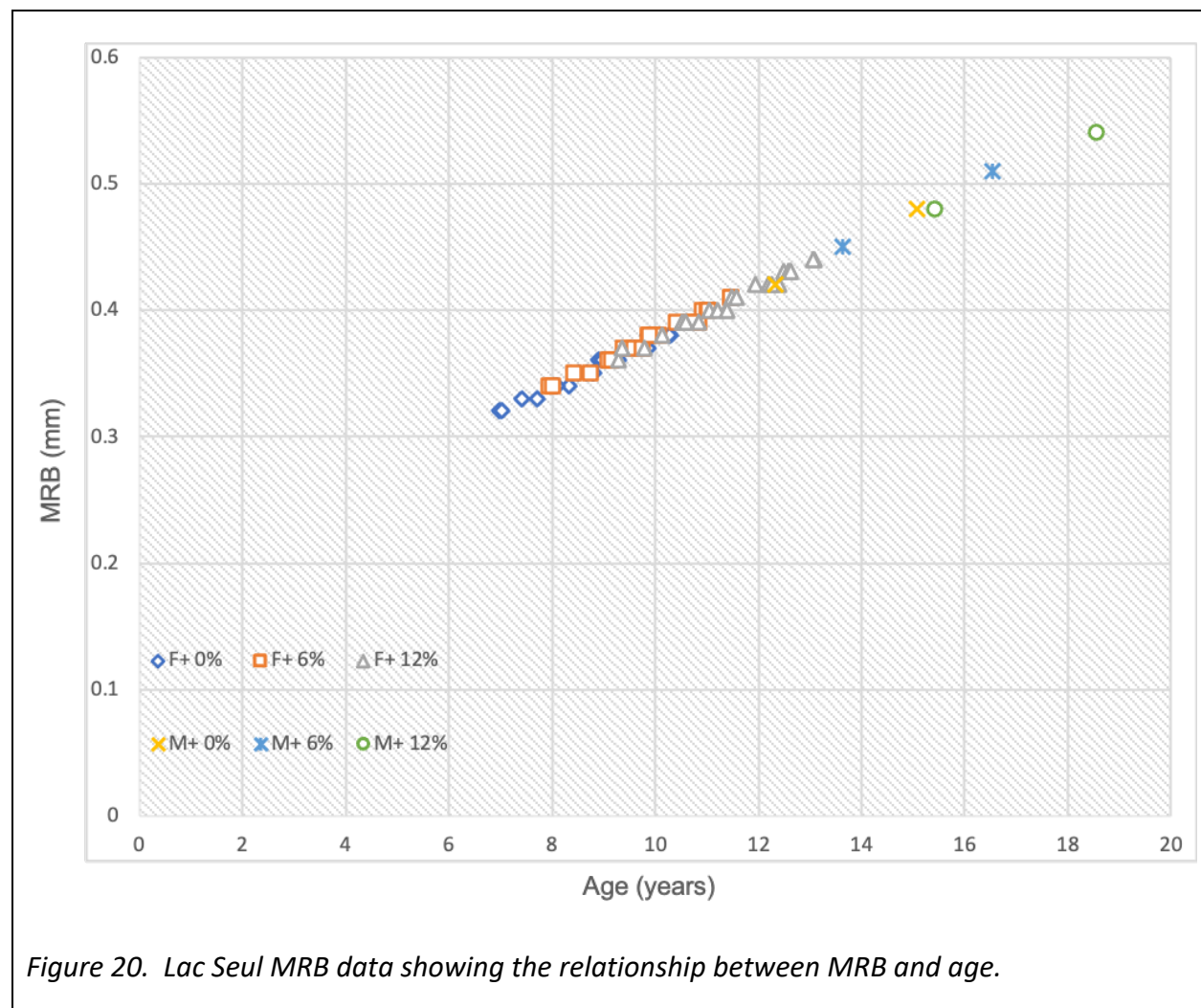
Table 6. Summary of age category result of study using Laing's (2021) criteria.

There are two prints that stand out, prints 3-B_a and 1-G_a. These two prints have the lowest ridge density (indicating a degree of male probability), as well as the highest mean ridge breadths. First and foremost, print 3-B_a is likely an adult print. According to Laing's data set, any mean ridge breadth above 0.5mm is an adult. After correcting for 6% shrinkage, the mean ridge breadth is 0.51mm, and after a 12% correction, 0.54mm. The other print, 1-G_a, is technically just below the adult mean ridge breadth threshold and would fall within the ambiguous adolescent/adult identification group. However, it does stand out as having a higher value than the other prints in the data set as well as having the lower ridge density, so it is worth highlighting.

The associated ages for the mean ridge breadth data for print 3-B_a are: 15.07 years at 0%, 16.53 years at 6%, and 18.54 years at 12%. On the other hand, 1-G_a's mean ridge breadth provides for an average age of 12.33 years at 0%, 13.63 years at 6% and 15.41 years at 12%. In making age interpretations it is important to note that there will be an error range. For this method the age range error is 5 years, or ± 2.25 years. The remainder of the prints fall within

the pre-pubescent age range and the ambiguous adolescent/adult group, being at least pubescent.

Using the Lac Seul data from Table 5, the linear relationship between the mean ridge breadth and aging can be illustrated, see Figure 20. The linear relationship of the Lac Seul data is compared with the linear progression of the Laing's (2021) comparative set illustrated in Figure 21.



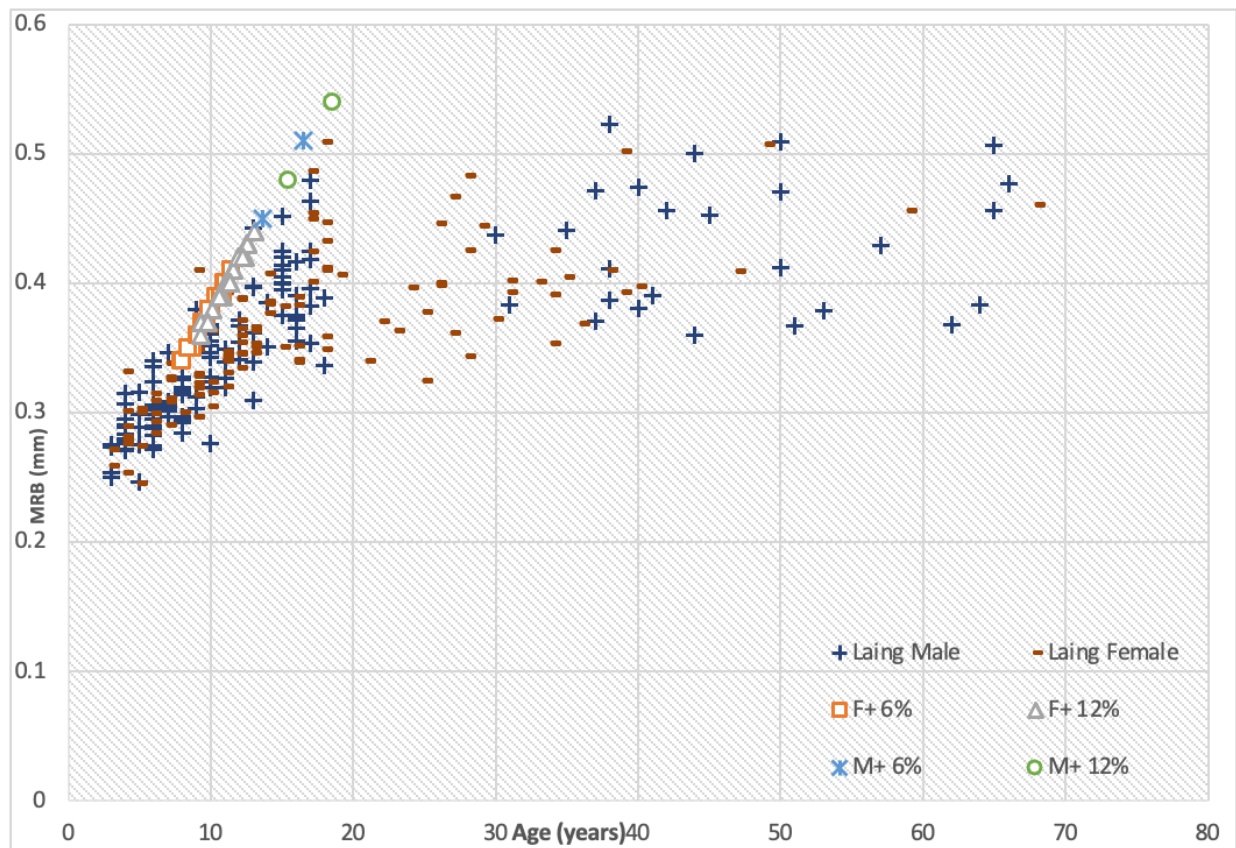


Figure 21. Comparison of the Lac Seul MRB data with the Laing (2021) data set.

The difference in the data sets likely means that age is underestimated. There is always a possibility that age will be underestimated using this model. However, it will not be overestimated. Because of this, age values are considered within a 5-year age range. Furthermore, age classifications are used in the same manner as age ranges are estimated in osteological assessments of age using skeletal markers of age assessment (pre-pubescent, adolescent/adult, adult). Additionally, Laing's study did not develop a regression equation for her data set. The fact that a regression equation developed based on a different data set was applied affects the results as well.

Application of Prints During Manufacturing

The interpreted data provides differing ages and potentially different sexes for fingerprints found throughout the vessel as a whole. However, another layer of analysis may prove to be useful for discussion purposes. As aforementioned the two prints with the potential to be male are present only on rim sherds. A partonomic analysis can be completed to see if the age varies based on location on the vessel. This could provide insight into the manufacture process. Figure 22 breaks down the vessel into different parts: Lip, Rim, Neck, Shoulder, Body (Upper and Lower).

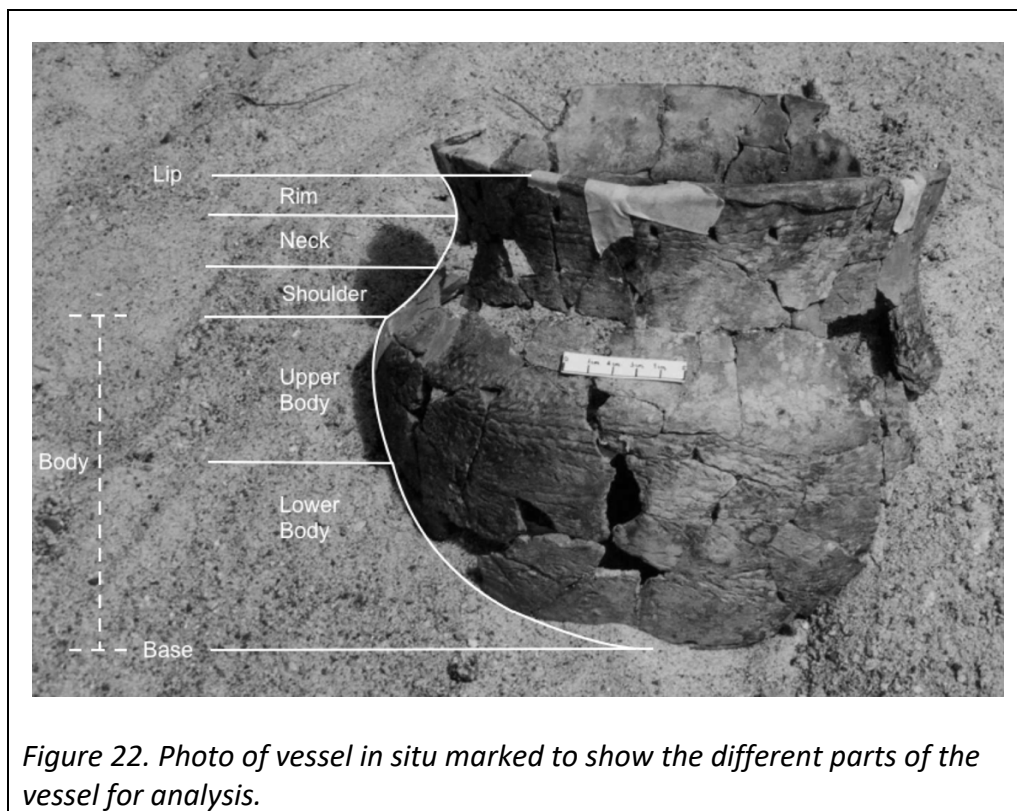


Table 7 sorts the combined age and sex data into the different parts. Regarding sex, the potentially male prints are seen under the “Rim” section of the table. In terms of age, the adult

male print is on the rim and the younger female prints run from the rim through the body of the vessel.

Imprint ID	Avg Age (yrs) 6%	Avg Age (yrs) 12%	Sex 6%	Sex 12%
Rim				
1-C_a	7.94	9.28		
1-D_b	9.37	10.83		
1-D_c	10.91	12.48	F+	F+
1-G_a	13.63	15.41	F+	M
1-H_a	10.84	12.40	F+	F+
1-H_b	8.00	9.35	F+	F+
2-B_b	9.58	11.05	F+	F+
3-A_b	9.98	11.48		
3-B_a	16.53	18.54	M	M+
3-E_a	11.00	12.58	F+	F+
3-E_b	11.46	13.07	F+	F+
3-E_c	11.01	12.59	F+	F+
4-A_a	9.86	11.36		
4-A_b	10.64	12.19	F+	F+
4-C_a	8.72	10.12	F+	F+
4-G_a	10.39	11.93		
4-G_b	8.41	9.79	F+	F+
5-A_a	9.08	10.51	F+	F+
5-A_b	9.73	11.21	F+	F+
5-B_a	11.02	12.61	F+	F+
5-B_b	11.44	13.06	F+	F+
Shoulder				
3-F_a	10.06	11.57	F+	F+
3-F_b	9.12	10.55	F+	F+
Body				
6-A_a	9.15	10.58	F+	F+
6-A_c	9.88	11.38		
6-A_d	10.71	12.26		

Table 7. Partonomic breakdown of age and sex data for fingerprint impressions from levels 1 through 3.

For the purpose of making age and sex determinations, smudge prints were of limited measurable value. However, as previously mentioned, these smudged indentations could provide other value, they could provide insight into the manufacture process. Smudge prints are more common early in the process, since the clay is still too wet to capture a clear print. The partonomic breakdown of level 5 smudge prints is found in Table 8.

Rim	4-A_c
Neck	2-L_a
Shoulder	2-F_a
	2-F_b
Upper Body	2-I_a
Body	6-C_b

Table 8. Partonomic breakdown of level 5 smudge prints.

Unfortunately, looking at Table 8, there is not enough data to make any such conclusions in this case. One of the reasons for this could be that the inside of the vessel was wiped and smoothed. Figure 23 exhibits the excessive wipe marks in the interior of the vessel.



Figure 23. Photo of interior body sherds illustrating the presence of wipe marks.

This is one of the unfortunate realities of ceramic production, fingerprints, tool marks, or impressions from other sources are often wiped off during production.

Effect of Curvature

I came across an additional element that has not widely considered in fingerprint analysis on objects. Sero, D. et al. (2023) addressed this, noting that “[c]urvature is also an issue as marks or sections of marks on sharply curved surfaces cannot be measured accurately from 2D images” (pp.1-2). This is relevant to the vessel studied as there are raised, curved surfaces on the interior surface opposite the punctate décor along the rim. Logically, the curvature of the uneven surface would affect the ridge breadth. There are no correction factors in the literature for the effect of curvature on ridge breadth or density measurements.

In this case, there were some fingerprints that encompassed an area large enough to take measurements on both the curved surface of the pot as well as the flat surface of the pot (Table 9).

Print ID	Avg MRB 0%	Avg Age (mo) 0%	Avg Age (yrs) 0%	Avg MRB 6%	Avg Age (mo) 6%	Avg Age (yrs) 6%	Avg MRB 12%	Avg Age (mo) 12%	Avg Age (yrs)12%
1-G_a									
Curved	0.44	158.07	13.17	0.47	174.28	14.52	0.50	196.53	16.38
Flat	0.37	117.53	9.79	0.40	131.31	10.94	0.43	150.22	12.52
Difference	0.07	40.54	3.38	0.07	42.97	3.58	0.07	46.31	3.86
1-H_b									
Curved	0.32	85.73	7.14	0.34	97.60	8.13	0.37	113.89	9.49
Flat	0.31	75.27	6.27	0.32	86.51	7.21	0.35	101.94	8.49
Difference	0.01	10.46	0.87	0.02	11.09	0.92	0.02	11.95	1.00
3-E_a									
Curved	0.39	128.36	10.70	0.41	142.78	11.90	0.45	162.58	13.55
Flat	0.35	102.85	8.57	0.37	115.74	9.64	0.40	133.44	11.12
Difference	0.04	25.51	2.13	0.04	27.04	2.26	0.05	29.14	2.43
3-E_b									
Curved	0.39	125.56	10.46	0.41	139.82	11.65	0.44	159.39	13.28
Flat	0.37	113.49	9.46	0.39	127.02	10.59	0.42	145.60	12.13
Difference	0.02	12.07	1.00	0.02	12.80	1.06	0.02	13.79	1.15

Table 9. Prints from which both flat and curved measurements were able to be taken, showing effect on curvature on print impressions.

The age model used for this experiment has an age range error of 5 years, ± 2.25 years. For this research, the curvature on this vessel does not have a significant impact on the results of this study; given the error range so was included. However, this is an avenue that could be explored in future research; for example, examining the effect of degree of curvature on fingerprints, if corrections should be made, at what threshold do they need to be made? Although this is far outside the scope of this study, it would certainly be a beneficial addition to the literature.

Summary

When the MRB and MRD data are compared (Figure 24), the results of this research show that most ridge skin impressions on the vessel were made by an adolescent or adult female at 6 and 12%. Two other fingerprints have a lower prob (66%) of being female at the 12% shrinkage rate. This print could have been produced by a late adolescent or adult male, but could only have been impressed on the vessel during the decoration stage of manufacture on the rim of the vessel. Although curvature does have an effect on the print analysis, it was not statistically significant.

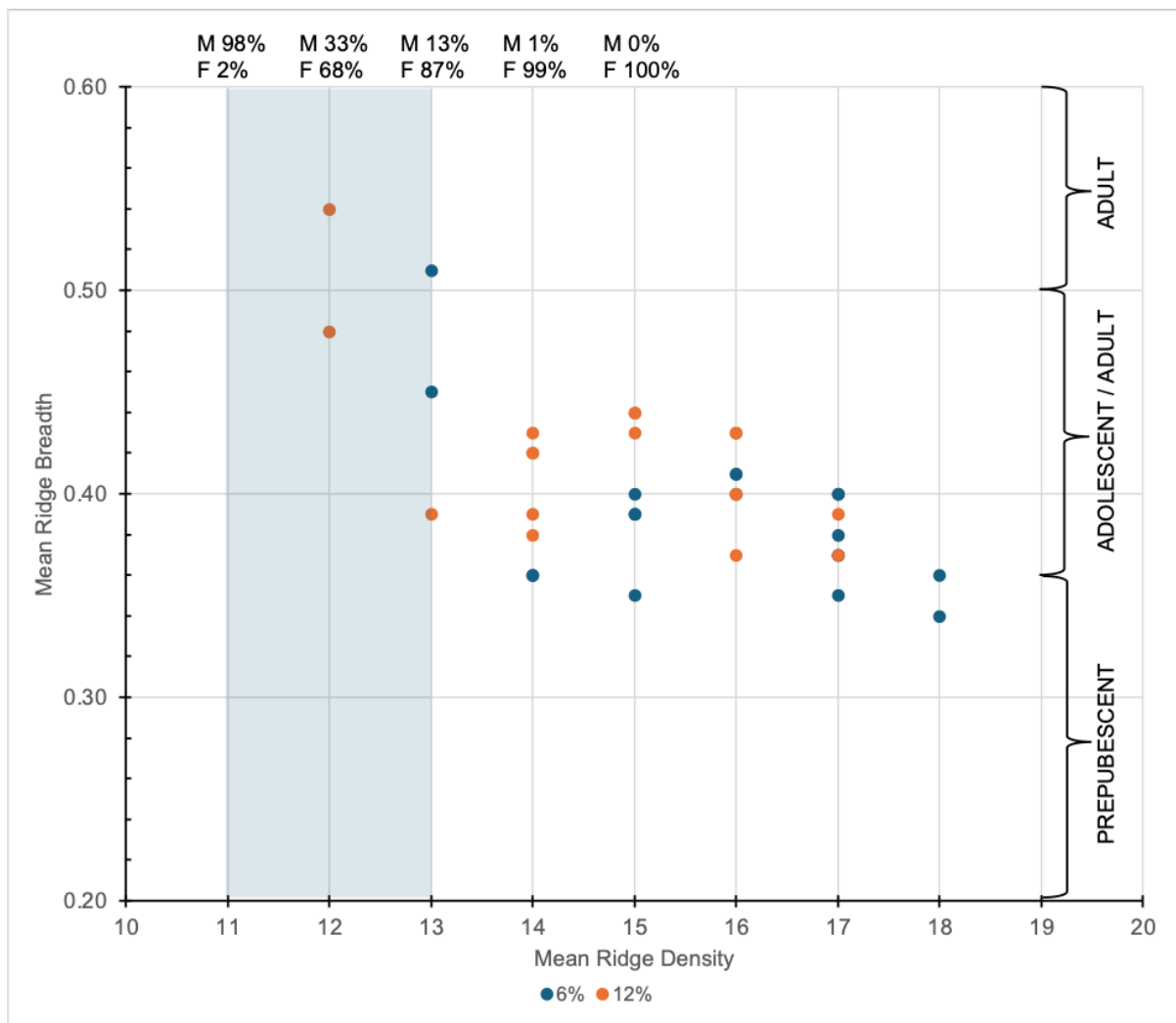


Figure 24. Cross-plot of MRB and MRD results.

Chapter V. Discussion and Conclusions

Objective

The primary objective of this research was to apply the analytical methods that have been developed in the dactylographic and dermatoglyphic literature to determine the age and sex of the potter(s) involved in the production of a Late Woodland vessel from the boreal forest region in Northwestern Ontario. This study successfully conducted these analyses, applying mean ridge breadth and ridge density models to make age and sex estimates based on partial fingerprints left on a Late Woodland ceramic vessel. Even though the fingerprint data set created in this study is restricted to the one vessel studied, broad ethnohistorical observations can still be made.

Summary of Methods and Model

The sex determination method used follows the Acree method, defining a 25mm² area in which the number of ridges is counted. This needed to be modified to a 6.25mm² area in some instances since these imprints were partial. The one downfall of using this method in the cases of ceramic artifacts is that since the prints are often partial, wiped off, or destroyed through use, it is in many cases impossible to determine the exact location of the print from which the measurement is being taken. Despite this, this technique has been used in studies such as Fowler et al. (2019). The sex determination model was based on comparative data collected by Stinson. There is an overlap between 11 to 14 mean ridge density values. However,

>98% prob males made prints with values 11 mean ridge density or lower and >87% prob females at 13 mean ridge density or higher.

The variation of the regression equation used in Fowler et al. (2019) was chosen for age determination for this study. It is based off Králík and Novotný's (2003) regression equation that uses mean ridge breadth as an independent variable. This is based on a modification of Kamp et al. original equation for that particular dataset. However, Fowler et al. (2019) use a variation designed to take into account alternate shrinkage rates; unlike Králík and Novotný's (2003) that only accounts for 7.5% shrinkage. This was necessary here since, based on the shrinkage tests, a 7.5% would not have been appropriate. There is a possibility that age will be underestimated, but it will not be overestimated. That is why age values are considered within a 5-year range of error and age estimates are classified into age categories.

Age estimates from mean ridge breadth measurements was interpreted against a large ink print dataset collected by Laing (2021). For this dataset, mean ridge breadth values <0.33mm correspond to prepubescent individuals, those greater than 0.50 mm represent mature adults, and values in between (0.32mm< to <0.50mm) account for individuals who are either experiencing or have completed pubescent growth (maturation).

Sex or age determination requires that the best-preserved impressions are used in analysis. This study proposes an impression quality analysis framework to sort the prints by quality and limit inclusion of those partial prints that would provide too few ridges for an accurate assessment of mean ridge breadth or mean ridge density.

Conclusions

Most of the ridge skin impressions on the vessel were made by an adolescent or adult female at 6 and 12% with two outlier fingerprints having a lower probability of being female. This print could have been produced by a late adolescent or adult male, but could only have been impressed on the vessel during the decoration stage of manufacture. Based on the age and sex analyses we can hypothesize that young women made pottery and that men may have also been involved at least in decoration stage, despite earlier assumptions that pre-contact Indigenous pottery made by women (Syms 1977; Taylor-Hollings 2017, p.110; Bales 1997), this analysis show that males could have been involved, or assisted in, the manufacture of Late Woodland pottery. However, the outlier male adult fingerprints could have been present on the rim sherds for a variety of reasons; whether directly involved in the decoration stage or specifically placed for symbolic reasons, for example.

The fact that there are differing ages could potentially point towards learning processes, especially since the prints were indicative of a young age. However, these young ages were found throughout the entire vessel and not necessarily alongside more mature prints. The more mature prints present on the rim sherds towards the end of manufacture, the decoration phase.

There are factors to take into account when gathering data for such analyses. The resulting data set is not a complete representative set. During the manufacturing process prints, tool marks, and other miscellaneous impressions are regularly wiped off. Furthermore, use-wear can affect the longevity of prints on the surface of a ceramic. Finally, these pots are

not made in a vacuum. There is no guarantee that only prints on the vessel are those of the potter (or individuals actively engaged in making the pot).

Issues

Shrinkage

There are however challenges when conducting these types of analyses. The solution to one of the challenges, shrinkage is built into the model. The shrinkage rates for the possible clays used to make this vessel were determined through experimentation. This provides a more specific and realistic shrinkage range as opposed to using an unverified standard of 7.5% shrinkage used by some researchers (Burnor 2023; Sanders et al. 2023). The results of experimental drying of regional clays derived from Boreal Forest glacial till bedrock within and related to the study area provided shrinkage values between 6% and 12%.

The experiment utilized raw clay samples from Lac Seul and other glacial clays from other boreal forest locations raw and tempered. To make this experiment more accurate tempered Lac Seul clay could have been used. Even though it is an air-drying experiment, the accuracy of the percent shrinkage would not be significantly impacted by including firing in the experimentation (Fowler et al., 2017).

Curvature

Unlike shrinkage, a factor that has not been accounted for in the model, is that of the curvature of the surface of the impression. Pots are not flat. The curvature I encountered was very minimal and when taking into account the age range error, did not pose a problem.

However, this will not always be the case with every ceramic. When does the curvature become an issue and need to be corrected and how would one correct it? These are just some research questions that can be looked at moving forward.

Conservation Efforts

Since this type of analysis is relatively recent in the field of archaeology, the conservation and reconstruction of artifacts has not taken into account this fingerprint archaeological evidence. I encountered this problem similar to that of Králík, Novotný and Martin (2002). Králík et al. encountered obstacles in the image capture of fingerprints created as a result of the conservation process. In that case, the varnish made it difficult for imagery. In this study, I found that the methods of reconstruction obstructed parts of prints and the glue, similarly, made image capture difficult. This could be a consideration for conservators moving forward. Given that this is a rapidly expanding area of archaeological research, conservators should be aware to try to limit interference when possible.

Age Underestimation

Using this model, it is possible that these ages are underestimated and other statistical treatments of the mean ridge breadth data may provide different insights into the age of individuals who left epidermal prints impressions on the vessel. In this case when comparing the Lac Seul data and Laing data in Figure 20, it appears that this may have happened in this case. Though, because of this, age data is interpreted with a range of error (in this case 5 years) and in terms of classes (pre-pubescent, adolescent/adult, adult).

Vessel Classification

Overall, the resulting data set adds to the literature as there is a void when it comes to Late Woodland Indigenous populations in this region. For this vessel to have more significance, it would need to be more confidently placed within a culture. In the meantime, similar vessels from the region could continue to be analyzed as a “regional grouping” as outlined by Taylor-Hollings (2017). A more accurate classification of the vessel could help place these demographic and manufacturing interpretations within the regional pottery traditions throughout the Boreal Forest region and adjacent areas. This would be required for future comparative palaeodermatoglyphic analyses of a larger sample of pottery covering a broader range of space and time.

Contributions

These results serve as hypotheses for future research on the identity of past pottery makers in pre-contact Indigenous societies in North America, how objects were manufactured, and how labour may have been organised to produce them. This study is the first analysis of pre-contact epidermal prints in this region. These data fill a void in the literature, as there are currently no fingerprint data sets for pre-contact Late Woodland Period from the boreal forest region in Northwestern Ontario. In general, there are very limited ethnographic observations and commonly held archaeological assumptions about who made pottery in pre-contact Indigenous societies in Boreal Forest and Plains cultures during the second millennium AD. This study is further significant because females, in general, have been difficult to identify in 66 palaeodermatoglyphic studies of other populations (see Sanders 2015; Fowler et al. 2020;

Kantner et al. 2019). Whereas, in this study the majority (all but two) impressions were high probability female.

Overall, palaeodactylographic research is valuable when there are no other means to investigate who made pottery in pre-contact Indigenous cultures in this region, or elsewhere. This research provides a basis for future studies examining other clay artifacts that can be undertaken with different data collection and analytical methods, and appropriate population-based interpretive models.

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Appendix A: Complete Average MRB data set from all quality levels with 0%, 6%, and 12% shrinkage corrections with corresponding age estimate in years.

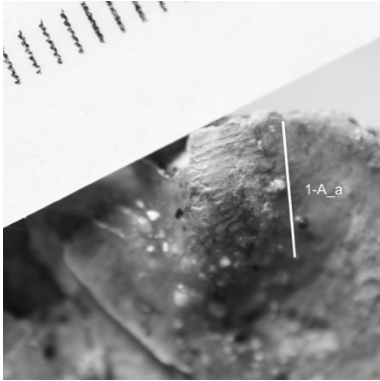
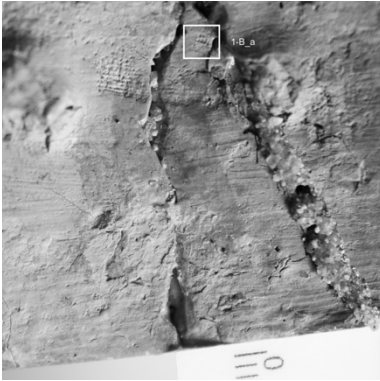
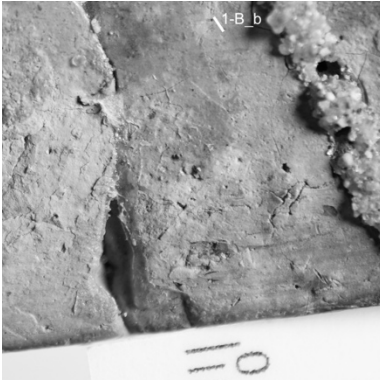
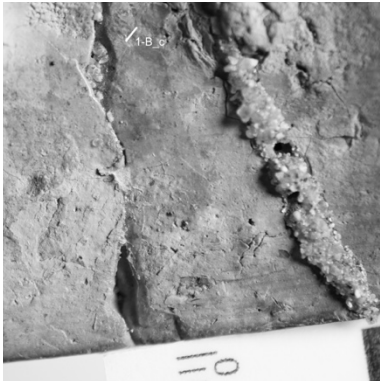
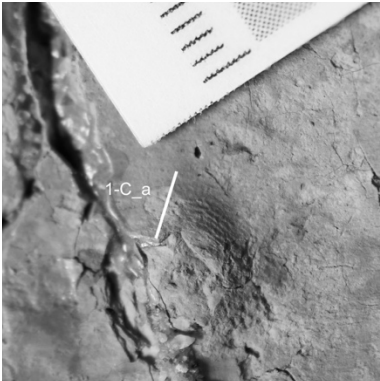
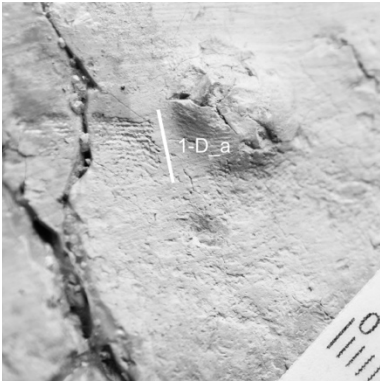
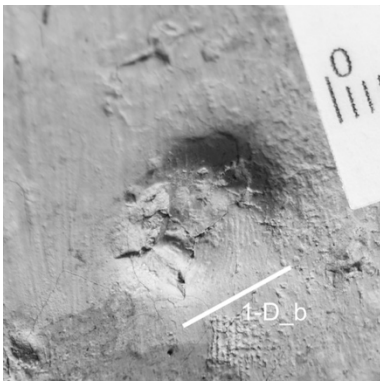
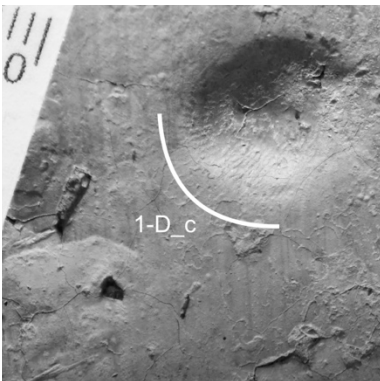
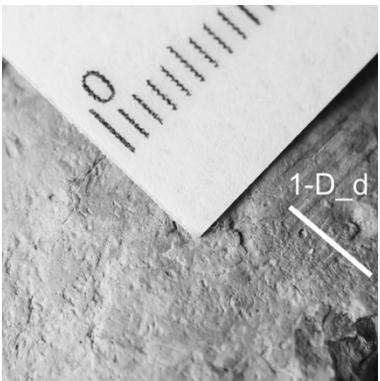
ID	MRB 0%	Average Age (yrs) 0%	MRB 6%	Average Age (yrs) 6%	MRB 12%	Average Age (yrs) 12%
1-A_a	0.36417	9.29987	0.38602	10.41786	0.41602	11.95324
1-Aa_a	0.37133	9.66656	0.39361	10.80656	0.42421	12.37215
1-Aa_b	0.35333	8.74556	0.37453	9.83030	0.40365	11.32000
1-Aa_c	0.36917	9.55570	0.39132	10.68904	0.42174	12.24550
1-Aa_d	0.40500	11.38918	0.42930	12.63253	0.46267	14.34006
1-B_a	0.27333	4.65223	0.28973	5.49136	0.31226	6.64377
1-B_b	0.11333	-3.53445	0.12013	-3.18651	0.12947	-2.70868
1-B_c	0.35667	8.91612	0.37807	10.01109	0.40746	11.51484
1-b._a	0.20417	1.11320	0.21642	1.73999	0.23324	2.60078
1-C_a	0.31844	6.96041	0.33755	7.93804	0.36379	9.28064
1-Cc_a	0.36833	9.51306	0.39043	10.64385	0.42078	12.19679
1-D_a	0.39068	10.65640	0.41412	11.85578	0.44631	13.50293
1-D_b	0.34493	8.31552	0.36562	9.37445	0.39405	10.82872
1-D_c	0.37318	9.76121	0.39557	10.90689	0.42632	12.48028
1-D_d	0.31958	7.01869	0.33876	7.99981	0.36509	9.34721
1-D_e	0.35200	8.67734	0.37312	9.75798	0.40212	11.24206
1-Dd_a	0.36333	9.25723	0.38513	10.37266	0.41507	11.90453
1-Dd_b	0.32708	7.40244	0.34671	8.40658	0.37366	9.78561
1-f._a	0.48000	15.22668	0.50880	16.70028	0.54835	18.72403
1-G_a	0.42335	12.32806	0.44875	13.62775	0.48363	15.41264
1-G_b	0.35667	8.91612	0.37807	10.01109	0.40746	11.51484
1-H_a	0.37189	9.69499	0.39420	10.83669	0.42485	12.40462
1-H_b	0.31961	7.01990	0.33878	8.00110	0.36512	9.34861
1-J_a	0.47289	14.86283	0.50126	16.31460	0.54023	18.30836
1-Lip_a	0.42528	12.42672	0.45079	13.73233	0.48584	15.52536
1-M_a	0.33833	7.97806	0.35863	9.01675	0.38651	10.44321
1-O_a	0.44185	13.27476	0.46836	14.63125	0.50477	16.49416
1-O_b	0.37325	9.76463	0.39565	10.91051	0.42640	12.48418
1-P_a	0.50458	16.48453	0.53486	18.03360	0.57644	20.16099
1-Q_a	0.19000	0.38833	0.20140	0.97163	0.21706	1.77270
1-Q_b	0.25567	3.74828	0.27101	4.53318	0.29207	5.61110
1-q._a	0.31250	6.65626	0.33125	7.61563	0.35700	8.93317

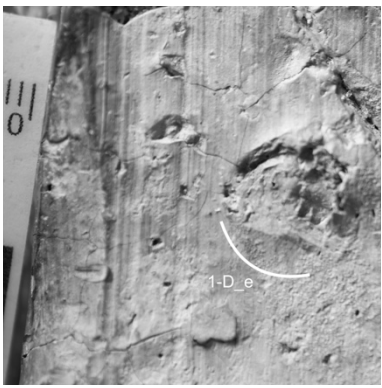
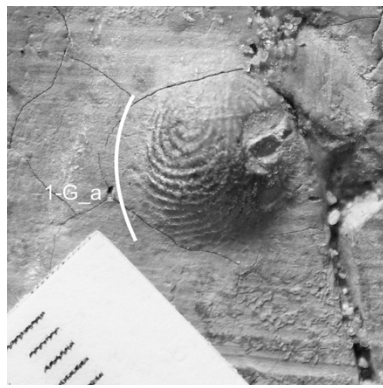
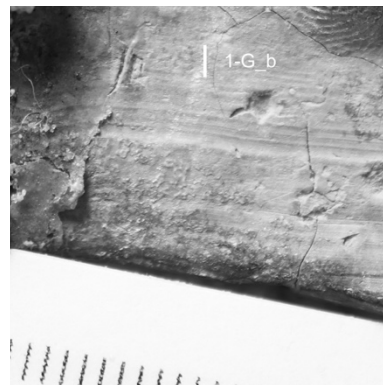
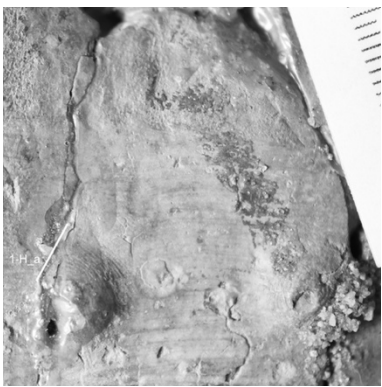
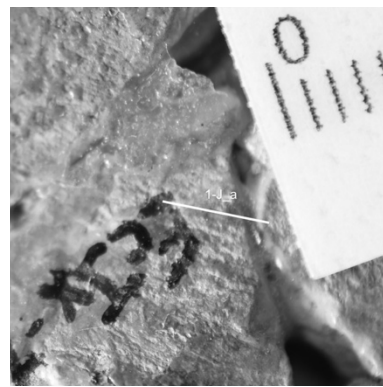
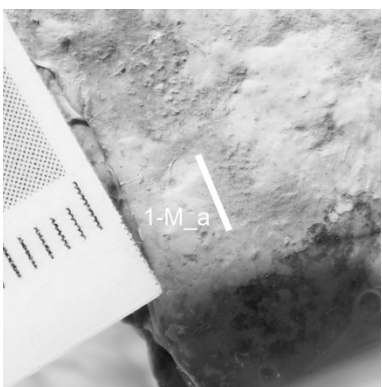
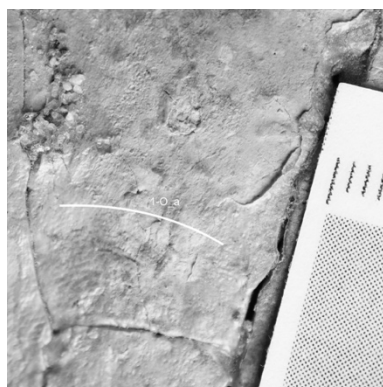
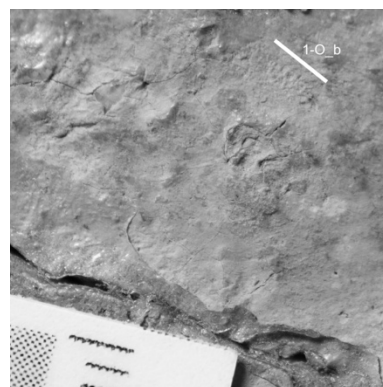
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1-s._b	0.19500	0.64417	0.20670	1.24282	0.22277	2.06496
1-s._c	0.23667	2.77611	0.25087	3.50268	0.27037	4.50050
1-s._d	0.41000	11.64501	0.43460	12.90371	0.46838	14.63233
1-z._a	0.34810	8.47758	0.36898	9.54623	0.39766	11.01385
2-B_a	0.33775	7.94821	0.35802	8.98511	0.38585	10.40911
2-B_b	0.34877	8.51190	0.36969	9.58262	0.39843	11.05306
2-B_c	0.33133	7.61989	0.35121	8.63709	0.37852	10.03404
2-B_d	0.39004	10.62381	0.41344	11.82124	0.44558	13.46570
2-D_a	0.45556	13.97594	0.48289	15.37449	0.52043	17.29518
2-F_a	0.59417	21.06821	0.62982	22.89230	0.67878	25.39739
2-F_b	0.43629	12.99027	0.46247	14.32968	0.49842	16.16915
2-F_c	0.37000	9.59834	0.39220	10.73424	0.42269	12.29421
2-G_a	0.35525	8.84363	0.37657	9.93425	0.40584	11.43203
2-G_b	0.47492	14.96678	0.50342	16.42479	0.54255	18.42712
2-I_a	0.39502	10.87873	0.41873	12.09145	0.45128	13.75693
2-I_b	0.41833	12.07140	0.44343	13.35568	0.47790	15.11943
2-L_a	0.59813	21.27117	0.63402	23.10744	0.68331	25.62926
2-M_a	0.35000	8.57501	0.37100	9.64951	0.39984	11.12516
2-P_a	0.26528	4.24005	0.28119	5.05445	0.30305	6.17290
2-P_b	0.38208	10.21661	0.40501	11.38960	0.43649	13.00052
2-P_c	0.27667	4.82278	0.29327	5.67215	0.31606	6.83861
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3-A_b	0.35611	8.88769	0.37748	9.98095	0.40682	11.48237
3-B_a	0.47689	15.06757	0.50550	16.53163	0.54480	18.54227
3-B_b	0.38667	10.45112	0.40987	11.63819	0.44173	13.26843
3-B_c	0.36000	9.08667	0.38160	10.19187	0.41126	11.70968
3-B_d	0.37000	9.59834	0.39220	10.73424	0.42269	12.29421
3-B_e	0.37222	9.71204	0.39456	10.85477	0.42523	12.42411
3-D_a	0.44438	13.40386	0.47104	14.76810	0.50765	16.64164
3-D_b	0.44958	13.67036	0.47656	15.05058	0.51360	16.94608
3-E_a	0.37484	9.84617	0.39733	10.99694	0.42822	12.57734
3-E_b	0.38333	10.28058	0.40633	11.45742	0.43792	13.07360
3-E_c	0.37514	9.86118	0.39765	11.01285	0.42856	12.59448
3-E_d	0.42194	12.25617	0.44726	13.55154	0.48203	15.33051
3-E_e	0.69750	26.35544	0.73935	28.49676	0.79682	31.43752
3-E_f	0.41667	11.98612	0.44167	13.26529	0.47600	15.02201
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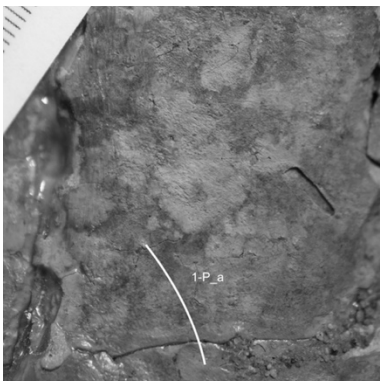
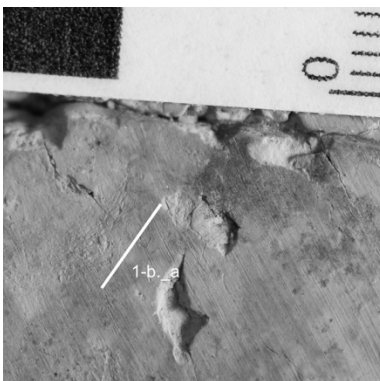
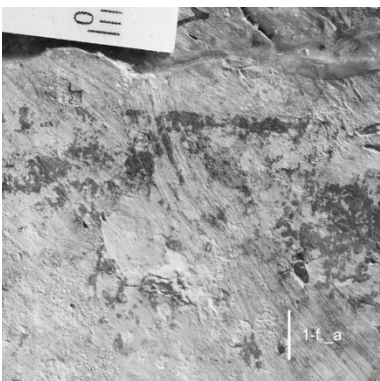
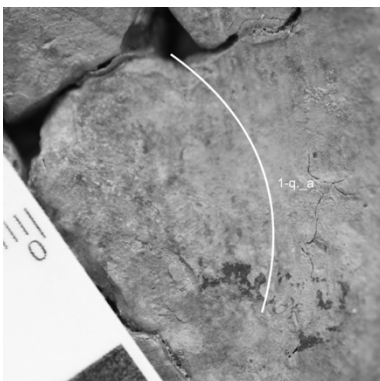
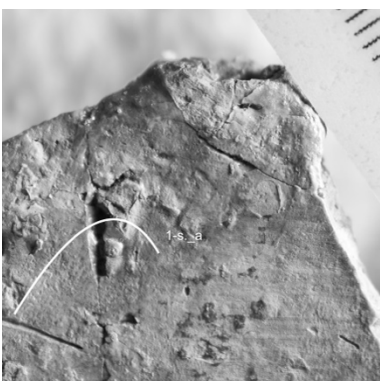
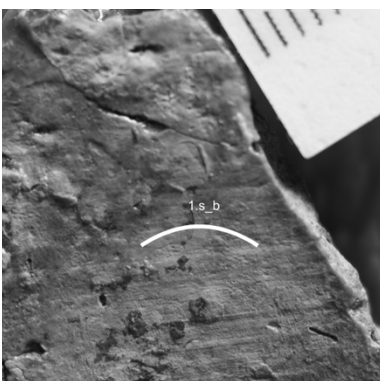
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3-F_c	0.33000	7.55167	0.34980	8.56477	0.37699	9.95610
3-F_d	0.50400	16.45468	0.53424	18.00196	0.57577	20.12689
3-F_e	0.33667	7.89278	0.35687	8.92635	0.38461	10.34578
3-G_a	0.49667	16.07946	0.52647	17.60423	0.56739	19.69824
3-G_b	0.36000	9.08667	0.38160	10.19187	0.41126	11.70968
3-J_a	0.16967	-0.65206	0.17985	-0.13118	0.19383	0.58416
3-Lip_a	0.34667	8.40445	0.36747	9.46872	0.39603	10.93031
3-N_a	0.29528	5.77505	0.31299	6.68155	0.33733	7.92649
3-O_a	0.24833	3.37306	0.26323	4.13544	0.28370	5.18245
4-A_a	0.35396	8.77754	0.37520	9.86419	0.40436	11.35653
4-A_b	0.36819	9.50575	0.39028	10.63610	0.42062	12.18844
4-A_c	0.32333	7.21056	0.34273	8.20320	0.36938	9.56641
4-B_a	0.28667	5.33445	0.30387	6.21452	0.32749	7.42314
4-C_a	0.33286	7.69796	0.35283	8.71984	0.38026	10.12322
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4-G_a	0.36372	9.27697	0.38554	10.39358	0.41551	11.92707
4-G_b	0.32723	7.40998	0.34686	8.41458	0.37383	9.79423
4-G_c	0.42689	12.50916	0.45250	13.81971	0.48768	15.61953
4-G_d	0.34667	8.40445	0.36747	9.46872	0.39603	10.93031
4-G_e	0.29250	5.63292	0.31005	6.53090	0.33415	7.76412
5-A_a	0.33941	8.03329	0.35978	9.07529	0.38775	10.50630
5-A_b	0.35146	8.64981	0.37255	9.72880	0.40151	11.21061
5-A_c	0.24667	3.28778	0.26147	4.04505	0.28179	5.08503
5-A_d	0.50125	16.31397	0.53133	17.85281	0.57263	19.96615
5-A_e	0.32167	7.12528	0.34097	8.11280	0.36747	9.46899
5-B_a	0.37533	9.87123	0.39785	11.02350	0.42878	12.60596
5-B_b	0.38302	10.26457	0.40600	11.44045	0.43756	13.05532
5-B_c	0.34500	8.31917	0.36570	9.37832	0.39413	10.83289
5-C_a	0.49250	15.86626	0.52205	17.37824	0.56263	19.45469
5-C_b	0.35861	9.01561	0.38013	10.11655	0.40968	11.62850
5-D_a	0.95500	39.53086	1.01230	42.46272	1.09099	46.48913
5-E_a	0.93333	38.42225	0.98933	41.28759	1.06624	45.22265
5-F_a	0.53000	17.78501	0.56180	19.41212	0.60547	21.64667
5-F_b	0.32750	7.42376	0.34715	8.42918	0.37414	9.80997
6-A_a	0.34074	8.10105	0.36118	9.14711	0.38926	10.58370
6-A_b	0.49667	16.07946	0.52647	17.60423	0.56739	19.69824
6-A_c	0.35433	8.79673	0.37559	9.88453	0.40479	11.37845

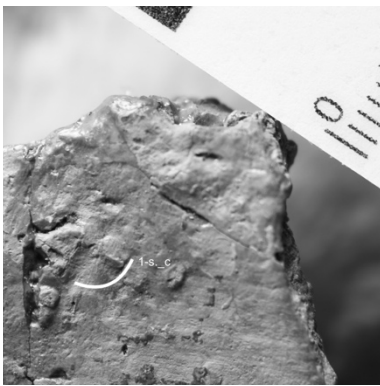
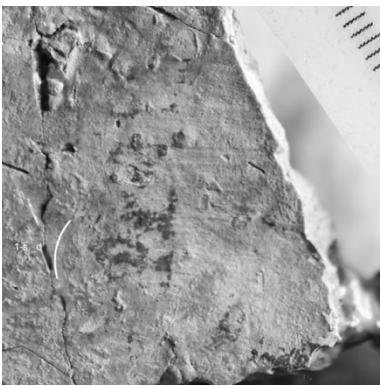
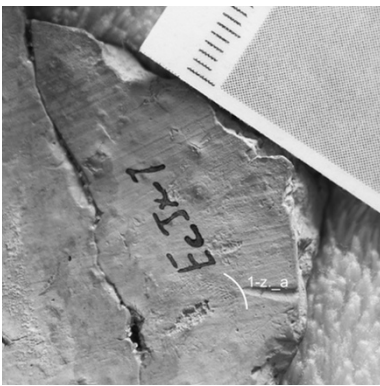
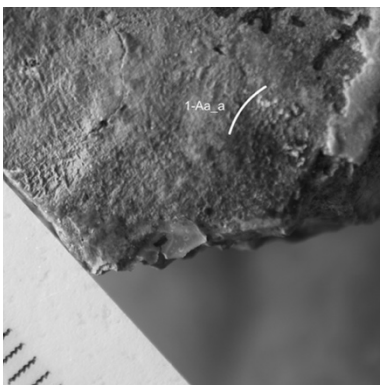
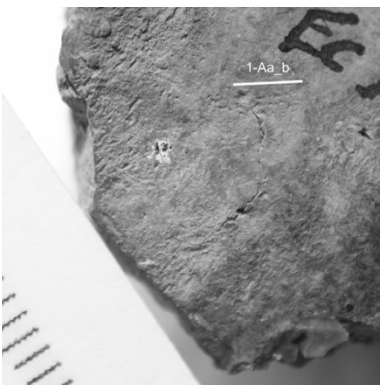
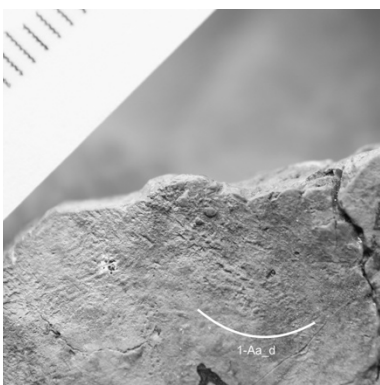
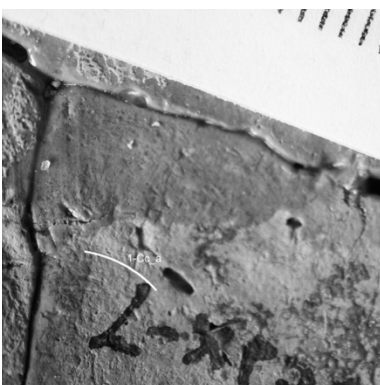
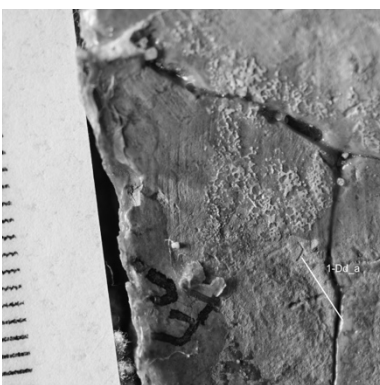
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6-B_a	0.32198	7.14127	0.34130	8.12975	0.36783	9.48726
6-B_b	0.37542	9.87549	0.39794	11.02802	0.42888	12.61083
6-C_a	0.43667	13.00945	0.46287	14.35002	0.49885	16.19107
6-C_b	0.43717	13.03504	0.46340	14.37714	0.49942	16.22030
6-C_c	0.32567	7.32995	0.34521	8.32975	0.37204	9.70280
6-C_d	0.47833	15.14140	0.50703	16.60989	0.54645	18.62660
6-C_e	0.27000	4.48167	0.28620	5.31057	0.30845	6.44893
6-D_a	0.32292	7.18924	0.34229	8.18060	0.36890	9.54206
7-C_a	0.21000	1.41167	0.22260	2.05637	0.23990	2.94176
7-Ext_a	0.43500	12.92418	0.46110	14.25963	0.49694	16.09365

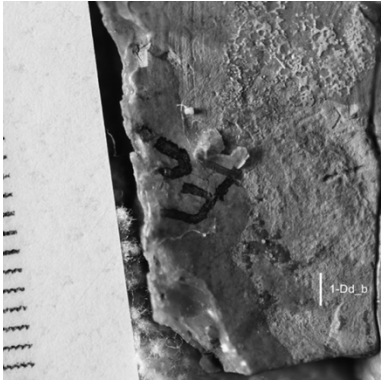
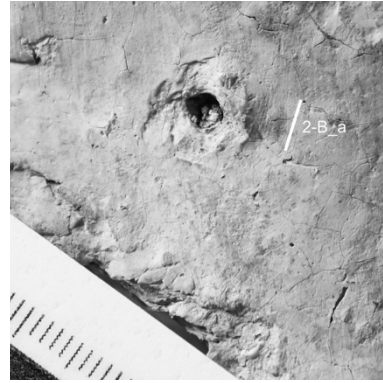
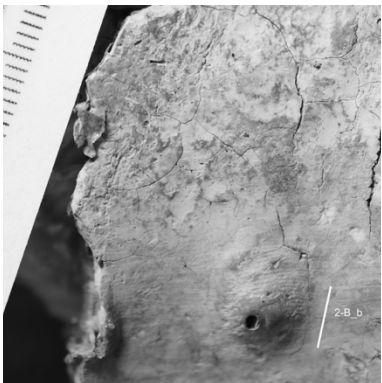
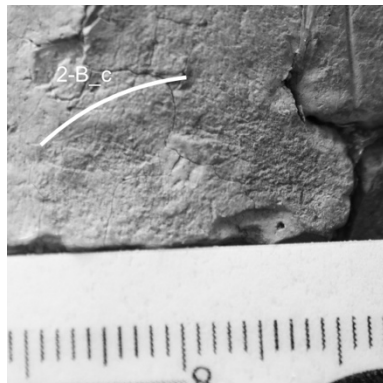
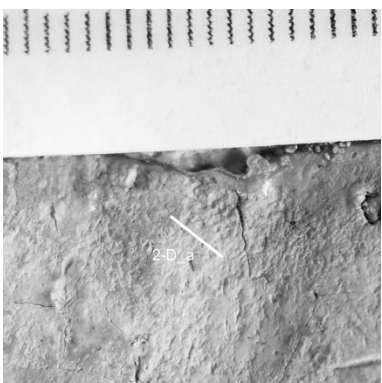
Appendix B: Impression Images with scale in mm

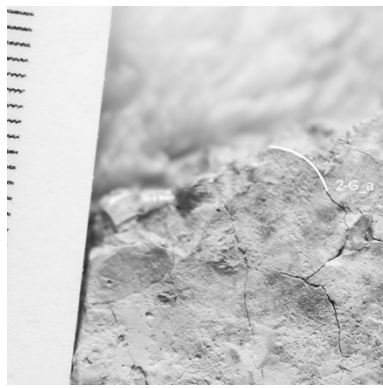
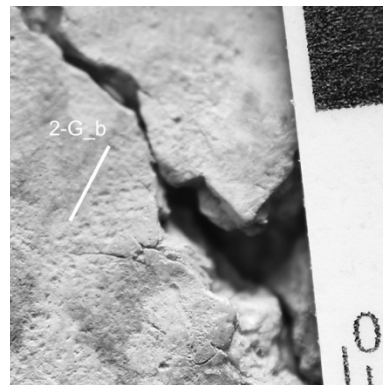
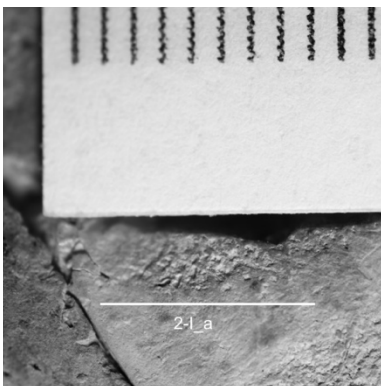
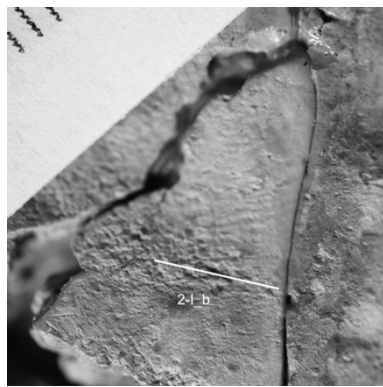
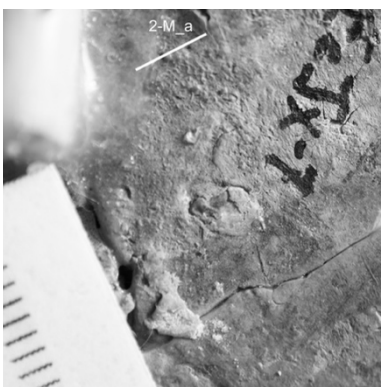
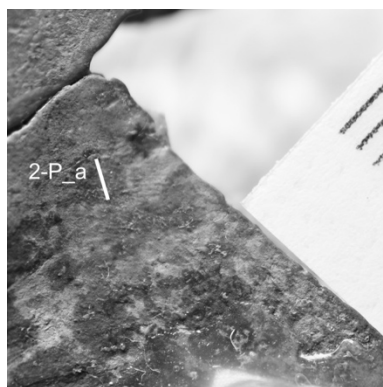
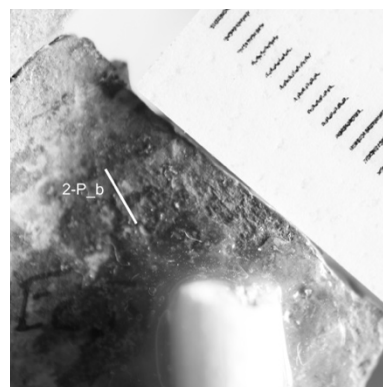
1-A_a	1-B_a	1-B_b
		
1-B_c	1-C_a	1-D_a
		
1-D_b	1-D_c	1-D_d
		

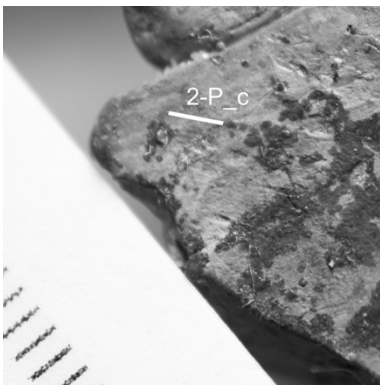
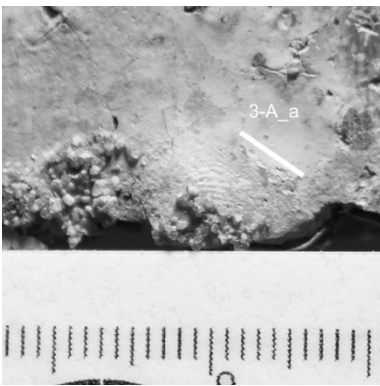
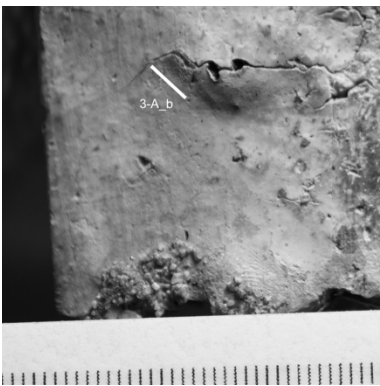
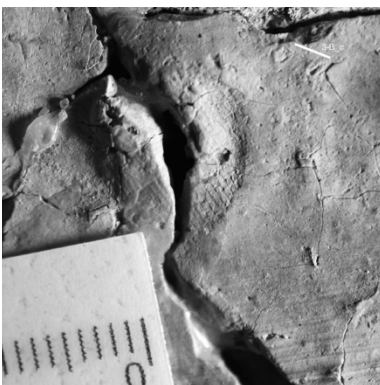
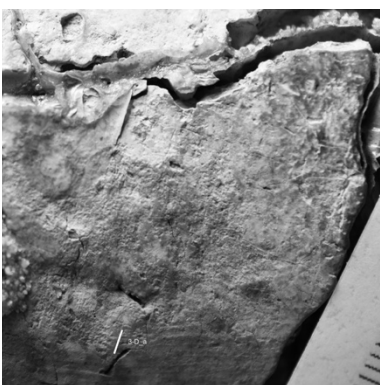
1-D_e	1-G_a	1-G_b
		
1-H_a	1-H_b	1-J_a
		
1-M_a	1-O_a	1-O_b
		

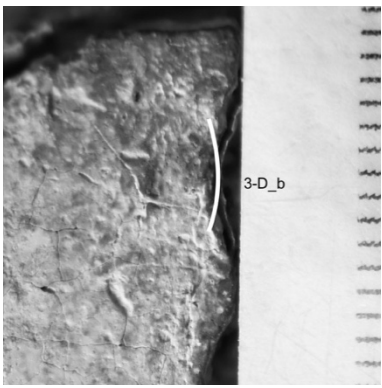
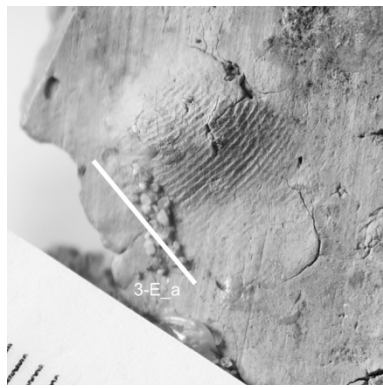
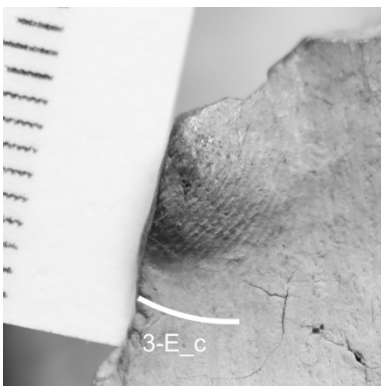
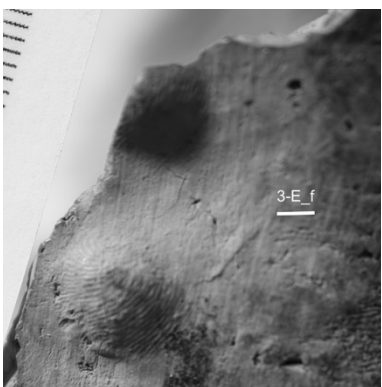
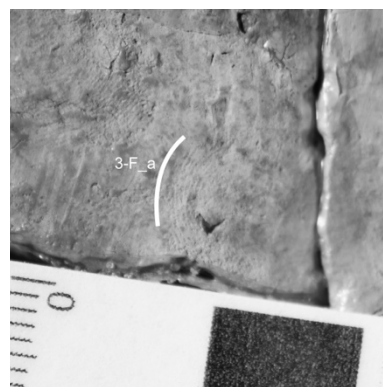
1-P_a	1-Q_a	1-Q_b
		
1-b_a	1-f_a	1-q_a
		
1-r_a	1-s_a	1-s_b
		

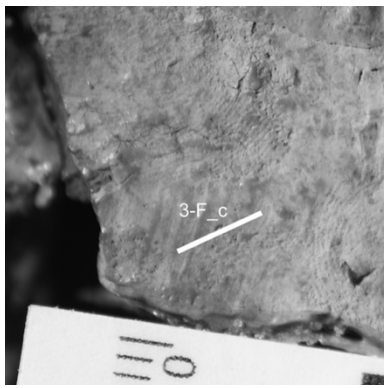
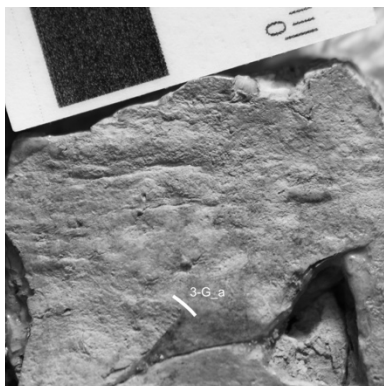
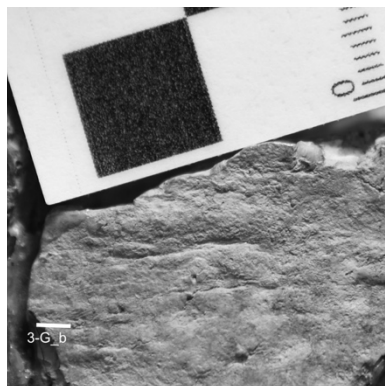
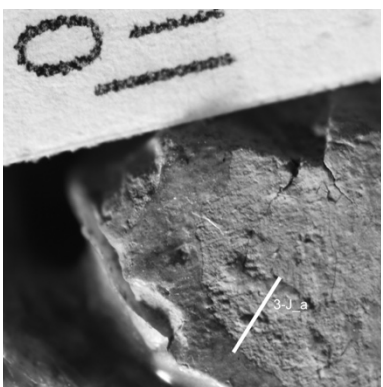
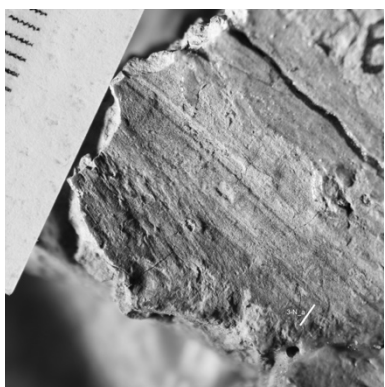
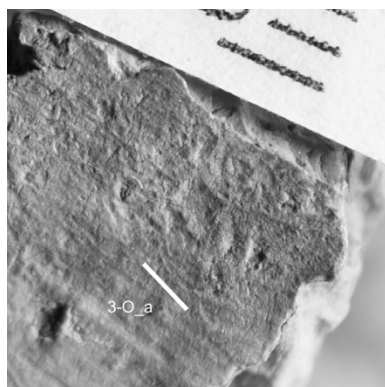
1-s_c	1-s_d	1-z_a
		
1-Aa_a	1-Aa_b	1-Aa_c
		
1-Aa_d	1-Cc_a	1-Dd_a
		

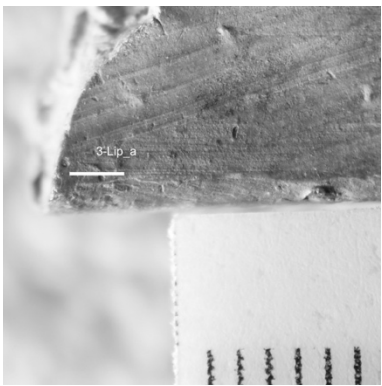
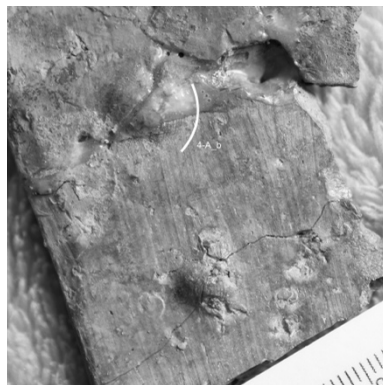
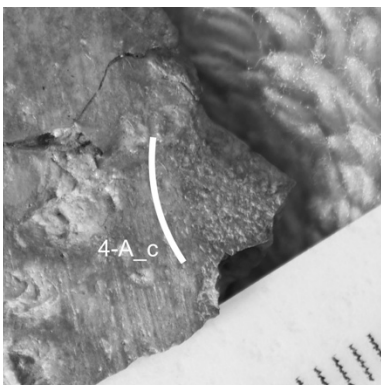
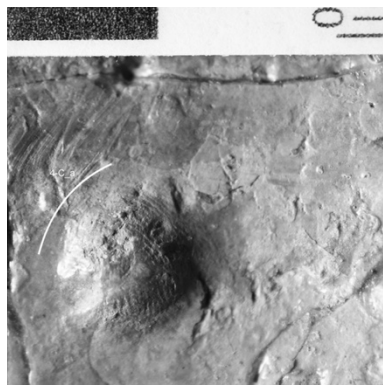
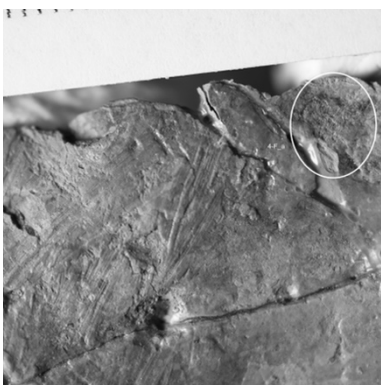
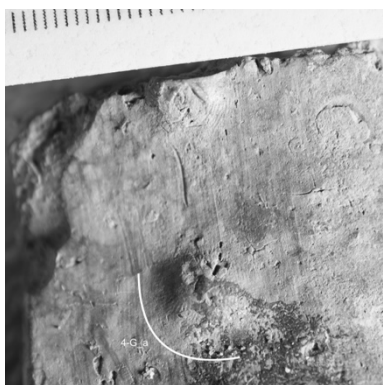
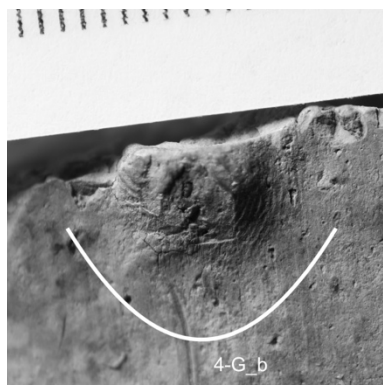
1-Dd_b	1-Lip_a	2-B_a
		
2-B_b	2-B_c	2-B_d
		
2-D_a	2-F_a	2-F_b
		

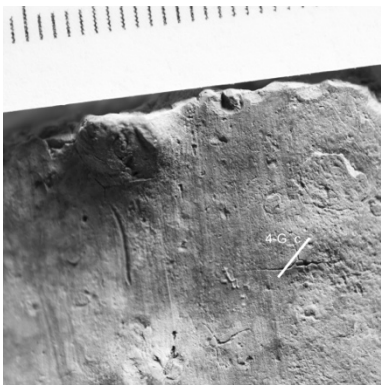
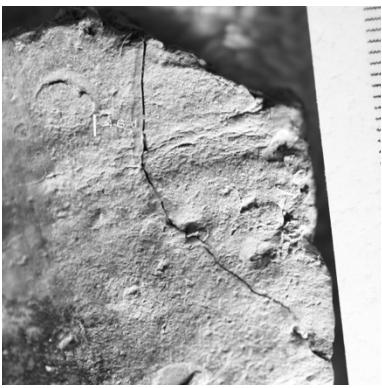
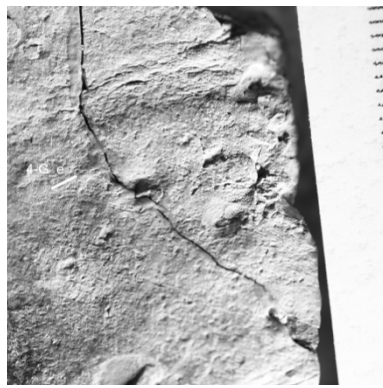
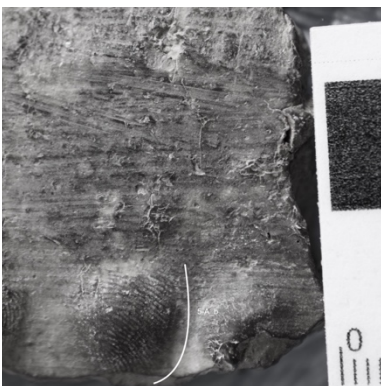
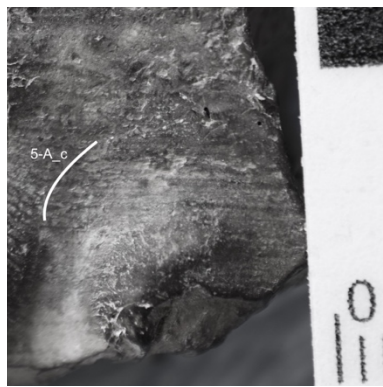
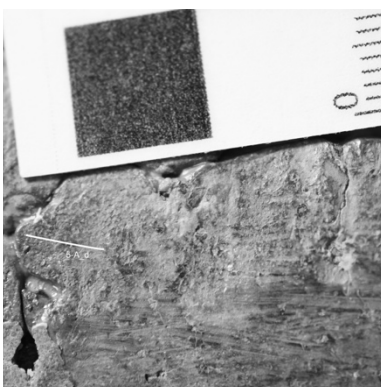
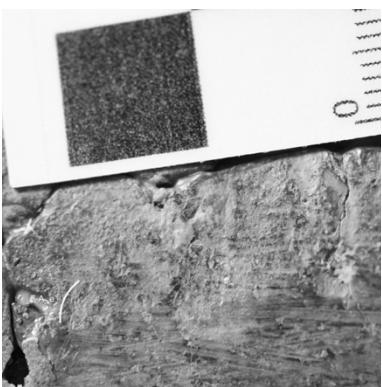
2-F_c	2-G_a	2-G_b
		
2-I_a	2-I_b	2-L_a
		
2-M_a	2-P_a	2-P_b
		

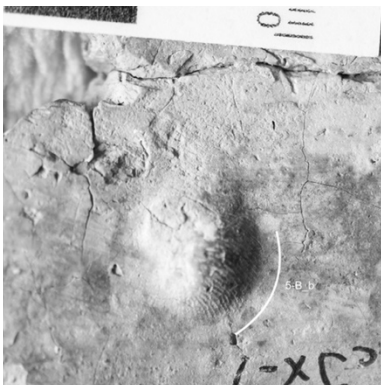
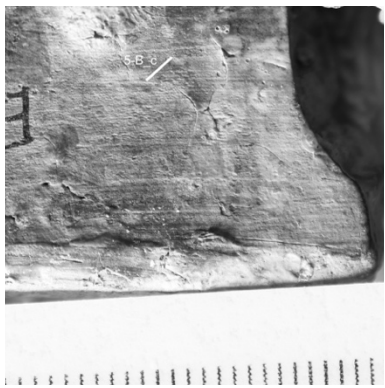
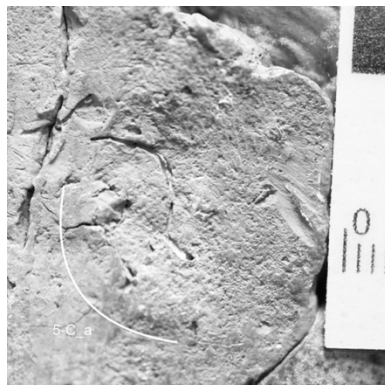
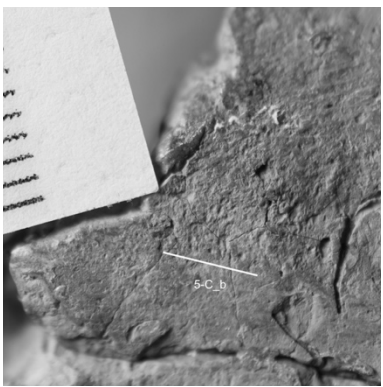
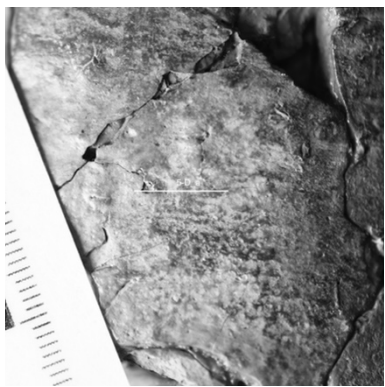
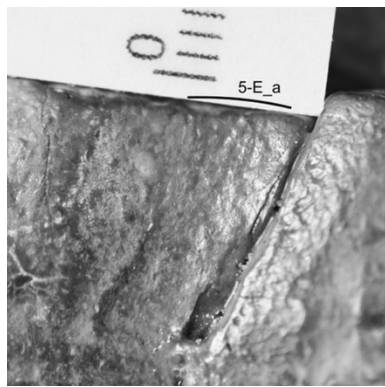
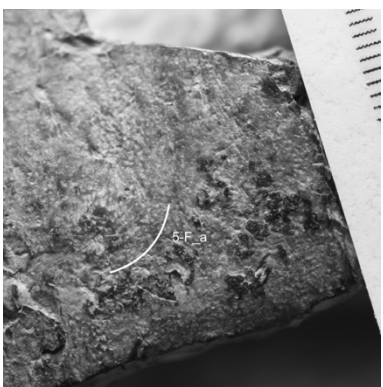
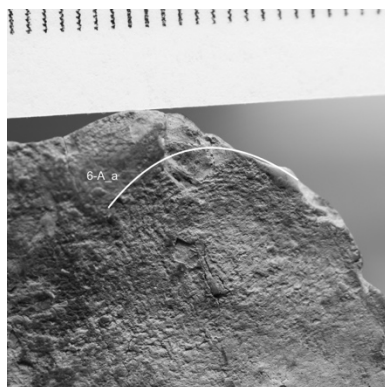
2-P_c	3-A_a	3-A_b
		
3-B_a	3-B_b	3-B_c
		
3-B_d	3-B_e	3-D_a
		

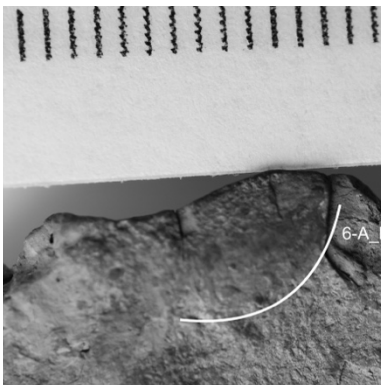
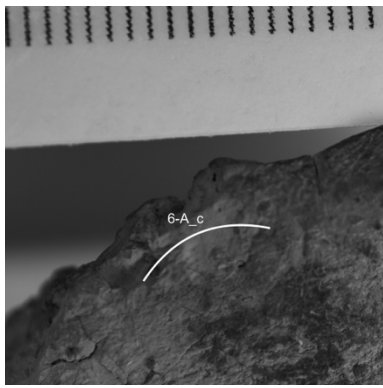
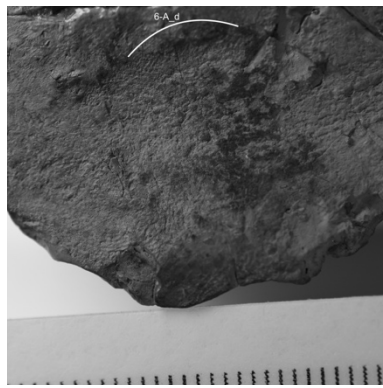
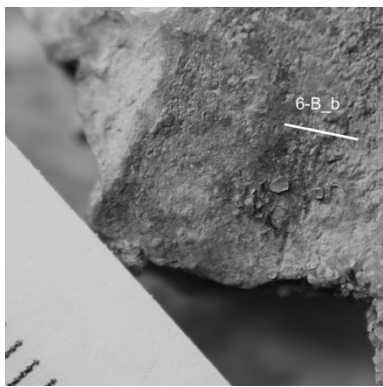
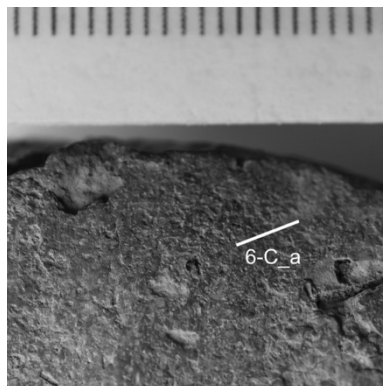
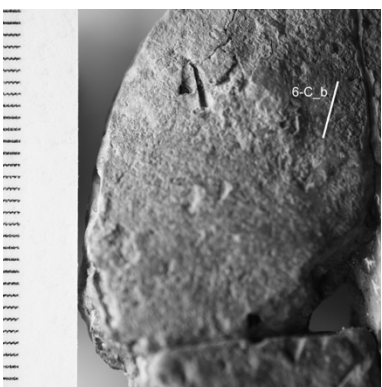
3-D_b	3-E_a	3-E_b
		
3-E_c	3-E_d	3-E_e
		
3-E_f	3-E_g	3-F_a
		

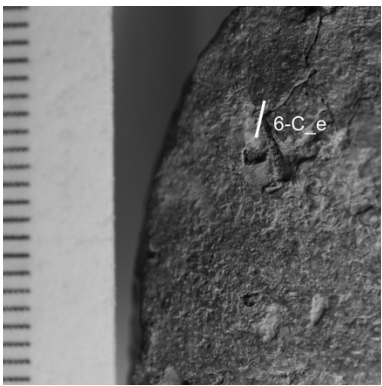
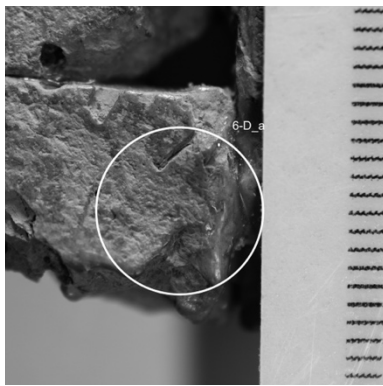
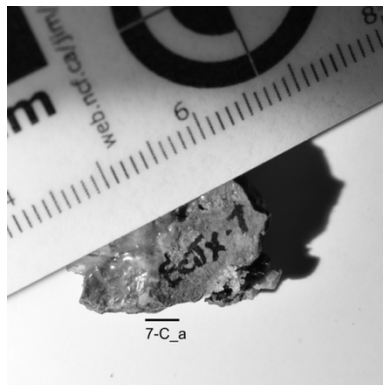
3-F_b	3-F_c	3-F_d
		
3-F_e	3-G_a	3-G_b
		
3-J_a	3-N_a	3-O_a
		

3-Lip_a	4-A_a	4-A_b
		
4-A_c	4-B_a	4-C_a
		
4-F_a	4-G_a	4-G_b
		

4-G_c	4-G_d	4-G_e
		
5-A_a	5-A_b	5-A_c
		
5-A_d	5-A_e	5-B_a
		

5-B_b	5-B_c	5-C_a
		
5-C_b	5-D_a	5-E_a
		
5-F_a	5-F_b	6-A_a
		

6-A_b	6-A_c	6-A_d
		
6-B_a	6-B_b	6-C_a
		
6-C_b	6-C_c	6-C_d
		

6-C_e	6-D_a	7-C_a
		
7-Ext_a		
