NONALIMENTARY TOOTH USE IN ANCIENT CALIFORNIA

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by

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San Francisco, California

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CERTIFICATION OF APPROVAL

I certify that I have read *Nonalimentary Tooth Use in Ancient California* by Jennifer Blake, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requests for the degree: Master of Arts in Anthropology at San Francisco State University.

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Prehistoric native individuals in the San Francisco Bay Area exhibit particularly extreme dental wear patterns. They are also known to have possessed the most intensive and advanced basket weaving tradition in ancient North America. It is hypothesized that examination of the microwear of individuals from CA-ALA-329 will reveal nonalimentary tooth use. This hypothesis was tested by taking dental casts of individuals from three sites. Casts were examined under a scanning electron microscope and the microwear features visually and statistically analyzed. It was found that differences exist between control and experimental groups in the frequency and metric dimensions of microwear features as well as in visually observable patterns. Differences were also found between males and females in the experimental sample, suggesting sexual division of labor. It is concluded that individuals in prehistoric central California were using their teeth intensively as tools. Further study is needed to determine which specific materials and techniques were used in these activities.

I certify that the Abstract is a correct representation of the content of this thesis.

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Chair, Thesis Committee Date

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This work is dedicated to my parents, Jo Ann and David Marks, the most important people in the world to me.

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INTRODUCTION

Dental wear is a topic in physical anthropology with rapidly evolving methods, technologies, and implications. Macroscopic wear patterns on teeth can be used to infer dietary habits (e.g. hunter-gatherer versus industrialized) and cultural applications of the dentition (e.g. deliberate filing or cordage processing). To go a step further and to study microscopic tooth wear is to even more specifically identify the ways in which people have used their teeth. Prehistoric populations wore their teeth at a rate of twenty times greater than industrialized populations (Addy and Shellis, 2006). We can easily enough trace dietary transitions from prehistory to the present. Food has become softer due to the trends of processing and refining, and industry has virtually eliminated the need for many societies to use their teeth as tools. However, prehistoric Native American populations tended to use their teeth in cultural processes other than eating.

It is demonstrated in the ethnographic literature that prehistoric central Californian populations, who display a particularly extreme dental wear pattern, used their teeth assiduously as tools (Leigh, 1928; Molnar, 1971a). They are also known for a prolific and artful basket weaving industry, particularly in the central regions (Elsasser, 1978). The problem to be addressed in this study is: what activity caused the advanced dental wear found in prehistoric central Californian populations? The following hypothesis will be tested: examination of dental microwear in a prehistoric Ohlone population will demonstrate a nonalimentary source of attrition.

The pursuit of this topic bears significantly upon bioarchaeology in California and elsewhere. A more intricate understanding of microwear patterns will afford easier inference of the methods, materials, and intensity of prehistoric culture, diet and economy. Studies such as that by Bax and Ungar (1999) used microwear to ascertain dominant handedness in Neanderthals through the observation of microwear orientation, offering yet another dimension by which to search for genetic and physical similarities in ancestral species. Diachronic dietary change within a population can be examined through microwear studies, such as that conducted by Schmidt (2001:139), who discerned even “relatively subtle” dietary changes in a prehistoric population from Indiana. Microwear studies are particularly informative when considered in conjunction with archaeological evidence. In a study of three pre-agricultural populations by El-Zaatari (2008), the microwear found in each population was in agreement with each population’s respective archaeological dietary materials. The archaeological materials of the Ohlone and surrounding central Californian cultures will be referenced throughout the current study and discussed in context of the statistical and observational results.

Studies of ALA-329 address the extreme tooth wear present in the population (Leigh, 1928; Schulz, 1977; Jurmain, 1990), but as yet no microwear studies have been attempted. Grant (2010) has constructed a possible classification system for macrowear patterns specific to central California. This study uses Grant's classification in the assessment of microwear, searching for particular patterns within each type macrofeature in an attempt to relate them to nonalimentary processing techniques. Macrowear has served as a guide to microwear before (Schmidt, 2010), but has never been applied to central California.

Research questions requiring further attention include the ways in which particular materials and techniques mark human enamel. Many studies have distinguished microwear created by animal protein from that created by plant materials (Ungar and Spencer, 1999; Kieser et al., 2001; Organ et al., 2005; El-Zaatari, 2008), but few attempt to identify microwear patterns produced by a combination of specific techniques and materials. The current study as well as future studies will benefit from ethnographic research of modern populations and the casting of their teeth to be used as guides to past microwear patterns.

It is intended for the following study to detect microwear signatures of nonalimentary dental activity in an archaeological population so that they are more immediately recognizable in future studies. This study also intends to contribute to the paucity of microwear studies in ancient California by providing methodology and illustrations which may be of assistance in continuing California studies.

The following study is primarily qualitative, with a goal to define a specific cultural microwear signature that can serve as a signal to future researchers of ancient central

California. Epoxy casts of teeth of ancient individuals were taken using non-destructive techniques and were examined under a scanning electron microscope. The resulting images were examined for patterns and the patterns related to the corresponding macrowear of the teeth. Microwear features were identified as either pits or scratches and quantified using MicroWare 4.2. Variables measured include overall feature count per micrograph, scratch width, pit length and width, pit-to-scratch ratio, and the predominant orientation of scratches as compared to the orientation of the macrofeature in which they were found. The data were subject to several statistical tests in order to search for significant differences between control and experimental individuals as well as males and females within the experimental sample. Visual observations were reconciled with statistical results and compared to similar studies which have defined typical cultural microwear.

Dental microwear can distinguish between nutritional and cultural activities, as well as document dietary change. Different materials and techniques can create different marks upon the teeth. These marks can be qualified and quantified and interpretations can be made as to ancient activity. However, as with the most well-intentioned of studies, limitations apply to the results of this experiment. In the course of conducting and presenting this study, new technologies and techniques are being applied to dental microwear studies, of which texture analysis is at the forefront. El-Zaatari (2008) used this technique to discern the dietary habits of modern hunter-gatherers from different climates. This technique allows for three-dimensional analysis of microwear features so that the variable of depth can be considered along with length and width. Dr. Peter Ungar provides an excellent overview of the technique on the University of Arkansas website. The current study was confined to the classic technique of two-dimensional quantification from scanning electron microscope-derived micrographs; therefore, depth is not included in the analysis, and any information this variable may provide is not available for present analysis.

A further objective of this study is to demonstrate that physical anthropology as a discipline is not only relevant to, but inextricable from the people from whom it borrows its materials. Without previous and ongoing ethnographic fieldwork, this study and future studies like it would certainly suffer. Throughout the twentieth and twenty-first centuries there has been a continuing effort in the Native American community to preserve traditional basket weaving. In this vein, it is hoped that this study will contribute to the current shift in the American archaeological paradigm that has thus far resulted in more Native American archaeologists and more open dialogue between archaeologists and descendents.

1. REVIEW OF PREVIOUS RESEARCH

Because teeth are the most durable tissue in the human body and often the best preserved in archaeological samples, it is imperative that osteological analysis exploits all levels of detail that the dentition offers. Dental microwear is a microscopic record of an individual's activity in life. Attrition, abrasion, and erosion are etched in the enamel and dentin and in favorable conditions are preserved in a state observable by the researcher. The myriad processes involved in dietary and cultural tooth use can be distinguished through the observation of macrowear to an extent; however, specific information regarding materials and mechanics is embedded in microwear. Microwear theory requires an analysis of several factors working concurrently to bear on a single microwear feature. Similarly, microwear features mean little unless studied in the context of surrounding features.

Theory and method both bear significantly on the results of dental microwear analysis. Technological advances in magnification, recording, and dental casting have rendered dental microwear analysis an accessible and routine technique in the examination of ancient nutritional and cultural practices. Therefore, it is a valuable investigative component in deciphering dental wear in ancient California, which is characterized as particularly extreme in the context of ancient North America (Leigh, 1928). What occurred at a microscopic level to produce such extreme dental wear? We can look to microwear for answers.

History of Microwear Studies

Initially, the primary illative method in animal dental wear studies was the analysis of tooth shape (Teaford, 1994). In anthropology, tooth shape represents the basis of dietary and nonalimentary analysis. In early attempts, conclusions regarding tooth use were derived from facets of wear and the overall degree of occlusal attrition and abrasion (Teaford, 1994). Teaford (1994) notes that scratches on teeth were always viewed as informative. However, it was not until the advent of scanning electron microscopy (SEM) that the analysis of scratches and pits became a viable source of information. Several rounds of experiments and theoretical evolution have led to the current sophistication of the technique.

Transition from Nonhuman to Human Studies. Dental microwear has in the last twenty years become increasingly more common in anthropology studies. Its foundations were established primarily through the study of nonhuman mammals, including nonhuman primate genera. Animal studies were an essential basis to the development of dental wear technique as they provided known diets against which to compare microwear features (e.g. Gordon, 1982; Teaford, 1994; Merceron et al. 2005). Walker and colleagues (1978) find that microwear analysis is capable of distinguishing a browsing mammal from a grazing one to a remarkable level of detail (e.g. the season in which a creature last grazed before death). In a study of chimpanzee dental microwear, Gordon (1982) found that jaw mechanics, as well as materials processed, bear on microwear patterns. Gordon (1982) acknowledges that these findings will inevitably differ between species, but emphasizes that the same techniques and theories are widely applicable. In a separate study that also used chimpanzees, Gordon (1984) isolated two indispensible concepts in microwear analysis: that thorough and consistent sampling technique is essential, and that within-group/species observation provided a necessary control against which to judge the causes of microwear patterns observed.

Aspects of dental microwear behavior gradually came to light through these early studies and were singled out for further observation. Teaford and Owen (1989) note that the manner in which microwear changes through time had not been sufficiently studied by the late 1980s. They accordingly conducted a study on vervet monkeys in which fluctuations in microwear were monitored, particularly those incurred through “formation and obliteration”, formation being the initial creation of the feature and obliteration being the eradication of that feature from subsequent dental processing (Teaford and Oyen, 1989:452). Dental microwear landscapes can change drastically in the course of one week (Teaford, 1994).

Directionality of the mandible as it manifests in microwear was explored by Ryan (1979), who found, through experiments that involved the simulated running of teeth along glass and sand to emulate specific directional wear, that direction can indeed be correlated to microwear features. For example, a scratch may be deeper on one end and more shallow on the other, indicating the area of initial occlusion (Ryan, 1979). Ryan notes that human and nonhuman primate teeth responded comparably in this regard, serving to validate the translation of key concepts from nonhuman to human studies.

Special focus on non-human primates, such as that conducted in a study by Krueger and others (2008), allows for more controlled laboratory observation and can lead to the discovery of concepts that can be further tested on archaeological remains and willing individuals of *Homo sapiens*. In this study, it was noted that microwear in individuals of different genera possessed different textures, even when induced by the same material and the same directional power stroke on the same facet. This type of analogue study can be usefully applied to human evolutionary studies when examining the diet and tooth-as-tool habits of ancestors from *Australopithecus* to *Homo*.

Particularly germane to the current study is a closer examination of dental microwear in gorillas. A dominant technique that gorillas use to obtain food is leaf-stripping (Ryan, 1981; Tennie et al., 2008; Estebaranz et al., 2009). This motion is described by Tennie and others (2008) as the closure of the gorilla's teeth around a stem, followed by pulling against the opposing force of the hand holding the stem, resulting in the deposition of the leaves into the mouth. This repetitive clamping and pulling motion through the teeth is similar to recorded basket weaving techniques (Larsen, 1985; Minozzi et al., 2003) and is hypothesized to rend a consistent intraspecies microwear pattern (Merceron et al., 2005; Ryan, 1981; Estebaranz et al., 2009).

While such studies provide a theoretical and methodological introduction to dental microwear studies in general, knowledge thus gained must be augmented according to the nature of human dentition in order to effectively be applied to anatomically modern humans. This transition naturally required the consideration of cultural, or nonalimentary, tooth use. Molnar (1972) delineates the basic mechanisms of cultural tooth use in a paper that traces the general trend of tooth wear from *Homo neanderthalensis* to early *Homo sapiens.* He notes that the processing of different types of plant fibers and gritty materials cause different patterns of tooth wear. However, as it was not commonplace to automatically consider microwear in archaeological analysis at that point, his conclusions were based on the analysis of macrowear. It is not until the 1980s that microwear studies regarding modern humans begin to appear in the literature. Puech (1979) produced one of the first papers outlining the technique of observing orientation, depth, length, and location of microwear features on human teeth as they vary between tool use and dietary processing. This is one of the key conceptual differences between microwear studies in nonhuman mammals and modern humans.

Interpreting Microwear Data. Once human microwear studies solidified a foundation in features and orientation, next came the task of meaningfully interpreting the data. Recall that the most instrumental concepts were deciphered early on: formation and obliteration, direction, force, materials used, and processing style. These factors are at play in each micrometer of each microwear feature. Therefore, the interpretation of the data must take into consideration each of these factors as they influence the others.

Gordon (1984:1044) warns that microwear features are not "categorically distinct manifestations of different activities, but rather are opposite poles on a microwear continuum characterized by varying degrees of compression and shear during occlusion". The interpretation of microwear features cannot be standardized to the point that a particular feature on a particular facet will indicate the same process and the same material each time. Rather, the animal's habits *in vivo* and taphonomic processes in death must be imposed upon analysis. Fortunately, in the current study, archaeological context is available and will be brought to bear upon dental microwear analysis.

Krueger and colleagues' study (2008) brings mastication power strokes into consideration. It was concluded that the Phase II power stroke, the stroke which represents the end of the initial tooth-to-material contact and the beginning of the uplift from the point of most force, produces more complex microwear features and is theoretically the most telling of material processed and of jaw motion. This theory was also applied in a study of diet in ancient east-central Mississippi populations by Hogue and Melsheimer (2008). Throughout the history of microwear analysis, more and more factors have been discovered at play. While this will prove beneficial, a balance has yet to be efficiently achieved, but will be with each future study (Teaford, 1994; Maas, 1991; Krueger, 2008).

Dental Microwear Technology. As dental microwear studies gained momentum, computer programming, SEM, and dental casting materials developed widely. Ungar and Spencer (1999) conducted a study with the goal of expanding the body of work on dental microwear quantification. Dentitions of forty-eight Native American individuals from three locations were scanned for wear features which were then quantified using the Microware 3.0 software. This method allowed for a statistical and visual quantification of significant differences between individuals of different sites. It was revealed by the size of scratches and heavy incisor microwear that the Aleut by far processed and consumed the most meat. This result is singularly relevant to the present study in that it records a cultural activity deciphered from microwear observation.

In archaeological analysis, the protection of the original specimen is always a concern. In microwear studies, as the instrument of magnification is extremely sensitive, it is also a concern that the specimen be as clean as possible. With these two factors in mind, the technique of molding and casting teeth has been meticulously refined since the advent of microwear analysis. Morel and colleagues (1991) applied a thin film of varnish to the original dentition, then removed the resultant replica for placement under the microscope. The method of creating silicon molds and epoxy casts of the original specimen was established early on in microwear studies and has evidently proved to be the most efficient (Gordon, 1982; Teaford and Tylenda, 1991; Bax and Ungar, 1999; Schmidt, 2001; Hogue and Melsheimer, 2008). Galbany (2006) tested the effectiveness of polyvinylsiloxane molds versus that of polyurethane casts when examined under a scanning electron microscope. It was found that both can be used to accurately assess dental microwear, but that caution should be used in the number of casts made from a single mold as features became distorted in the fourth cast and onward. It was also noted that lightweight materials resulted in less distortion of features and conveyed more detail than did heavyweight materials.

With the assistance of specified computer programs such as MicroWare, statistics programs such as SPSS, and scanning electron microscopes, dental microware data are now easily quantified. These types of data manipulation are imperative to interpretation of the variety of shapes, frequencies, and orientations that microwear features exhibit.

Application of Ethnography. As acknowledged above, a key confounding factor in the study of human dental microwear is the fact that humans utilize dentition as a tool. While making analysis more complex, this aspect of human adaptation also presents a unique opportunity: the transfer through hundreds of generations of traditional methods allows the direct observation of those processes that created microwear in ancient populations. In 1985, Larsen foresaw the need for and ethnographic supplement and applied it to his study of dental tool use in the Great Basin. While Larsen did not conduct an original ethnographic study, he consulted documentation, including photographs, from others who had recorded the methods of Native American basketweavers and logically applied them to the dental wear he observed in the archaeological remains before him. Larsen relates an ethnographic study conducted by Wheat wherein a woman is observed splitting willow fibers. Larsen concluded that the orientation of the fibers in the woman's teeth corresponded exactly to those grooves that Larsen observed in his own individuals.

Dental Microwear Foundations

Dental wear observable to the naked eye is the result of thousands of smaller imperfections in the enamel and dentin imposed on the enamel by everyday activities. Each of these individual marks on the tooth can be characterized by shape, dimension, and the orientation with which it was formed on the tooth. The ways in which microwear features manifest are dependent upon the structure of the enamel and the force and direction with which they are inflicted upon the tooth. Macrowear patterns, enamel behavior, and mechanics of processing form the theoretical and practical basis from which to analyze microwear.

Dental Macrowear. Dental microwear features amalgamate and are visible to the naked eye in the form of macrowear. The three processes that result in dental wear are attrition, abrasion, and erosion. Attrition refers to tooth-on-tooth contact, while abrasion refers to contact between the teeth and other materials (Lukacs and Pastor, 1988; Kieser et al., 2001). Erosion is best defined by Kieser and colleagues (2001:207) and Deter

(2009:247) as the “chemical dissolution” of the surface of the tooth and results in a uniform wear pattern. These three destructive processes come into play in both mastication and nonalimentary tooth use. It is hypothesized in the current study that attrition resulting from cultural activities may appear macroscopically differently than that caused by nutritional tooth use. It logically follows that the corresponding microwear should likewise be distinguishable through the analysis of feature patterns.

It is generally accepted that the degree of dental wear noticeably and quickly decreased with the advent of agriculture and even more so with the development of industrial economy (Molnar, 1972; Larsen, 1995; Kaifu et al. 2003). Kaifu and others (2003), in an examination of the adaptive aspects of attritional occlusion, note that a decrease in the degree of wear in the anterior dentition was the first indicator in the archaeological record that dental wear was decreasing in severity overall.

There are particular patterns that are observable macroscopically that are characteristic of repetitive processing of plant and animal fibers for use in cultural manufacture. Minozzi and colleagues (2003) conducted a study on the dentition of a male skeleton found in a rockshelter in Libya with the intention of macro- and microscopically documenting nonalimentary tooth use. They attributed a series of dental grooves and the corresponding microwear patterns to the cultural processing of plant fibers toward a hypothesized end of mat- or basket weaving, or net or rope processing. It was found that microwear features ran parallel to macrogrooves in a labio-lingual direction. Larsen

(1985) observed the same phenomenon wherein microstriations followed the axes of the grooves in which they were found. This phenomenon is of particular importance here; if it is observed in the ancient Californian individuals, it may inform the analytical stage of this study and possibly support the research hypothesis. Pitting was found on canines and premolars and became more frequent as observation moved further distally. Upon comparison with a skeleton possessing similar patterns, Minozzi and colleagues (2003) tentatively concluded that the microwear was caused by *Typha* fiber processing. It was emphasized that while it is possible to distinguish nonalimentary activities from dietary processing, more research is necessary to distinguish specific activities and materials used from one another.

Properties and Principles of Human Tooth Enamel and Dentin. To thoroughly comprehend and apply dental microwear analysis, it is necessary to deconstruct and understand human tooth enamel. As microwear can also be seen on the dentin of individuals with severely worn dentition, the character of dentin must also be examined.

Enamel has a 96% mineral content in the form of hydroxyapatite, rendering it the hardest material naturally occurring in the human body with a score of 4.5 - 5 on the Mohs hardness scale (Cuy et al, 2002; Mahoney, 2007). The remaining 4% is composed of water and of organic amelogenins and enamelins, proteins which guide tooth development and placement of minerals (Fincham et al., 2000). The mineral components lie as mostly organized crystals within an organic protein matrix (Boyde, 1967). The direction of this matrix dictates the orientation of the mineral constituents. Orientation changes throughout the tooth, creating a scatter of differently shaped prisms (Boyde, 1967; Cuy et al., 2002). Enamel prisms are cylindrical structures that range from 3-6 micrometers (µm) in diameter (Cuy et al. 2002). This prism orientation is the canvas upon which materials processed by the individual create microwear features and patterns; therefore, an individual's particular prism orientation and chemical composition will bear on the ways in which microwear features are laid down (Cuy et al., 2002). Conversely, Ungar (1994) concluded that there was no significant difference between the breadths of scratches oriented mesiodistally and incisocervically. The human enamel prism pattern will not be specifically targeted for analysis in this study, but the foundations presented here can add to a broader understanding with which to interpret the results.

Dentin composes the layer beneath the enamel and, being slightly less calcified than enamel, is more flexible (White and Folkens, 2000). The literature directly addressing the microwear inflicted on dentin is scarce. However, the topic has been studied enough to deduce that dentin behaves differently in the context of microwear. Zheng and colleagues (2003) found that, when enamel and dentin wear was simulated by running titanium along human teeth, a particle trail of titanium could be seen on the enamel surface, while no particles were present on the exposed dentin. The study also found that the troughs created by the abrasion were deeper in the dentin than in the enamel, illustrating the more pliable nature of dentin. A study by Burak and colleagues

(1999) found that under low force loads, enamel will wear slowly relative to dentin; however, at higher load levels, as load increases, the brittleness of enamel will cause it to wear with correspondingly greater rapidity, while dentin keeps a more steady wear rate under loads of varying force. This may be a factor in the differences in macrowear shapes between nutritional and non-nutritional types of tooth wear.

The mineral density of enamel and dentin dictates the tooth's ability to withstand strain. This property is expressed in measures of hardness (*H*) and elasticity (*E*). The property of *H* is influenced by the mineral to protein ratio while the property of *E* is influenced by prism orientation (Cuy et al. 2002). These factors fluctuate throughout a single tooth (Cuy et al. 2002). The study conducted by Cuy and others tested human enamel for *H* and *E* using Young's modulus, a system for measuring the level of hardness and elasticity in a given material. It was found that the occlusal surfaces of teeth possessed the highest mineral content and also the highest values of *H* and *E*, with the absolute highest values of *H* occurring in the intercuspal regions. The authors concluded that enamel hardness is governed by the mechanical functions of different regions of the tooth. Specifically, lingual enamel was found to be harder than buccal enamel. This is an important factor to integrate in consideration of microwear dimensions, particularly depth, as harder enamel may be less affected by certain materials than softer enamel. They also noted that the values of *H* and *E* decreased with closer proximity to the enamel-dentin juncture.

It is essential to consider ways in which the mechanics of these principles interact with prism orientation in dental microwear analysis. Cuy and colleagues (2002) note that hydroxyapatite is an anisotropic material, meaning that it behaves differently as it is manipulated along different axes. They found that when insult is inflicted upon the tooth transversely to prism alignment, the *E* value was 24% higher. Shimizu and colleagues (2005:427) assert that the nature of enamel prisms is such that they "effectively dissipate contact stress" on the tooth's surface and will influence the rate of dental wear. Shimizu's and colleagues' study found that the more obliquely a prism is oriented to the original enamel growth base, the better it stands up to stress. What appears to be a common thread in the increase of strength in tooth enamel is obliquity: the more transverse the attack on a tooth, the better the enamel holds, while a more perpendicular organization of prisms offers the greatest protection against insult. Maas (1991) warns that prism boundaries will potentially create areas of weakness that fractures will prefer, resulting in variations in microwear features that may be erroneously interpreted. The study was designed to decipher the relationship between particle size, shearing force, and enamel structure. Maas concluded that, depending upon the direction of force and subsequent angle of the particle to the enamel, the resulting microwear feature will be wider or smaller depending upon the orientation of the prism plane under attack. The mechanics of chewing and processing will combine with enamel composition and prism orientation to produce a wide range of microwear features. Therefore, care must be taken to consider these properties of enamel when assessing how a particular material and processing technique will appear in the microwear set. However, the application of particular techniques and materials is a direction of future study, as the present study is limited to the presence or non-presence of cultural tooth-as-tool use.

Causes and Patterns. At the time of a study conducted by Schulz (1977) on CA-SAC-145, it was becoming more commonplace to consider microscopic wear as a matter of course when analyzing possible causes of macrowear in ancient dentition. Schulz discounted the possibility that tooth-picking caused a particular grooving pattern because the microscopic evidence was contradictory, providing an example of the potential of microwear analysis to identify specific causes of dental wear.

Below is an outline of the features and concepts of consequence in dental microwear analysis. Feature shape, size, frequency, and orientation and their corresponding significance in the discipline thus far will be summarized, as will the relevance of these data to the current study.

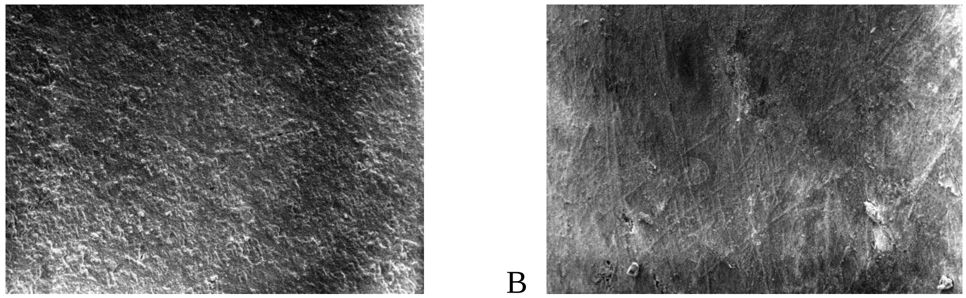
Dental microwear is observed and recorded with a small and concise set of terms that correspond with certain shapes microscopically appearing on the tooth. The two categories encompassing most microcharacteristics are scratches and pits. According to the degree of severity, these features may be assigned more descriptive names to the discretion of the author, such as “gouge” for deep scratches or a small region of scratches with different orientations (Gordon, 1988; Ryan and Johanson, 1989; Ungar and Spencer, 1999). Comprehensive definitions can be compiled from those given in different studies. Pits are features that are essentially equal in length and width and which can be produced by tooth-on-tooth impact (Gordon, 1988; El-Zaatari, 2008). Scratches are “linear features with a discernible angle of orientation” and with a length-to-width ratio of 4:1 (Gordon, 1988:1140; Organ et al., 2005). Striations exhibit the appearance of scratches, but are finer and not so pronounced as are scratches (Larsen, 1985; Gordon, 1988; Teaford, 2007). They ways in which these features interact with one another can indicate specific combinations of movement and material; for example, a striation may possess an “impact pit” at which a particle first meets the occlusal surface of the tooth before continuing on to create a striation or scratch (Gordon 1984:319). Pits, when defined by the common 4:1 length-width ratio, are created by a more direct maxillary cusp to mandibular cusp contact during both Phase I and Phase II strokes, with the greater incidence occurring during Phase II due to maximum cusp-to-cusp contact. Scratches are formed throughout the Phase I to Phase II complete stroke as cusps slide past one another with oblique rather than directly vertical contact. These are the core definitions that have held the general consensus among microwear researchers. However, Grine and colleagues (2001) stressed that considerable hazard still lies in the possibility of inter- and intraobserver error. They warned that the imposition of new wear features upon old ones is a phenomenon that may confuse the diagnosis and consequently the analysis of a pit or scratch (Grine et al., 2001).

Schmidt (2010) explains that scratches are created through different types of occlusal contact. If the Ohlone used the posterior dentition as a third hand as well as a platform for softening tough materials as hypothesized in the present study, then it is expected that scratches will dominate the micrographs.

The range of feature size depends upon the type of and the force with which material is processed. Width can be indicative of force; for example, a striation or scratch that is wider at the origin and narrower at the end suggests heavier force at the beginning of the motion while one that is narrower at the origin than at the end suggests heavier force at the end (Gordon 1984). These properties vary according to tooth, as well as to the location on the tooth. Each facet on the tooth responds to force and direction differently, and thus records damage differently (Gordon, 1984; Maas, 1991).

Throughout interpretation of dental microwear in the present study, care will be taken to distinguish between any chemical erosion of the enamel from mechanical attrition and abrasion. A visual example is provided below as published Kieser's and colleagues' (2001) study on pre-contact Maori dentitions (Figure 1.1).

Macrowear as a Guide to Microwear. It can be intuitively asserted that macrowear is a function of microwear. Attrition, abrasion, and erosion wear down microscopic areas which gradually converge into a feature visible to the naked eye. In the early stages of this type of research, Molnar (1971a) observed in a sample of prehistoric individuals



A B

Figure 1.1. Dental microwear resulting from erosion (A) as opposed to mechanical abrasion (B) (Kieser et al., 2001).

from California's Central Valley a series of grooves on lingual surface of the maxillary incisors, suggestive of material being repetitively pulled through the same area. The interproximal groove is a common pattern resulting from pulling material repetitively through the teeth, as seen in many prehistoric Californian populations (Scott and Turner, 1988). Very distinct grooves concentrated on a particular plane do not appear to be characteristic of masticatory tooth use: attrition and abrasion owing to food processing tends to result in a more diffused pattern and with more involvement of the molar teeth, with most cusps of the occlusal surface involved (Smith, 1984; Scott and Turner, 1988).

Schmidt (2010) explicitly addresses the relationship between macro- and microwear in a study of prehistoric individuals from Indiana. A guiding philosophy in this study is that microwear is caused by a cooperation of several influences rather than one component alone (e.g. particle hardness). Location on the occlusal surface on which microwear appeared, i.e. Phase I or Phase II facets, material type, particle size and particle hardness all influence the microwear feature and in turn the amount of macrowear. It was found that a greater mean scratch width per tooth had a significant positive correlation with a higher macrowear score, with the relative width of a scratch presumably existing as a value along the continuum of ratios 4:1 and above. Pit percentage was found to have no significant effect on the amount of enamel loss. Schmidt notes, however, that a population with larger pits may yield a different result. Schmidt concludes that shearing resulting in scratches creates a greater degree of wear. If the ancient Californian population exhibits a greater frequency of relatively wider scratches, then it may be supported that the Ohlone were shearing material with the molars with frequency great enough to produce the aforementioned unusually high wear.

In Schmidt's study, the process of obliteration again presents itself. It was found that a higher scratch frequency was associated significantly with lower macrowear scores. On the opposite end of this correlation, a low scratch frequency per micrograph (presumably meaning wider scratches and therefore a smaller number of scratches being able to fit in the space of a micrograph) suggests a result of a higher macrowear score. This may be due to the fact that a lightly worn enamel surface would display more distinctly any insult, as these features may not have had the chance to be obscured by more intense wear. Looking at the evidence presented thus far, smaller features will amalgamate into larger ones, particularly upon frequent repetition of a similar process (e.g. cultural tooth-as-tool use or therapeutic picking). It is possible that Schmidt's observation was a result of polishing through obliteration and the amalgamation of smaller features into larger ones, culminating in higher degrees of macrowear.

The scoring systems that will be used to guide the analysis of microwear in this study are the Molnar (1971a) occlusal wear scale and the Grant (2010) scale which was designed specifically to measure macrowear patterns in ancient Californian dentitions. The Molnar scale is constructed around the degree of dentin exposure on the occlusal surface, while the Grant scale observes particular macrowear shapes. The processes of dentin exposure that bear on the Molnar scale can be found above. Particular macrowear features used in Grant's scale have been observed in several other populations and have been attributed chiefly to nonalimentary processes. The vast majority of macrowear features have been classified as grooving, cupping, tilting (obtuse plane wear), and rounding.

Grooving has been attributed to palliative activities such as toothpicking (Lukacs, 1988; Fox and Frayer, 1997). These studies often note that toothpicking has been overused as a suggested cause of grooving and cite sinew and plant fiber processing as more likely causes. Schulz (1977) found that in an ancient population from Sacramento, California, microstriations ran parallel along the axis of groove features, a pattern also observed by Larsen (1985) in a Great Basin population. Schulz concluded that the grooves were most likely caused by a repetitive, habitual movement involving tough plant fibers. He compares his results to a study by Cybulski (1975) of a prehistoric population from British Columbia. In Cybulski's study, grooves were found exclusively on the occlusal surface and were found to have modified at least half the occlusal surface in most cases. Schulz suggests that this was due to the processing of larger pieces of material. Larger materials may play a role in the etiology of another macrowear feature, that of cupping.

Cupping is often described as a result of the hardness discrepancy between enamel and dentin, a natural trough on the occlusal surface occurring gradually with everyday nutritional and non-nutritional wear as well as erosion from bodily and dietary acids (Kieser et al., 2001; Ganss, 2008; Deter, 2009). Kieser and colleagues (2001) associated cupping with a marine-based diet similar to that exploited in the pre-contact San Francisco Bay Area, likely due to the eroding properties of accompanying grit. To distinguish normal cupping wear from that which may be attributed to a specific and intensive activity, Hinton (1981:557) in a study of aboriginal populations recorded only "deeply and prominently" cupped features that left a significant enamel rim. Grant's scale transposes the cupping concept to reflect the high rate of extreme wear in ancient California, and refers to this feature as "scooping". This is a change that the author finds appropriate for this study, for the feature is so pronounced that the tooth appears to have been scooped out. Little information is available regarding the direct link of microwear to cupping, and it is hoped that this study will contribute to this database.

Wear that results in an oblique buccolingual plane is typically known as the Monson curve (Kieser et al., 2001; Kaifu et al., 2003). In attrition achieved through normal occlusion, this incline is caused by the occlusion of complimentary mandibular and maxillary molar wear facets (Sengupta et al., 1999; Kaifu et al., 2003). A reversed Monson curve is one in which the incline is slanted downward buccally in the mandibular molars and upward lingually in the maxillary molars, a condition resulting from heavy cusp wear (Osborn, 1982). In cases of heavy wear, the Monson curve along the molar row creates what is known as a helicoidal pattern, with a reverse Monson appearing on M1, a flat plane on M2, and a classic Monson on M3 (Osborn, 1982). What is found in ancient San Francisco Bay Area populations is what Kieser and colleagues (2001:210) call an "accentuated" Monson curve, where the cusps are worn flat and a steep angle is created. Kieser and colleagues also found heavy abrasion and erosion features in the microwear profile of Monson planes. Grant renames the Monson feature "slant" in his California macrowear scoring system.

Rounding has been recorded on the anterior as well as the posterior dentition in hunting and gathering societies. Scott and Turner (1988) suggest that labial rounding of the anterior dentition is caused by grasping material with an even amount of force along all affected teeth. Brace (1964) argued that the extreme rounding wear seen in Neanderthals decreased in later populations because, as technology progressed, so did the need to use teeth as tools. Once again, this was observed in the anterior dentition;

however, it was attributed to extreme habitual tooth-as-tool use (a conclusion which was subsequently contested by those who believed that rounding wear was caused by dietary grit – a similar debate to that which guides the current study). Hinton (1981) found that hunter-gatherer populations exhibited rounded features while agriculturalists did not. In a study by Wallace and colleagues (1975), the microwear profile on rounded features in a sample of aboriginal individuals was characterized by a high density of small scratches. Very little is mentioned regarding rounding wear in the molar row. As this study focuses on the molars and premolars, any rounding features observed will serve to add to what is now a paucity of data on the subject.

These past studies have informed the expectations of the current study by providing some relationships between microwear and specific macrowear features. Those relationships include microscratches that have been found to be parallel to the macrofeatures in which they were observed, as well as s high frequency of microfeatures being found slanting features. These relationships will be explored further in the discussion of dietary as opposed to cultural microwear features.

Dietary versus Nonalimentary Microwear

Several studies have been conducted regarding the microwear produced in non-human primates and other mammals through dietary processing (Walker et al., 1978; Gordon, 1982; Teaford, 1994; Merceron et al. 2005). These studies provided the methodological and theoretical basis for microwear studies in general. In the discipline of physical anthropology as it relates to archaeological populations, it is now necessary to further distinguish microwear into the genres of dietary microwear and cultural microwear. This distinction has the potential to enlighten anthropologists as to past cultural habits and tool-making, as well as provide auxiliary evidence to bolster or disprove past assumptions regarding dietary and environmental reconstruction. In the current study, it is of utmost significance that microwear features created by the cultural processing of materials be distinguished from dietary features, and that their influence upon one another in terms of the processes of formation and obliteration is recognized and understood. A good point from which to begin distinguishing between nutritional and cultural microwear is gross observation of the micrograph. In studies such as Fox's (1992) and Lozano's and colleagues' (2008) which focus on nonalimentary microwear, a very clear pattern of parallel scratches can be observed on the provided micrographs. In studies focusing on nutritional microwear (which far outweigh those focusing on non-nutritional microwear) such as Organ's and colleagues' (2005) and the many others described in this study, microwear deemed nutritional is startlingly more randomly oriented. Macrowear features are increasingly guiding microwear studies, a particularly useful strategy in nonalimentary studies.

Dietary Features. Scratches and pits are the two most general categories of dental microwear features. Elements of plants and animals (e.g. rougher stalks and sinew, respectively) that are normally chosen for food are different than those chosen for cultural manufacture. Those materials used in non-dietary activities tend to be significantly more fibrous and are therefore repetitively processed in the teeth (Brown and Molnar, 1990; King et al., 1999). In gorillas, the act of stripping leaves from branches involves repetitive dragging of fibrous materials across the teeth. While the leaves are stripped in the process of nutritional consumption, the act of stripping is pre-masticatory and can be used here to illustrate a motion comparable to human nonalimentary manipulation of fibers and therefore a possibly comparable microwear pattern. In several studies on dietary microwear, features appear as conglomerates of pits and scratches that appear somewhat random in orientation (Larsen, 1985; Brown and Molnar, 1990; Ungar and Spencer, 1999). Conversely, non-dietary features are typically organized in groups of parallel features running in one direction (Larsen, 1985; Fox, 1992). Kieser and colleagues (2001) attribute both "cross-hatch" and parallel scratch patterns to abrasion and attrition, but do not distinguish between those created by attrition or abrasion. Attrition can occur in normal mastication as well as in fiber manipulation. A possible measurement of microwear that may assist in ascertaining the difference between these parallel scratches is scratch width, as this has been directly associated with type of material processed (Schmidt, 2010). El-Zaatari (2008) notes that, as meat is typically considered to be too soft to wear the enamel directly, microwear from meat consumption is most likely caused by attrition rather than abrasion and results in a microwear signature consisting of a high pit frequency and small scratches.

Nonalimentary Features. What will prove to be a difficult task in the current study is the differentiation of scratches and pits as generated by nutritional versus cultural manipulation of material. A study by Lozano and colleagues (2008) is one of the most explicit in addressing this dilemma. This study utilizes an extremely specialized "extramasticatory", or nonalimentary, microwear feature key to analyze findings in the study samples of hominins from the Sima de los Huesos site in Spain and Australian Aborigines. Building on those definitions of pits and scratches provided above, features found to be exclusively associated with nonalimentary attrition are given more specific classifications. Those are, according to Lozano and colleagues: vestibular striations, enamel flakes, vestibular-lingual striations, and polished enamel. These are features that have failed to appear in previous studies only geared toward dietary habits in species that do not use their dentitions as tools to the same degree as do humans. However, Lozano's and colleagues' study addresses only the anterior dentition, while the current study will address only the molar rows. Enamel polishing is the most likely feature to translate from the anterior dentition to the molars as the creation of the other features described by Lozano and colleagues are dependent upon the morphology of the incisal edge.

Polished enamel features are areas of smoothed enamel that, even under SEM, are devoid of other microwear features. Lozano and colleagues (2008) do not specify whether the latter feature occurs due to lack of significant interaction with material or due to a particular type of interaction that results in a microscopic level of polishing. However, as noted above, repetitive manipulation of gritty fibrous material can result in polished microwear. King and colleagues (1999) note that larger particles, as opposed to creating proportionately larger pits and scratches, actually serve to erase previous wear features, an example of the phenomenon of obliteration as discussed by Teaford and Oyen (1989). This dilemma can be overcome by accepting polished microwear as evidence in itself, suggesting repeated manipulation of material that contains some grit; however, whether the grit originated from sandy food products or gritty culturally manipulated fibers will be less apparent.

Enamel flakes present a taphonomic dilemma, for they can be produced ante-, peri-, or postmortem. Lozano and colleagues (2008) remind us that the same guideline for distinguishing ante- and postmortem breaks in other bones can be used here: the perimeter of an antemortem flake will be rounded and polished. It is stressed in this study that the enamel flake is typically found on the borders between the occlusal and labial surfaces.

In their study of Neanderthal handedness, Fox and Frayer (1997) consider the placement of a feature to be one of the more significant factors in classifying it as dietary or nondietary. Features on the para-occlusal surfaces were more confidently classified as resulting from tooth-as-tool use than were those on the occlusal surfaces. In the current study, the unusual wear in question occurs primarily on the occlusal surfaces. Therefore, other criteria must be employed in distinguishing nonalimentary wear from its nutritionally derived counterpart.

Minozzi and colleagues (2003) examine microwear in a prehistoric Libyan male hypothesized to have dentally manipulated vegetable fibers. Microwear features in the individual were identified as either “pits” or “striations” and were analyzed according to relative size and shape. An interesting technique was employed in this study: first, macrowear features were identified; microwear features were then analyzed in the context of their placement and character within each macrowear feature. The prehistoric individuals concerned in the present study exhibit distinctive and numerous macrowear features. As the macrowear present on these individuals is hypothesized elsewhere to be a result of cultural manipulation of plant fibers, the microwear examined here will be restricted to that found within macrowear features.

Phytoliths. Phytoliths are microscopic mineral bodies that are formed and stored in the stems, leaves, and blossoms of living plants (Gugel et al., 2001). A phytolith may be composed of crystalline calcium oxalate or, most commonly, of non-crystalline silica. Both forms are harder than human enamel and dentin (Danielson and Reinhard, 2005; Piperno, 2006). Phytoliths are believed to play a number of important roles in plant development and protection; for example, to protect plants from pathogenic fungi and consumption by herbivores (Piperno, 2006).

In earlier studies such as Gordon's (1984) of chimpanzee molar microwear, phytoliths were treated cautiously in causational discussions of microwear. Gordon notes that grass-grazing mammals typically bore an average scratch density of 300 per mm^2 while the frugivorous chimpanzee average was 368 per mm^2, showing that high scratch densities can appear in the absence of plant opal. In contrast, in a study of prehistoric hunter-gatherers, Danielson and Reinhard (1998) discovered a plethora of calcium oxalate phytoliths in coprolites. They concluded, in opposition to the standard belief of the time, that these crystalline phytoliths do significantly contribute to dental wear. This study represents a worthwhile and successful attempt to draw much needed attention to the analysis of this cast aside type of phytolith. Gugel and others (2001) were able to distinguish phytoliths according to the type of cereal grain from which they originated. It will not be a goal of the current study to use dental microwear to speciate plants; however, this course of research can be extremely useful in future microwear studies. Danielson and Reinhard (1998) stress that the presence of phytoliths in coprolites and in the intestinal lumen proves that they are in fact freed from their cellular matrix in the process of mastication, thus coming in contact with the surfaces of the teeth.

Sanson and others (2007) expressed doubt that phytoliths contribute significantly to dental wear in mammals. This conclusion was based upon the study of dental wear in sheep and applied broadly to the mammalian class. As noted above, microwear studies concerning non-humans can provide valuable bases from which more focused human studies can branch. However, enamel properties must be taken into account before eliminating phytoliths from the equation. Sanson and colleagues use the Vickers hardness levels to gauge the hardness of enamel and phytoliths. Sheep enamel possesses a higher Vickers hardness level than humans with an average rating in the upper-200s (Sanson et al., 2007), while humans average in the mid-200s (Wongkhantee et al., 2006). Certain grasses possess Vickers levels of up to the mid-200s (Sanson et al., 2007). Vickers hardness is just one of several methods by which to measure relative hardness. Considering that phytolith hardness can vary widely even within a single plant, and that enamel hardness can be measured through any of several means, the conclusions derived by Sanson and colleagues and similar studies are not evidence enough to eliminate the consideration of phytoliths in dental microwear analysis.

Significance of Anterior Dentition. Non-nutritional use of the human anterior dentition has been frequently observed in ethnographic and archaeological contexts and has been dubbed the “third hand” by anthropologists (Ryan and Johanson, 1989; Fox et al., 1992). Fox and colleagues (1992:290) applied microwear studies in the context of the use of anterior dentition as a “third hand”. The anterior dentition is often used to grasp, manipulate, and steady material as it is worked with the hands. Some of the most frequent and intense use of this method has been noted in native Alaskan populations, where ethnographers have observed use of the anterior dentition to remove the lids from gasoline drums (Merbs, 1968). The ways in which this technique manifests in the microwear of the anterior dentition depends upon the material used and the amount of load and force (Merbs, 1968). In Merbs' review of several populations that regularly apply the third hand technique, it was discovered that material manipulated varied between the sexes according to culturally dictated duties. Merbs found that females tended to process hides and materials that required a wider distribution of force among the anterior dentition, whereas males processed thinner, denser materials, such as sinew and other fibers appropriate for fishing line. This is demonstrative of a basic principle of microwear studies: microwear begins with the type of material processed, with factors such as direction and force being dependent upon the material and its cultural application. A study by Hinton (1981) revealed that hunter-gatherer populations exhibited more anterior wear than agricultural populations, suggesting more intensive third hand activity.

In Schulz's (1977) sample, ancient Californian individuals exhibited macrowear features exclusively in the anterior dentition. Conversely, distinct wear patterns are present along the molar rows of the individuals included in the present study. This may have been due to a lack of available individuals in Schulz's study who may have participated in different molar-heavy cultural activities, or simply due to culture-wide material manipulation techniques which differed from their western Ohlone neighbors. Deter (2009) focuses on anterior wear as found in hunter-gatherers. Deter suggests the manipulation of fish hooks and nets as possible causes of extreme anterior wear, but does not mention basket weaving. The historical concentration on cultural tooth use as it is implicated in anterior wear does not, therefore, rule out the use of the molar row in cultural activity, since basket weaving is often not specifically considered in these studies. In an intensive basket weaving culture such as the Ohlone, it is possible that the third hand concept translates from the anterior dentition to the molar row.

Dental Wear in Ancient California

Ancient Californian populations are known to exhibit a particularly extreme level of wear (Leigh, 1928; Schulz, 1977; Jurmain, 1990). This is due in part to the odd "variety" of wear features fitted together in close proximity (Schulz, 1977:87). An example of this is shown in Figure 1.2. These individuals often exhibit more extreme pulp cavity exposure at younger ages than individuals in other Native American populations (Leigh,

Figure 1.2. Example from ALA-329 of a variety of macrowear features occurring in succession.

1928). Pulp exposure in ancient Californians is so severe as to be cited in early studies as the cause of 97 percent of osseous alveolar lesions in Bay Area archaeological populations (Leigh, 1928). Molnar (2008:425) described tooth wear in a Neolithic population from Sweden as exhibiting “occlusal excessive load”; photographs of these teeth showed that at an “excessive” level, they were still not as extremely worn as those of pre-contact Californians. Barrows (1967) received a report that it was common to observe tooth crowns that were half worn away in forty-five year old, healthy men. This level of crown wear occurs in the individuals of ALA-329 in the early- to mid-thirties (Jurmain, 1990). The Ohlone as well as the Miwok of central California heavily exploited marine resources, a subsistence pattern that is hypothesized to cause specific types of dental wear (Molnar, 1972). However, the degree of wear in the Ohlone and Miwok often surpasses that seen in other Californian coastal populations, for example in individuals from the Santa Barbara area (Leigh, 1928). The current study intends to determine whether basket weaving and similar cultural manipulation of material significantly affects dental wear patterns in ancient Californians.

The Ohlone of Central California. The current study focuses on the microwear of individuals from archaeological Ohlone sites in the San Francisco Bay Area. Information regarding ancient Ohlone culture is some of the most elusive in Californian studies, partially due to a loss of archaeological remains through sea level rise, and partially to colonial and bureaucratic influence (Moratto, 1984; Laverty, 2003). It has been common practice to refer to ethnographic information about surrounding groups, such as the Miwok, in the discussion of Ohlone culture, with the assumption that some diffusion took place. The following account of the populating of central California is adapted from Moratto (1984). The Ohlone and their ancestors have existed in California for at least the last 7000 years, occupying areas from the Monterey Peninsula up through San Francisco and extending to parts of the Central Valley. The presumed Ohlone predecessors, the Esselen, are believed to have occupied San Francisco and its southern coast down to Monterey prior to approximately 2000 B.P. This date signifies an economic shift apparent in the cultural strata to a sudden heavy exploitation of abalone, presumably caused from the Esselen exploitation and subsequent depletion of mussels.

Archaeological evidence such as tool manufacture patterns and available carbon dates argues for an Ohlone presence that originated in the East Bay, then began to advance. (The reason for this advance is not known.) It is hypothesized that the Ohlone either absorbed or displaced the earlier Esselen community into the Monterey coastal territory. The Esselen then occupied the central coast until the mission era rendered their culture extinct. At the cusp of missionization in the late 18th century, approximately 10,000 Ohlone occupied the Bay Area (Moratto, 1984; Skowronek, 1998).

Close proximity to the estuary system and other marine resources of the San Francisco Bay and surrounding areas allowed the Ohlone access to an extensive variety of flora and fauna. Leigh (1928) notes that California Native Americans consumed the widest range of species from both the plant and animal kingdoms than any other ancient North

American population, including but not limited to fish, mollusks, game, insects, bones, grasses, acorns, clover, berries, nuts, and seaweed.

The Ohlone (sometimes referred to as the Costonoans in earlier literature, an Anglicization of Costaños, the name given them by early Spanish explorers) produced shellmounds, which are large features of food refuse consisting mostly of discarded shells. The mounds were likely sacred areas as opposed to simply disposal sites and contained significant numbers of burials (Luby and Gruber, 1999; Jacknis, 2004). The Ryan Mound was at first interpreted as a shellmound; however, opinion has shifted and it is now considered to be an earthen mound due to the small proportion of shell in the mound (Leventhal, 1989, 2011). Over 90% of the artifacts found in the mound were grave associated. Most of the food refuse was likely mortuary related, used during burial rites and anniversaries of deaths (Leventhal, 2011).

The Ancient Ohlone Diet. The Ohlone were semi-sedentary hunter-gatherers, exploiting seasonally a variety of plants, game, and insects (Harrington, 1942; Heizer and Elsasser, 1980; Skowrenek, 1998). The acorn is cited most often as the staple of the Ohlone diet, being used typically as flour for cakes and mush (Jurmain, 1990; Bartelink, 2006), while buckeye was used in much the same way in the months when acorns were unavailable.

Foods were eaten raw and cooked. Pulverization in stone mortars of foodstuffs from plants to small mammals, bones and all, was performed for those with inadequate teeth (Jacknis, 2004). Cooking methods included the aforementioned stone-boiling, as well as roasting in leaf-lined earth ovens or directly on hot coals or in hot ashes (Jacknis, 2004). Some Sacramento Valley cultures were known to add red clay to acorn bread, introducing direct grit into the diet (Jacknis, 2004). These various techniques all have the potential to introduce exogenous grit into the mouth, either through directly chewing the gritty particles along with the food, or through the swishing of particles through the dentition in saliva.

Hypotheses Regarding Ohlone Dental Wear. A common hypothesis regarding dental wear in coastal populations cites grit in food as a primary cause (Leigh, 1928; Molnar, 1972; Larsen, 1995). Leigh (1928) provides an early and comprehensive summary of possible causes for the extreme dental wear in coastal Californian populations. Ohlone methods of food preparation involve the introduction of grit into the food, increasing dietary grit that is already present in natural marine resources (Leigh, 1928). Stone pestles were used to grind acorns and seeds, while heated stones were mixed with food in watertight baskets to boil the contents, a technique shared by the neighboring Miwok (Leigh 1928; Barrett and Gifford, 1933; Davis and Treganza, 1959). Foods that inherently contained a certain level of sandy grit were introduced to further grit through the preparation and cooking processes. In consideration of cultural processing of materials, grit that naturally adheres to plant materials will likely play a factor; however, in lieu of exogenous grit introduced by such tools as a mortar and pestle that would naturally not play a part in tooth-as-tool activity, phytoliths are hypothesized in the current study to produce much of the wear created in nonalimentary processing. Leigh (1928) also suggests that tobacco chewing contributed to Ohlone dental wear. Tobacco was mixed with mollusk shells which had been burnt to the calcined stage, resulting in dental decalcification when chewed (Leigh, 1928). Another potential source of tooth wear was the habit of shucking acorns with the teeth, a practice observed in the Miwok (Barrett and Gifford, 1933) and possibly such an intuitive technique that it could logically be assigned to the neighboring Ohlone as well. Jacknis (2004) suggests that while the acorn was indeed a staple, the significance of acorns may have been over exaggerated in the literature due to a Western interest in them. Jacknis (2004:302) relates the observations of Yosemite settler Elizabeth Grinnell: "Every little acorn was shelled by the teeth of these patient folk….The strong, white teeth of these women might well be the envy of our own peoples who dare not even crack a filbert or a peanut between their brittle grinders."

Cordage and Basketry in Ohlone Culture

It is hypothesized in this study that weaving and cordage manufacture is the likely primary agent of any nonalimentary tooth use detected in the teeth of ALA-329. The ethnographic literature, summarized below, supports cordage as an indispensable element of native Californian economy and daily life. Among the several applications of cordage and weaving, basket weaving can be labeled the most intensive and therefore the most likely to create the most wear on the teeth. This activity is most often attributed to females. However, males did manufacture several types of cordage-based items. It is possible that participation in the manufacture of a variety of items may inflict similar wear levels but with different microwear patterns as the intensive, basket-dominated activity among females.

Cordage in Ohlone Life. Kroeber (1904:83) observed about Ohlone material culture that "rope and string were everywhere". Cordage of plant and animal materials was a significant element in many essential items, such as baskets for food transportation and processing, mats, rope for transporting lumber, and fishing nets (Anderson, 1999; Jordan and Shennan, 2006). Fish were exploited less often than mollusks, but the process of fishing did involve the placement of nets at the mouths of streams (Davis and Treganza, 1959). Baked clay lumps were recovered from ALA-329 exhibiting fiber impressions from either a twined basket or mat (Coberly, 1973). Cordage was also used in diversionary items such as musical bows, bull roarers, and decorative baskets used in ceremony (Harrington, 1942). Cordage would have had many miscellaneous binding applications, evidenced in part by a charmstone with asphaltum exhibiting cordage impressions found at ALA-329 (Coberly, 1973). Also found at ALA-329 was a twig encompassed by carbonized strands of fibers, possibly from a cremation mat (Coberly, 1973). Aprons of braided grass, tule, or buckskin were worn by women, and both sexes donned hide capes in cooler weather (Harrington, 1942; Skowronek, 1998). Cordage was involved in the manufacture of hairnets, twined basket caps, and feather headbands (Rawls, 1984; Anderson and Moratto, 1996). The adoption of the bow and arrow in California occurred around 500 AD, well within the accepted dates of the Ryan Mound (Grant, 2010). This would have involved either a fiber or sinew twine with which to secure arrows and create tension in the bow. In addition, while not a cordage activity, teeth may have been used to shape and refine arrow shafts, for which elderberry wood was used (Bocek, 1984). Plant and animal materials used in general cordage included deer grass (*Muhlenbergia rigens*), pine (*Pinus*), nettle (*Urtica*), willow (*Salix*), bear grass (*Nolina*), cattail (*Typha latifolia*), dogbane (*Apocynum*), and deer sinew (Heizer and Elsasser, 1980; Margolin, 1978).

It is extremely important to remember in the current study that both sexes participated in the manufacture of cordage (Harrington, 1942). Males were likely to have woven the materials which they used in male-oriented activities, such as hunting, which included netting and bows and arrows. An activity typically confined to male Miwok was the playing of the musical bow, during which either the bow or the string was held in the teeth (Barrett and Gifford, 1933). A clear sexual division of labor did exist among the Ohlone, but when dictated by necessity, males and females did alternate roles (Jacknis, 2004). This exchange of duties may have applied to cordage and weaving as well. Consideration of how these activities might affect the male dentition as opposed to its female counterpart will suffer from a lack of study of specific manufacturing technique, but if the ALA-329 males were participating in nonalimentary tooth use, it is expected that general characteristics of this nature will be observable.

Basketry. Basketry tradition in ancient California has been described as "the most highly developed California art form" and the most sophisticated basketry technique in North America (Elsasser, 1978:626). It has been described as surpassing other world cultures' basket weaving technologies in terms of complexity, diversity, and consistency (Bibby, 1996). Rawls (1984:9) asserts that "in basketry the California natives exceeded all others in skill and accomplishment". Native baskets were admired even by the colonists and European travelers who derided all other aspects of native culture (Rawls, 1984). To have earned such renown in the skill of basketry, ancient Californians likely invested considerable time and effort into honing and maintaining the art. It is largely for this reason that the hypothesis of the current study cites tooth-as-tool use as a main cause of attrition.

Literature regarding specific weaving methods used in prehistoric Ohlone populations is extremely scarce. Between the tumultuous geological history of the Bay Area, the extremely perishable materials used in weaving, and the colonialist obliteration of Ohlone culture and cultural records, documentation of weaving methods is relegated to comparison to neighboring tribes. The tradition of destroying a weaver's baskets upon her death also contributed to the poor preservation of woven goods in the archaeological record (Shanks, 2006). Modern Ohlone descendents are the most informative resource when studying indigenous weaving traditions, and their instructional articles and videos will be referenced throughout the following discussion.

The Use of Baskets in Food Processing. The Ohlone used baskets "in all areas of the food quest" (Bibby, 2004:2). Acorns required substantial processing in order to eradicate bitterness and dispose of indigestible casings (Moratto, 1984). Such processing was accomplished through the use of groundstone and basketry (Heizer and Elsasser, 1980). It has been hypothesized that the efficiency of baskets in acorn processing may explain the lack of pottery in the native Californian tool collection (Heizer and Elsasser, 1980). Openwork baskets provided a vessel in which to leach acorns of their unpalatable tannic acids and to sift acorn flour into different levels of coarseness for use in several preparations (Leigh 1928; Harrington, 1942; Bocek, 1984; Anderson, 1999). This was also achieved by filtering acorn meal with water in a sandy pit.

Baskets were used for seed gathering in at least four capacities. The first two involved the procurement of seeds; first, for separating grains from stems; and second, for catching the seeds as they are beaten from the plant. This process is known as "winnowing", and the baskets named such (Weltfish, 1930; Anderson and Moratto, 1996). Baskets were also used as vessels within which to roast seeds such as chia with hot coals (and possibly hot stones among the Ohlone in particular) (Lightfoot and Parrish, 2009). Baskets were also used to store the seeds as well as other food items. Storage was a major use for baskets in native California (Anderson, 1995). The acorn granary, or large storage center, was most commonly woven from willow, a material also used for baskets (Hector, 2006). They were able to be made watertight, and used not only for the boiling process as described above, but for water transport and storage (Shanks, 2006).

Ohlone Basketry Techniques and Materials. Despite the extolment of California Native American basketry, the literature pertaining specifically to Ohlone techniques is sparse. In the Ohlone archaeological record, poor preservation has resulted in a lack of plant material (Jordan and Shennan, 2003). However, enough was accomplished in the early 20th century in an explosion of early American anthropological interest in native populations, as well as a few subsequent large studies, to provide a foundation of basketry data for this study. Jordan and Shennan offer an intensive scholarly study regarding California basketry traditions. They conducted a cladistic analysis of basketry elements and techniques and concluded that geographic proximity influenced transmission of technique and style. Within groups sharing similar basketry cultures, many mutually unintelligible languages were present. Weltfish (1930) cites J.A. Mason as suggesting that Ohlone basketry most strongly resembled that of the Miwok. This suggests that Miwok and Yokut basketry can provide valuable clues as to Ohlone basketry technique.

Though most ethnographic material dates from the 18th century onward (from the notes of Spanish explorers such as Anza, from early 20th century ethnographers such as J.P. Harrington), it can be surmised that ethnographically observed Ohlone basket weaving techniques were similar to those employed by the individuals from sites dated much earlier. The ample flora and fauna available to the Ohlone were used not only for sustenance, but for tools and artistic endeavors. Art and utility were often meshed, particularly in the methods of basketry.

Materials used by the Ohlone were chosen for the best balance of strength and flexibility (Heizer and Elsasser, 1980; Bibby, 2004). Weaving materials in central California included pine, nettle, bear grass, and cattail, but the most utilized were deergrass, tule (*Schoenoplectus acutus*), and the fiber of the willow (Anderson, 1996; Heizer and Elsasser, 1980; Bocek, 1984). It is estimated that at least seventy-eight species of plants were used in basketry manufacture in California (Heizer and Elsasser, 1980). Plants were also chosen for their contributions to color patterning. For example, to create black patterning, botanical materials such as maidenhair (*Adiantum*), golden-back fern (*Pityrogramma triangularis*), and tule were used; among the Miwok, the boiled brake fern (*Pteris*) was the preferred material for black patterning (Merrill, 1923). Bracken fern (*Pteridium aquilinum*) root was also a popular source in central California for black patterning (Shanks, 2006).

The “coil” and “twine” methods were the most used techniques among central Californian basket weavers (Heizer and Elsasser, 1980; Shanks, 2006). A coiled basket is one which produced mostly round and oval bowls. It employs horizontal warps (the stiff “skeleton” of the basket) around which the wefts (the fibers in motion, those which are woven across the warps) are looped. Twining was used for all manner of baskets, including two styles known to have been used by the Ohlone: tule cradles and the walaheen, a U-shaped twined winnower (Bibby, 2004). Twining involved the use of vertical warps around which the wefts were woven and sometimes crossed with one another (Jordan and Shennan, 2003). It is believed that the particular twining styles used by the Ohlone were adopted at least in part from the Esselen (Shanks, 2006). This is an oversimplification of these techniques; further discussion would be best suited to a study regarding modern weavers and particular tooth involvement as employed with specific techniques. Shanks (2006) asserts that the Rumsen Ohlone, those inhabiting Monterey and Carmel, used exclusively the twined method; however, the Miwok were known to have used both twining and coiling, and the Muwekma Ohlone at ALA-329 were geographically adjacent to the Miwok but over eighty miles from the Rumsen.

A technique used to prepare plant fibers for basketry is described in Barrett and Gifford (1933:237):

> The splitting was begun at the outer or small end of the twig, the outer end of the twig being bitten in half longitudinally. Then one-half of the split end was held between the teeth, while the fingers carefully guided the splitting for the full length. The unsplit portion was held rather tightly between the right thumb and forefinger. With the left hand the loose half was pulled downward. Simultaneously the right hand was slid downward, so that the splitting took place just above the right thumb and forefinger which guided the course of the splitting, while the left hand furnished the motive power. Thereafter the two halves were similarly split into quarters. The pit was removed from each quarter by biting it free at the small end first. The woody portion was then held in the teeth and the separation of pith and wood continued for the length of the quarter with the fingers.

Unfortunately, the literature regarding the role of the dentition in each of these respective techniques is scarce; this data will have to be derived from studies of modern weavers.

Females as basket weavers. It is heavily emphasized by researchers that basket weaving in California was primarily engaged in by females (Jordan and Shennan, 2003; Cardozo, 2005). It is the female descendents of basket weaving tribes who consciously retain the knowledge of traditional techniques and materials and pass them on to succeeding generations of descendents (Cardozo, 2005). In the current study, microwear in female dentitions will be compared and contrasted to that in male dentitions. If microwear found in female dentitions are significantly different than that in males, and both sexes are different from the control sample, then basket weaving may be considered as a primary factor in ancient dental wear.

Ethnographic Research. Lukacs and Pastor (1988) admonish that it may behoove physical anthropologists to employ ethnographic methods. After conducting a dental microwear study on individuals from prehistoric Pakistan, they stress the following: "Explaining aberrant abrasion patterns is problematic because past behaviors are not always represented among living people. Nevertheless, direct associations between wear patterns and extant occupational or dietary behaviors await carefully controlled ethnographic documentation of tooth use and microscopic study of resulting abrasions" (397). Similarly, Molnar exhorts: "Thorough, carefully documented studies on tooth usage and diet in living peoples need to be done if a basis is to be provided for the interpretation of man's skeletal record" and laments that "little has been done with ethnographic investigations of primitive technologies" (1971a:188).

Larsen's (1985) correlation between the grooves observed on a modern basketweaver and those observed on his archaeological samples is an example of the visual correlation that the author intends to apply in the present study: the recording of techniques used by modern basketweavers and their correlation with specific microwear features. Another such study, conducted by Brown and Molnar (1990), refers to a film taken of an aboriginal Australian cordage artisan processing kangaroo sinew in the manufacture of a spear-thrower. The motions observed accounted for the interproximal grooving of the posterior dentition. It was observed that the sinew was drawn between the teeth from one side to the other repeatedly, with removal and replacement of the sinew before each pass, as opposed to back-and-forth without interspersed removal of the sinew. Study of such techniques and of corresponding microwear in living participants can provide a database of patterns that can be used to assess specific techniques used by ancient populations.

Data Analysis Methods

Dental microwear data consists of several measurements and components that have the potential to be greatly misleading if their relationships to one another are not thoughtfully connected and clearly presented. Gordon (1984) emphasizes that a metric comparison of dental wear between species is inadequate without consideration of the quality of features. The same can be said of the intraspecies study presented here, since the goal is to distinguish between dietary and cultural wear. Once the data are collected, equal care must be taken in counting features and measuring them, as well as in measuring the macrowear feature to which they are related. Once quantification brings relationships of microwear features into focus, then the other factors that bear on microwear, such as materials processed, prism orientation, and location on the tooth, can be considered.

A new method of microwear measurement has, at the time of this study, been published by Ungar (2009). Ungar stresses that, with the high turnover rate of microwear, the two-dimensional method of SEM imaging can cause the observer to conflate overlapping features, resulting in error. Ungar therefore employs three-dimensional texture analysis using a scanning confocal profiler and fractal analysis software to more finely discern new features from old features as well as surface roughness versus smoothness. This technique will not be taken advantage of in this study due to time and resource constraints; however, it has great value and promise for future studies.

Quantifying Microwear Data. If particle size and material type were all that influenced dental microwear, then qualification studies would suffice. However, in consideration of the myriad processes that affect a microwear landscape such as chewing mechanics, facet location, and obliteration, the data must be carefully quantified.

Dental micrographs are typically taken of sections of the tooth measuring anywhere from 100 μm to 1000 μm in width and length, with variations depending upon the researcher's needs (Fox et al., 1992; Teaford, 1994; Ungar, 1999; Minozzi et al., 2003). Within this space, features are counted according to type, and the width, length, density (frequency of occurrence), and sometimes depth of each feature measured (Fox et al., 1992; Teaford, 1994; Ungar, 1999; Minozzi et al., 2003). In Minozzi's and colleageus' study, grooves on the occlusal surfaces were suspected to have been produced by the use of the dentition as a third hand. Experimental grooves were created on a medieval tooth with plant fibers and the resultant microwear was consistent with that found on the Libyan teeth. It was concluded that 1) tooth-as-tool use can be deciphered through microwear studies, and that 2) tooth-as-tool use produces certain microwear features that can correspond directly with macrowear features. These conclusions were drawn through precise quantification methods. Grooves were measured with digital calipers to an accuracy of 0.01 mm, and microwear feature dimensions were measured by feeding the image into Microware 3.0. As the study was conducted on a single dentition, it was practical to present microwear measurements in a single table with directions and patterns written out according to tooth. In the current study, it will be necessary to quantify higher volumes of microwear on several dentitions and craft visual representations in the form of plots and graphs so that comparisons can be easily expressed and accessed by the researcher and the reader alike.

Studies by Ungar (1999) and Teaford (1994), where larger samples were analyzed, present dental microwear measurements through clear and cohesive box-and-whisker plots. These allow microwear features of different samples can be visually compared side-by-side. Microwear data fit nicely into these types of visual representation and lend themselves to meaningful comparison. Also beneficial in processing information from several individuals is the microwear index. Ungar (1999) utilized a microwear index that expressed the relationship between length and width (length/width $\times$ 100), which can be used to more cohesively present data in visual forms and to “clean up” data.

Teaford (1994) notes that methodological standardization has been problematic in dental microwear analysis. He offers a strategy in which specific tooth facets are observed to keep the information consistent from sample to sample. Measurement methods described above, particularly the microwear index, can serve to keep information consistent at least among several samples in a single study. Microwear features can be largely observed objectively because it is a matter of measuring and counting. Subjectivity confounds matters when it comes to determining which facets will provide the most amount of significant information in a small space. Also subjective are measurement boundaries: when does a dietary scratch end and a nonalimentary scratch begin, and vice-versa? At the same time, quantification cannot stand alone. Gordon

(1984) notes that frugivore hominoids and grazer hominoids display similar quantities and densities of microwear features, but the features themselves are qualitatively different; thus, to place the weight of analysis on quantification would egregiously skew results. The solution must involve more observation regarding combinations of patterns and how they are linked to specific materials. Recognizing recurring patterns in the quantification of features and relating those quantities to space and individual featuers characteristics will lead to more accurate analysis.

Statistics can serve to stabilize data and compare microwear features in a mathematical framework. They alert the researcher as to significant differences in length, width, and index between groups. Ungar (1999) used MANOVA and ANOVA tests to determine differences between groups. He found that a gradient existed from those groups who consumed and processed primarily plant materials (who possessed higher densities of smaller features) to those who consumed and processed primarily animal materials (who possessed more features on the incisors). These statistical tests are extremely important in deciphering relationships between shape, size, and frequencies of microwear features.

Summary of Previous Research

Dental microwear studies are proliferating in physical anthropology, with beginnings in animal studies. Researchers have found that particular activities leave unique impressions on tooth enamel and dentin at a microscopic level. Dietary and non-dietary attrition and abrasion result in microfeatures that are typically classified as either pits or scratches, while chemical erosion serves to obscure the surface of the tooth with a homogenizing effect. Pits and scratches vary in orientation and dimension depending upon the material and technique with which they were applied. Abrasive materials such as endogenous and exogenous grit as well as natural phytoliths in plant materials are the most commonly cited causes of tooth wear. Nutritional wear is commonly characterized by random patterning of scratches, while a high incidence of pitting is attributed to a gritty diet. Nonalimentary wear is often characterized by parallel scratches and wider scratch width relative to those lain in a crosshatched pattern of presumed nutritional wear. Factors such as enamel prism orientation, the relative hardness of materials processed, and the occlusal facet being observed are often cited to have an effect on the parameters of microwear features.

The population concerned in the present study are the prehistoric Ohlone, who occupied much of the San Francisco Bay Area for approximately 7000 years. A diet heavy in marine sources and cooking techniques involving high levels of endogenous and exogenous grit has been most commonly cited as the cause of particularly extreme dental wear observed in the Ohlone. However, the Ohlone, both males and females, are also documented to have participated intensively in cordage and weaving, with a particularly sophisticated basket weaving tradition being attributed to females. As cultural tooth use has been found through past dental microwear studies to contribute to extreme wear, it is possible that cultural wear has contributed also to the wear seen in the Ohlone.

Dental microwear has most often been studied via the technique of dental casting and the observation of these casts under SEM. Previous research shows that this technique requires careful quantitative and qualitative assessment of the data, as analysis benefits from consideration of visual and statistical information in tandem.

2. MATERIALS AND METHODS

Individuals from ALA-329 were randomly selected until a sample comprised of comparable number of males (n = 11) and females (n = 8) was chosen so that the effect of sex on microwear could be assessed, making a total sample number of nineteen individuals. The control group was chosen from individuals who exhibited little or no dental wear on the Molnar (1971a) and Grant (2010) scales. Sex, age-at-death, and pathology were collected from the original burial records, with sex and age being confirmed by the author using methods developed since the original analysis.

Impressions were taken of the occlusal surfaces of all molars and premolars exhibiting macrowear features and extreme wear according to Grant (2010) and Molnar (1971a), as well as molars and premolars deemed suitable to serve in the control group. Teeth were swabbed with alcohol and then distilled water and allowed to dry before taking molds so that any remaining matrix and dust did not compromise the impression. The negative molds were obtained by pressing teeth into polyvinylsiloxane molding material, allowing the material to dry, and then carefully peeling the material from the tooth. Clear epoxy, moderately slow-drying in order to pick up miniscule detail, was poured into the molds then extracted when dry. Casts were sputter-coated with gold palladium to promote conductivity, maximizing visibility under scanning electron microscopy. The surfaces of the casts were viewed under a scanning electron microscope, resulting in digital frames of sections of microwear. These collection methods have been proven effective in previous microwear studies as described above and are those which are most accessible within the scope of this study.

Taphonomy did not present an issue in data collection, as the collection is in an excellent state of preservation. Photographs were taken of each dentition from ligual, labial, superior (mandible) and inferior (maxillae) aspects, with care taken to document any apparent relationships between tooth positions, i.e. possible working platforms. The method of this study is structured to facilitate the comparison of highly worn, individual teeth to unworn or lightly worn individual teeth. Teeth were taken from three central Californian prehistoric sites with the experimental sample taken exclusively from ALA-329 due to its excellent level of preservation and presence of several complete dentitions. Four individuals from ALA-329 possessed teeth with enough enamel intact to contribute to the control sample. Two individuals from the remaining two sites were used exclusively in the control sample. This data set will be used to assess the relationship of microwear in these individual teeth to the macrowear features in which they are found. In order to effectively compare dentitions, it was necessary to produce replicas from the archaeological samples in a uniform manner so that the tooth surfaces may be manipulated and viewed from several angles and yield information of a consistent quality. Once this uniformity in data collection was ensured, then the images collected from the tooth surfaces could be confidently qualified and quantified. Parametric and nonparametric statistics were employed in accordance with each specific research question.

CA-ALA-329, The Ryan Mound Site

ALA-329, commonly called the Ryan Mound after the owner of the first historic residence on the site (Coberly, 1973), was excavated in several increments from 1949 into the mid-1960s by archaeology classes from UC Berkeley, Stanford University, and San Jose State University (SJSU) (Moratto, 1984). During the 1925 attempt at construction of a reservoir on the mound, graves and artifacts were exposed and subsequently compromised through looting (Coberly, 1973). One hundred thirty-nine individuals were housed at Stanford University until they were reinterred in 1992; the remaining individuals are currently housed at SJSU and represent one of the largest curated collections from a western United States site (Jurmain et al., 2009).

Occupation Theories. Two primary occupation theories have been assigned to ALA-329. Nels Nelson's original interpretation was that the site represented a typical shellmound (Nelson, 1909). Leventhal (1993) describes the site as an earthen mound that served several surrounding villages as a burial complex. This is in contrast to typical Ohlone earthen mounds, which are usually interpreted to be sedentary habitation sites (Jurmain, 1990). Jurmain and Bellifemine (1997:44) label it an "earth/shellmound site"; however, Jurmain and colleagues (2009:463) later describe it as a "conspicuous earthen mound" with some shell distributed throughout, but not as densely as that of a true shellmound. Coberly (1973) notes that approximately two feet of midden was present underneath the deepest burials, being possibly indicative of occupation prior to the site's existence as a cemetery. There is enough of a consensus among these studies to conclude that for the majority of its occupation, the site was primarily a burial complex.

Located in the Coyote Hills of Fremont, California, it is flanked by several Ohlone shellmound and non-shellmound sites collectively known as the Fremont Plains sites (Figure 2.1). It is suggested that the site was much closer to the bay shore during occupation, allowing its inhabitants instant access to the varied resource base available to central Californian populations (Jurmain, 1990; Leventhal, 1993).

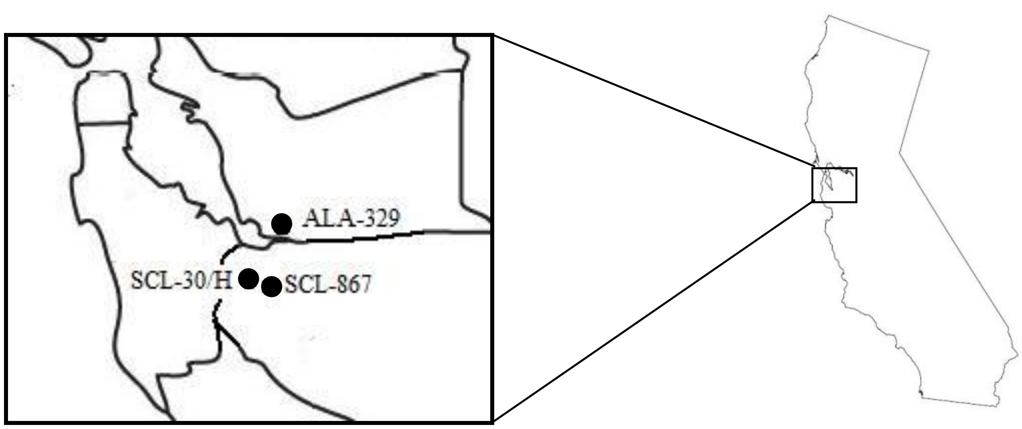


Figure 2.1. Location of ALA-329, SCL-30/H, and SCL-867, San Francisco Bay Area, California.

Four hundred and forty burials were recovered during excavation, comprising one of the best-preserved skeletal assemblages in the western United States (Jurmain, 1990;

Jurmain and Bellifemine, 1997; Weiss, 2007). Luby and Gruber (1999) state that most of the California shellmounds were formed during the Middle Period. The remains at ALA-329 were given dates ranging from 2,180–250 BP (Weiss, 2007). Leventhal (1993) obtained calibrated carbon dates from two burials of 1165 BP and 1142 BP.

Sex, Age, and Pathology. Estimation of sex, age, and pathology of the experimental and control groups are relevant as all three factors bear on the development of human tooth wear. Several methods to ascertain sex, age, and pathology were employed by the original investigators and others were added to the analysis in the author's examination of the collection. A summary of sex and age for the experimental and control groups can be found in Table 2.1.

Methods for estimating sex and age in skeletal remains are being continuously tested and amended. At the time of the initial osteological analysis of ALA-329, from 1962 to 1969, several methods were not yet developed that have since been tested and endorsed by the anthropological community. In any assessment of sex and age, it is necessary to employ all methods possible with the available elements in order to obtain the most precise estimate, and to weigh the results according to each method's relative reliability (White and Folkens, 2000).

The original analysis of ALA-329 relied upon some markers of sex more heavily than others. Relative robusticity, the width of the sciatic notch, the presence or absence of a preauricular sulcus, and various cranial markers were the primary methods used. Most of

TABLE 2.1. Demographics of experimental and control groups.

Male		Female	
Burial	Age	Burial	Age
ALA-329		*ALA-329*	
5	25-30	*6	25-30
10	35-40	12	40-45
19	35-40	15	35-40
23	30-35	*92	20-25
65	35-40	93	40-45
69	25-30	111	35-40
*70	20-25	*113	20-25
94	20-25	*158	30-35
135	40-45	192	50+
145	20-25	217	40-45
177	40-45	251	25-30
254	40-45	269	35-40
SCL-867			
*1	40-45		
SCL-30/H			
*3	25-30		

* Denotes individual contributing at least one tooth to the control group.

the individuals included in the present study were largely complete and well preserved, so the multifactorial approach was possible in most cases.

Cranial methods of sex assessment may not be appropriate for certain populations (White and Folkens, 2000; Buikstra and Ubelaker, 1994). Much of the study regarding sex assessment has been conducted using industrialized populations and museum collections of individuals of African and European descent such as the Terry and the Hamann-Todd (Loth and Henneberg, 1996; Ali and MacLaughlin, 1991; Giles and Elliot, 1963). It is possible that cranial markers are less reliable indicators of sex in this population. Females from ALA-329 possessed relatively robust supraorbital ridges, gonial angles of the mandible, and zygomatic extensions. These landmarks are all involved in the process of mastication, anchoring muscles and providing structural support as chewing forces act upon the cranium (White and Folkens, 2000; Tortora and Nielsen, 2009). Therefore, the advanced tooth wear found in native Californian populations may be correlated with these recurring cranial characteristics in ALA-329, rendering cranial methods less effective in sex estimation.

The presence or absence of a preauricular sulcus was used often and heavily relied upon in the original analysis of ALA-329. This method is unreliable when used alone because many nulliparous females may exhibit pelvic lesions due to other stresses, while parous females do not always display lesions (Spring et al. 1989). The width of the greater sciatic notch weighed heavily in the original sex assessment. This feature has been proven to vary by population and to be influenced by age-at-death in adults, but in a study by Walker (2005) yielded an 80% accuracy rate. Upon reassessment of sex in ALA-329, the author employed the Phenice method (Phenice, 1969) in addition to the above techniques, often described as the least subjective, most straightforward method of sex determination using the pelvis (White and Folkens, 2000). It of course is subject to idiosyncratic variation, but its employment along with the methods originally used in ALA-329 served to obtain the most precise sex estimates possible.

Age-at-death assessment was accomplished in the original analysis of ALA-329 using the techniques of epiphyseal fusion, suture closure, tooth eruption, and tooth wear. Tooth wear in aboriginal populations can to some degree indicate age, particularly when considering the first and third molars, respectively the first and last molars to erupt. Wear tends to appear first on first molars and is least extreme in the third molars in relatively young individuals for this reason, and the progression of wear as patterns continue along contiguous occlusal surfaces can be indicative of age (Phebus, Jr. 1973; Molnar, 1971b; Smith, 1984; Deter, 2009). When used with other age assessment techniques and considered as an intrapopulation continuum, tooth wear can be a useful indicator. Original age estimates were confirmed by the author using these same methods.

The following demographics were collected from the original site records and sex and age were reassessed and confirmed by the author as described above. The human skeletal remains from ALA-329 total 346 individuals representing both sexes and ranging in age from *in utero* to old adulthood. The remains range in degree of completion from the presence of only a single element to a nearly complete condition including the retention of the hyoid. Of the individuals for whom enough elements were present to assess sex, 47% (*n* = 89) are female and 53% (*n* = 99) are male. These individuals represent 54% of the total. Ascertaining the sex of the remaining individuals (*n* = 158) was not possible due to a young age-at-death or poor preservation. One individual was determined to have died *in utero* due to association with an adult female. The following age categories were taken from Buikstra and Ubelaker (1994) and assigned to the individuals of ALA-329 by the author. Percentages are of the total collection. Twenty per cent (*n* = 69) are in the category of infant; 6% (*n* = 20), child; 10% (*n* = 35), adolescent; 18% (*n* = 62), young adult; 27.5% (*n* = 95), middle adult; 0.5% (*n* = 2), old adult; and 18% (*n* = 62) were of indeterminate age.

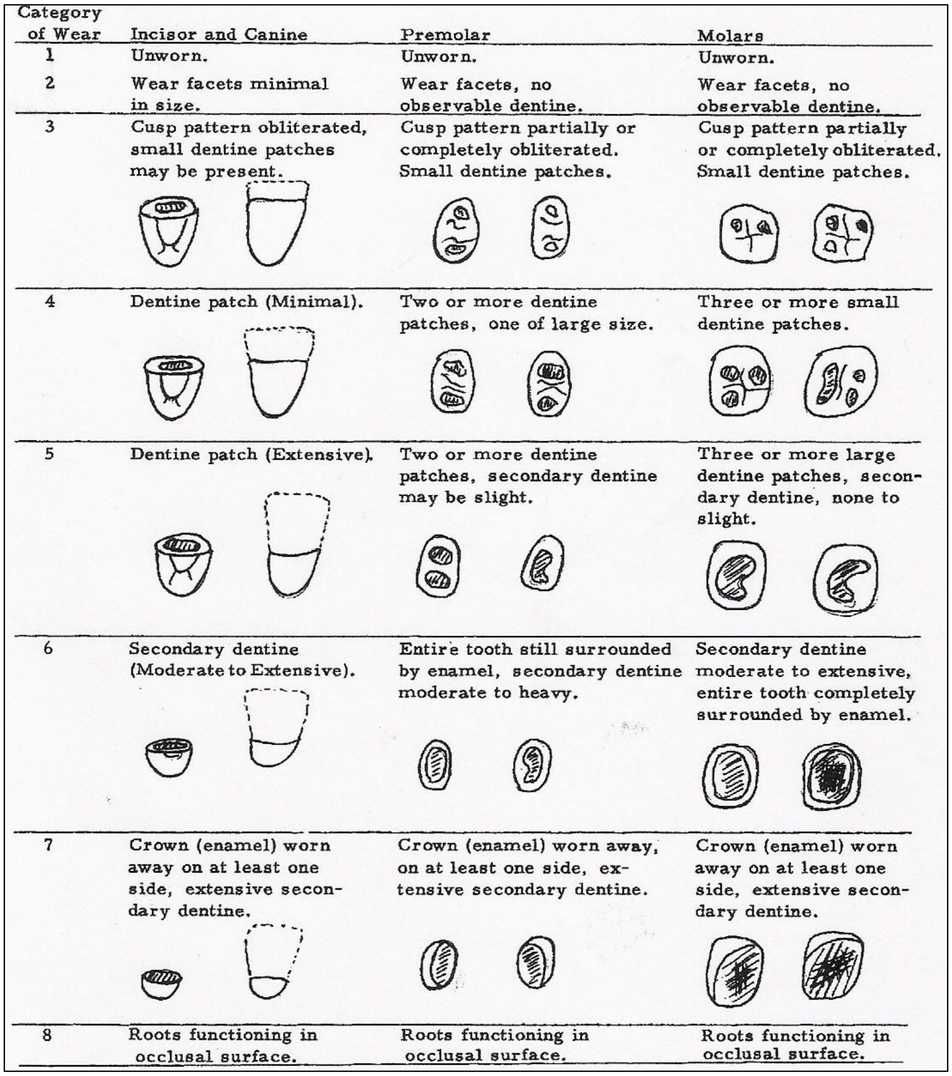
The pathology of pre-contact native Californians is comparable to that of other hunter-gatherer, semi-sedentary populations (Walker and Thornton, 2002). Infection, specific (e.g. staphylococcus, tuberculosis) and nonspecific was common in pre-contact California. Cranial trauma occurred with far less prevalence than in other Native American populations, the least being in central California (Walker and Thornton, 2002). A diet of marine resources and a variety of plant foods and game resulted in better overall health than Native American populations exploiting primarily maize (Walker and Thornton, 2002). However, some pathological conditions found in native Californians have been attributed to diet. Walker (1986) attributed cases of porotic hyperostosis in a Channel Island population to contaminated water sources and periodic marine resource scarcity. Bridges (1992) attributed cases of osteoarthritis in the hand, wrist, and elbow in California hunter-gatherers to the demands of frequent seed grinding. Growth disruptions appeared with comparatively greater frequency during the Middle Period, a phenomenon that Walker and Thornton (2002) suggest may have come of a period of resource scarcity, which in turn may have served as the catalyst for heavier acorn exploitation. It is possible that this transition to acorn dependence may have spurned a more intense basket industry, as baskets were the main acorn processing tools – a series of events that may have played a role in more intense tooth wear.

Skeletal pathology in ALA-329 was not reassessed in depth by the author but is here summarized from the original burial records. In the ALA-329 individuals, degenerative joint disease is the most prevalent with 5% (*n* = 18) of the individuals inflicted, followed by fractures and dislocations. Skeletal evidence of nonspecific infections (i.e. osteomyelitis and periostitis) was noted in 1.7% (*n* = 6) of the collection. Cleft sacra were recorded in three individuals, one with an accompanying lumbarized first sacral vertebra. Two separate individuals also displayed sacral shifts. Osteoporosis, metabolic disturbances, congenital deformities, and puncture trauma collectively accounted for 2% (*n* = 7) of the pathologies in ALA-329. These cases are in keeping with the pathological profile of native Californians, with perhaps even less prevalence than is typical.

Dental Pathology. The skeletal remains of the individuals from ALA-329 were excellently preserved. Several individuals display full or nearly full dentitions. The dentitions display consistency with many prehistoric Californian populations in terms of an overall high rate of dental pathology. Jurmain (1990:335) observes that "the most common dental pathology is severe attrition, manifested throughout the dental row. Such involvement is pervasive in this population, affecting all individuals with teeth in occlusion for 2 years or more." Rates of wear are significantly higher than average, with rates of “severe” wear as high as 72.4% for the lower first molar (Jurmain, 1990). Heavy wear was observed even in the deciduous teeth of subadults (O’Connor et al., 2005). It was found in a study of ALA-330 that younger individuals exhibiting the beginnings of molar wear showed wear occurring first on M1 in all quadrants (Phebus, Jr., 1973). This phenomenon was repeatedly observed by the author in ALA-329. Extreme tooth wear at a young adult age was also observed in the nearby sites ALA-330 and SMA-22. Researchers have suggested an etiology of leather processing at both sites, noting extreme wear in the molars in particular (Phebus, Jr., 1973).

It is important to examine the concept of degree of wear applied by Jurmain in the ALA-329 study. Jurmain adhered to Molnar’s (1971a) standards of measuring gross attrition as outlined in a study of cultural dental wear. Molnar (1971a:176) created his wear scale under the assumption that “a meaningful correlation can be made between human dental attrition patterns and the way in which the teeth were used during the individual's life”. Molnar employs dentin exposure as the chief indicator of degree of wear, the continuum spanning from a lack of wear to root exposure with various levels of primary and secondary dentin exposure in between (Figure 2.2).

The prevailing dental pathological conditions noted in the ALA-329 individuals are those commonly caused by exposure to pathogens facilitated by moderate and severe wear, most notably abscess (Jurmain, 1990). Dental caries, a condition seen to accelerate in correlation with the appearance and dependence upon processed carbohydrates, occurs



Category of Wear	Incisor and Canine	Premolar	Molars
1	Unworn.	Unworn.	Unworn.
2	Wear facets minimal in size.	Wear facets, no observable dentine.	Wear facets, no observable dentine.
3	Cusp pattern obliterated, small dentine patches may be present.	Cusp pattern partially or completely obliterated. Small dentine patches.	Cusp pattern partially or completely obliterated. Small dentine patches.
4	Dentine patch (Minimal).	Two or more dentine patches, one of large size.	Three or more small dentine patches.
5	Dentine patch (Extensive).	Two or more dentine patches, secondary dentine may be slight.	Three or more large dentine patches, secondary dentine, none to slight.
6	Secondary dentine (Moderate to Extensive).	Entire tooth still surrounded by enamel, secondary dentine moderate to heavy.	Secondary dentine moderate to extensive, entire tooth completely surrounded by enamel.
7	Crown (enamel) worn away on at least one side, extensive secondary dentine.	Crown (enamel) worn away, on at least one side, extensive secondary dentine.	Crown (enamel) worn away on at least one side, extensive secondary dentine.
8	Roots functioning in occlusal surface.	Roots functioning in occlusal surface.	Roots functioning in occlusal surface.

Figure 2.2. Molnar's (1971a) tooth wear continuum, applied by Jurmain (1990) to ALA-329 and used in the current study to distinguish control and experimental individuals.

in low frequency at ALA-329 even when compared to that in other preagricultural Californian societies (Jurmain, 1990). Jurmain (1990) reminds us that dental caries is a disease that is characterized by defects in the enamel and suggests that the low rate of caries in ALA-329 individuals can be attributed to their lack of enamel. This is a testament to an unusually progressive degree of dental wear at ALA-329. Alveolar resorption indicative of antemortem tooth loss was observed by the author among individuals as young as 25 years of age at death (a phenomenon also noted by Jurmain), as were abscesses along the molar row in older individuals. Very few individuals displayed carious lesions, likely due to Jurmain's enamel loss theory. Those lesions which were present were found on third molars, the molar which most often displayed the lowest wear score and therefore the most enamel according to Molnar's system, and were shallow with diameters of 1 mm or less. Dentin and pulp exposure render the individual more susceptible to infection (Lukacs, 1996).

Selection of Teeth

For each individual, partial tray casts were taken of teeth which exhibited particular macrowear patterns according to the Grant and Molnar wear scales. This process was limited to molars and premolars as these teeth displayed the most extreme macrowear patterns. Data points are teeth rather than individuals, a method addressing the specific research question: Does the extreme dental wear found in ancient central Californian populations exhibit microwear patterns particular to cultural processing of materials? The author acknowledges that the type of statistical tests traditionally applied in similar studies work upon the assumption of independent samples. However, it is hypothesized that, if nonalimentary activity can account for the microwear patterns found here, different teeth were likely used for different types, angles, and frequencies of cultural manipulation of materials.

Control Group. Teeth were chosen for the control group if they exhibited both of two conditions: 1) wear on the Molnar scale of a score of 3 or less; and 2) no score on the Grant scale, indicating an absence of the extreme macrowear and therefore microwear with which this study is concerned. Very few individuals among the three sites studied here possessed teeth free of either of these conditions. Two individuals from whom control groups were taken from the San Francisco Bay Area sites SCL-867 and SCL-30/H, with the remaining control individuals taken from ALA-329.

CA-SCL-867. Known as the Coolidge Avenue site, the human remains recovered consist of a single male individual. As in ALA-329, this territory was occupied by the Ohlone. The site was given a calibrated midpoint date of AD 754 (1256 BP).

CA-SCL-30/H. The following brief overview of this site is summarized from Skowronek and Wizorek (1997). Also known as the Murguía Mission site, SCL-30/H is the third location of the Mission Santa Clara. The church experienced five incarnations (four reconstructions), with the remains used in this study associated with the neophyte cemetery of the third church, or the Murguia Mission. This incarnation of the mission was completed in 1781. The neophytes were at first exclusively Ohlone, but this was to expand to include Miwoks and Yokuts in future incarnations.

Macrowear Features in ALA-329. Macrowear was observed in the ALA-329 sample according to a system devised by Grant (2010). Grant's system was structured in response to the dental wear found in prehistoric individuals from the San Francisco Bay Area and for this reason was used in this study as a guide to collecting microwear data. All molars and premolars in the experimental group exhibited some degree of patterning according to Grant's system.

Grant classifies macrowear under four categories: slanting, scooping, rounding, and grooving. In the randomly chosen individuals used in this study, if a tooth did not exhibit a Grant feature, enough of the occlusal enamel remained to use it in the control group. The control teeth exhibit flat wear, a condition that is the typical macrowear pattern in many studies of nutritional wear (Kieser, 2001). An example of flat wear can be found in Figure 2.3. Under each of these categories, teeth can be given a score of 1 through 4, with 1 being the minimum expression and 4 being extreme expression. The method of this study requires that teeth in the experimental group exhibit some degree of wear, so the score of zero, or of no expression, was not used in the experimental group and is implied in the control group.

Figure 2.3. An example of flat wear from SCL-30/H.

Slanting. Slanting is defined by Grant as an angular wearing away of the mandibular molar on the buccal side and the maxillary molar on the lingual side. Grant states that this pattern can be attributed to typical masticatory activity, implying nutritional tooth use. This implication will be explored through examination of microwear. The significance of studying slanting patterns in ALA-329 lies in the extremity of wear. An example from ALA-329 is shown in Figure 2.4.

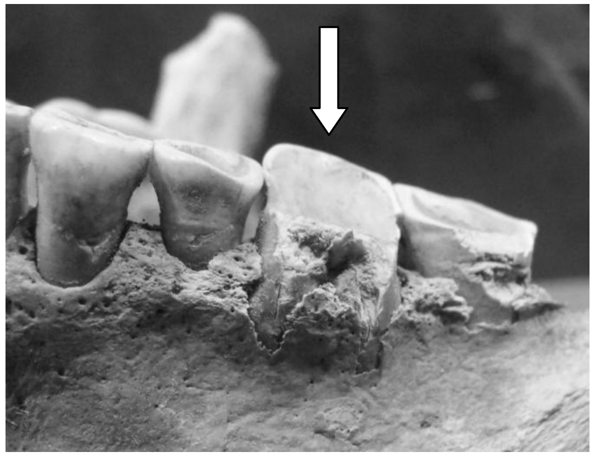


Figure 2.4. An example of an extreme expression of the slant feature from ALA-329, Burial 69 (LLM1).

Scooping. The scooping pattern is described by Grant as a trough on the occlusal surface of the tooth with enamel rims left only on the buccal and lingual sides, creating a mesiodistally oriented valley-like feature in the tooth. An example from ALA-329 is shown in Figure 2.5. Grant notes that this feature occurs in ancient Californian populations most commonly on the mandibular molars.

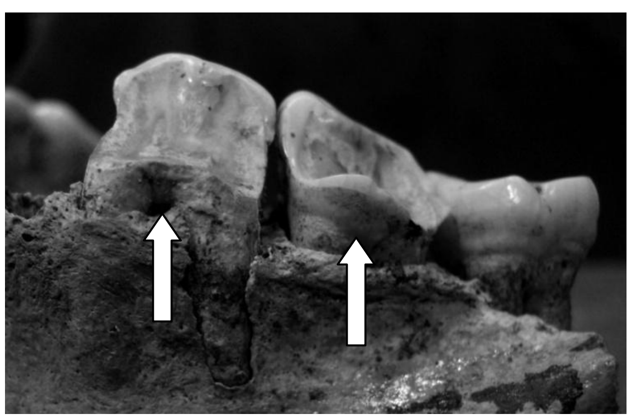


Fig. 2.5. An example of extreme expression of the scooping feature from ALA-329, Burial 94.

Grooving. Grooves are characterized by Grant as narrow, linear depressions most often seen on the interproximal or occlusal surface of the tooth. Occlusal grooves noted in ancient Californian populations should be distinguished from interproximal grooving commonly found in other regions, but their etiologies may originate in similar processes. An example of this feature from ALA-329 is shown in Figure 2.6.

Figure 2.6. An example of extreme expression of the groove feature from ALA-329, Burial 254 (LLM2).

Rounding. Rounding wear is a dulling of the enamel rim on any number of sides of the tooth and can occur on any tooth in the arcade. The result is a smooth edge on the occlusal rim that produces the appearance of polish. Grant (2010:213) notes that extreme cases will give the tooth a “dome” appearance. Examples of the rounding feature are shown in Figure 2.7.

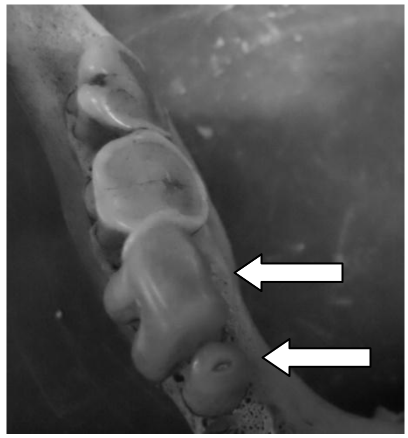


Figure 2.7. Extreme expressions of molar rounding in ALA-329 (Burial 93, LRM1 and LRP4).

Dental Molding and Casting

Materials for molding and casting were chosen for their compatibility with and resolution under SEM. The molding materials and techniques are non-destructive and leave no trace on the bone.

Molding Materials and Techniques. Teeth were first wiped with a swab saturated with 90% rubbing alcohol and again with a swab saturated with distilled water, then allowed to air-dry completely. Coltène® President Jet Plus regular body polyvinylsiloxane was chosen due to the success of polyvinylsiloxane epoxy in prior studies (Semprebon et al., 2004; Hogue and Melsheimer, 2008; Estebaranz et al., 2009; Waters-Rist et al., 2010; Ungar and Scott, in press) and its indicated use for single-phase impressions. The material was poured into a shallow plastic vessel and the apparatus placed on a flat surface. When making an impression of a single disarticulated tooth, the tooth was placed directly into the material and allowed to independently stand in place in order to minimize distortion due to shaky hands or other possible sources of movement. When taking the negative of teeth still articulated to the mandible or maxilla, the molding material was directly applied to the occlusal surface then looped around the crown in order to create a lip. The method used with disarticulated teeth was not possible with intact elements because, as the human skeleton is not often symmetrical enough to conform to flat surfaces, one side of the cranium would typically tilt, lifting the other side off the table, allowing the molding tray and material to slide off the teeth. Trial and error was necessary to judge how much extra material needed to be poured into the tray in order to form a lip around the occlusal impression high enough to contain the casting material. The material was allowed to set for the time recommended by the manufacturer. The molds were then carefully peeled from the teeth, labeled, and bagged to avoid contamination.

Casting Materials and Techniques. Epo-Tek® low-viscosity, clear epoxy was used to create the casts. The two-component epoxy was mixed thoroughly in proportions recommended by the manufacturer then poured into the molds with a medicinal syringe. The casts were allowed to dry at room temperature for a minimum of two days, then released from the molds when set. An effort was made to complete this task with minimal skin contact in order to minimize contamination of the cast surface and also to minimize outgassing from human oils in the scanning electron microscope.

Complications arose in the casting process because the steep wear angle present on most of the teeth resulted in a nearly vertically angled mold. The base of some of the molds needed to be trimmed so that they laid flat enough to contain the casting material. It was discovered at this stage that molds taken of single teeth, particularly of disarticulated teeth, were more amenable to casting, and that full dentitions were the most challenging. This is because, using the partial tray approach, it was not possible to create an ample lip on the mesial and distal ends of the mold of the molar row since the canine interfered. It is suggested that the researcher take full tray molds (which in some cases may be excessive and a waste of molding material) or take a mold of at least the next tooth in the row along with the sample tooth to provide a dam for the casting material.

Scanning Electron Microscopy (SEM)

The basic principle involved in the production of a SEM image is that of deflection. The following is summarized from Goldstein and colleagues (2003). Electron coils or an electron gun scan the surface of an object in successive lines and bounce electrons off of points along those lines so that the various deflections culminate in a faithful image. As magnification increases, a smaller area is scanned and more points are scanned in that area. This technique allows measurements in nanometers and micrometers. This level of microscopy was necessary for a clear view of features and for accurate measurements.

SEM Facility. The instrument used for this study is housed at the California Academy of Sciences in San Francisco, California. The calibration of the instrument is so sensitive as to require it to be stored in the basement of the building in order to avoid surrounding vibrations. The machine model is a LEO/Zeiss 1450 VP SEM. Images produced are viewed on a connected computer and can be manipulated from there using a set of manual controls. The controls consists of a joystick and scrollers which allow tilting and shifting of the specimen along X, Y, and Z axes, allowing the specimen to be viewed from all angles.

Obtaining the SEM Image. Dental casts were mounted onto 0.5 inch (12.7 mm) aluminum SEM specimen stubs using conductive copper tape. The use of a conductive adhesive helps to focus the electron beam in order to obtain a more precise image. The mounted specimens were sputter coated with gold palladium using a Denton Desk II sputter coater. This process also increases conductivity for a clearer image. Micrographs were taken at a magnification of 500X with a working distance of 20 mm. A magnification of 500X was chosen for the best chance of capturing possible cultural features, including the finest features which have been documented from widths just above 1 µm (Fox, 1992).

The entire tooth surface was scanned at a lower magnification than that at which the final micrograph was taken. This magnification varied depending upon what facilitated the best view for each tooth. The purpose of this preliminary scanning was to gather an overall picture of the nature of the microwear on each tooth so that the final micrograph captured an image most representative of the microwear of the entire tooth. In many cases, the occlusal enamel was so extremely worn away that only the underlying dentin was visible throughout most of the preliminary scanning process. In these cases, the dentin (or secondary dentin) texture was insufficient to relay distinct features. In teeth displaying this level of wear, micrographs were taken from the very limits of the macrofeature, that is the junction between the remaining enamel rim and the beginning of dentine exposure. Most microwear researchers in the past have opted to work with a single facet in order to control for intratooth differences (Teaford, 1994). However, the enamel in the posterior dentitions of ALA-329 was extremely worn, and what little remained appeared to have a homogenous character during preliminary scanning. This difficulty arose also in a study by El-Zaatari (2008) of prehistoric native Alaskans, in which the crown was worn away so extremely as to limit data collection to those locations with remaining enamel.

When the final micrograph was captured, care was taken to keep the electron beam at a 90^{o} angle to the specimen. Gordon (1988) and Fox and Frayer (1997) suggest that the electron beam be aimed perpendicularly to the specimen in order to minimize any distortion of features caused by a visual shortening of the surface.

Qualification and Quantification of Microwear Features

Micrographs obtained through SEM were loaded in MicroWare 4.02. Microwear features were identified and counted and the resulting data summarized for each tooth in preparation for statistical analysis. Gross visual assessments were made as to the nature of feature distribution and orientation (i.e. pit frequency as compared to scratch frequency and preferred angle of placement of scratches). Data were entered into SPSS 17.0 for Windows in a manner compatible with analyses between control and experimental groups and males and females.

Qualification of Microwear Features. Microwear features were first analyzed for form. Each feature was determined to be a pit or a scratch. To assess scratch orientation between control and experimental groups, the measurement provided by the computer program MicroWare (discussed below), “Striation Vector Length”, is used. While this variable was quantified and used in statistical tests, it was initially observed in the context of visual pattern and compared between control and experimental groups; for example, upon gross inspection, the author noticed that the control sample individuals showed pits more often than did the experimental individuals and that the rougher dentin layer was exposed more often in the experimental individuals.

Quantification of Microwear Features. Digital micrographs of the dental casts were converted from TIFF to bitmap format and loaded into MicroWare 4.02, a program created by Peter Ungar of the University of Arkansas and designed specifically for dental microwear quantification. The program allows the researcher to semi-automatically delineate features, then provides a measurement in micrometers of length and width and an overall feature count. Statistics are calculated by the program such as mean width and length of the features on each micrograph and the preferred orientation of the majority of features. It is able to distinguish between pits and striations, with the default pit measurement being a 4:1 length-to-width ratio. Figure 2.8 provides a representation of the process of delineating features with MicroWare.

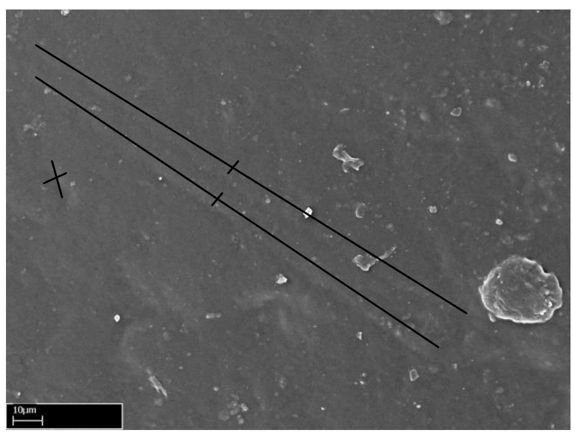


Figure 2.8. Representation of feature delineation using MicroWare 4.02. Striations (center) and pits (far left) are distinguished using a 4:1 length-to-width ratio.

A gross count of microwear features was conducted for each micrograph to obtain a feature density. Features were then counted according to type and the prevalence of each feature expressed in percentages. Quantification of features was a necessary counterpart to visual observation, as the latter method may not register these differences to a meaningful degree.

Statistical Methods

Statistical methods were chosen according to their compatibility with the parametric and non-parametric data sets collected from the SEM micrographs. Methods were chosen for their ability to elucidate a significant difference in the occurrence of particular microwear features and in their orientation in order to demonstrate a non-alimentary origin; or, alternatively, to accept the null hypothesis. Statistics were calculated with data collected from one micrograph per tooth. The statistical analysis for this study was designed to assess the differences between the control and experimental groups and also within the experimental group between age groups and males and females. In the case of correlations, the control and experimental groups were considered as one cohesive group, with each individual designated as experimental or control in illustrative graphs. All statistical analyses were run using the program SPSS 17.0 for Windows.

Correlations. Pearson and partial correlations are used in this study to detect linear relationships between variables. A Pearson correlation works to detect either a positive correlation, in which the value of one data point of a certain variable rises along with a corresponding data point in another variable, or a negative correlation, in which the value of one data point decreases as the other increases. Correlations do not mean causal relationships, only illustrations of a change in one variable as compared to a change in the other (Hinton, 2004). Partial correlations seek linear relationships while controlling for a possible confounding variable. In this study, correlations are used in order to establish a starting point for future finer analyses; in order to discover a cause, a relationship must be detected in the first place.

Independent T-Tests. Several two-tailed independent t-tests were run in lieu of a multivariate analysis of variance (MANOVA) s as the MANOVA is most robust when variables consistently display moderate correlations (Meyers et al. 2006). In only five out of fifteen possible correlations, which will be described in the Results chapter below, did two variables display a moderate correlation according to Cohen's (1988) standards. Independent t-tests are intended to detect differences between two groups, and to discern if these differences are large enough to assign the two groups to two different populations (Urdan, 2010). This test works under the assumptions that the samples are randomly chosen, that the sampling distribution is normally distributed, and that the samples are from populations of equal variance (Hinton, 2004).

Independent t-tests can be one- or two-tailed. A one-tailed test predicts that the test sample is higher or lower than the normal distribution of the population, while a two-tailed test leaves room for results to be discovered in either of these extremes. However, in a two-tailed test, the chosen alpha level must be divided by two. As a result, any part of the sample falling, for example, within the bottom 2.5% of a 0.05 alpha level will not be detected. This is to avoid a Type I error (finding a difference where there is truly none) or a Type II error (missing a true difference) (Hinton, 2004; Urdan, 2010). Two-tailed tests were chosen to allow for detection of unexpected results, as microwear studies in individuals with wear as severe as that found in ALA-329 are few. Also, this study is intended to forge a beginning to a genre of similar studies, so it is expected that future studies with larger samples may be designed more specifically to test for certain results. The alpha level for all tests was set at $p \leq 0.01$ in order to minimize the risk of Type I error (this was done in the interest of compensating for multipile *t*-tests). There is a risk of Type II error due to the small sample size. All variables are normally distributed and homoscedastic except for mean scratch width, in which case the SPSS-generated significance value for a violation of equal variances was used.

Analyses Between Control and Experimental Groups. Concerning comparison between the control and experimental groups, the following specific questions were addressed: 1) Does a statistically significant difference exist in the preferred orientation of scratches between groups? 2) Does a statistically significant difference exist in pit percentages between groups? 3) Does a statistically significant difference exist in scratch width between groups? These results will be applied to the broader questions: 1) What general material type were the individuals in ALA-329 processing with their teeth, and how did they process it? 2) Can the macrowear patterns found in ALA-329 be attributed to nonalimentary processing, and is this information relevant to other ancient central Californian populations, or other ancient populations with similar dental wear patterns?

Analyses Within Experimental Group. Differences in each of the seven variables were assessed between males and females using two-tailed independent t-tests. Age groups were compared using partial correlation analysis controlling for sex. The author believes that a larger sample size with a wider distribution of more specific age assessments is necessary to obtain meaningful results with other statistical tests. Dental wear is a common and typically reliable method of age assessment, the guidelines of which vary according to population (Lovejoy, 1985; Walker et al., 1991). While it is valuable to dedicate future studies to the relationship of dental microwear to age, as this may prove useful when faced with disarticulated teeth or tooth fragments, a larger sample with a wider age distribution as well as a more controlled selection of tooth position would be necessary. In addition, a more representative sample of each gradation of Grant scores would need to be collected in order to assess the ways in which microwear varies with age and with the creation of Grant macrowear.

By comparing individuals within the experimental group and between sexes, the following specific questions were addressed: 1) Are there statistically significant differences in microwear features between males and females? 2) Does scratch width affect macrowear severity? 3) Using age data, can Teaford's obliteration theory in dental microwear be demonstrated? These analyses will be applied to answering the broader questions: 1) Are males and females both engaging in nonalimentary tooth use? 2) If so, is there a division of labor according to activity (e.g. males rendering fishing nets while women weave baskets, etc.)? 3) What can be learned about the nature of microwear obliteration that can be applied to further study?

3. RESULTS

Results follow for gross observational and statistical analyses of six microwear variables. Variables are first described in detail and followed by a presentation of visual and statistical findings. Results of correlations and independent t-tests are used in support of either the research or the null hypothesis for each research question.

Description of Variables

This section provides detailed descriptions the variables used in this study, as well as justification for their use. mean gross feature tally, mean scratch width, mean pit percentage, mean pit width, mean pit length, and mean orientation homogeneity. Scratch length was not chosen as a variable in analysis because the degree of magnification was such that many scratches continued beyond the perimeter of the micrograph, and the use of scratch length under these conditions would lead to erroneous qualitative and statistical observations. Variables are explored in relation to one another and to age and sex groups. Codes for these variables can be found in Table 3.1.

Mean Gross Feature Tally. Gross feature tally was derived by counting the total number of microwear features in each micrograph used in analysis. This total includes all striations and pits visible at 500X magnification but is not inclusive of larger striations or pits that may have been so large as to include the smaller features but not appear in their entirety in the micrographs. Mean gross feature tally, the variable used in statistical

TABLE 3.1. Description of abbreviations of microwear features.

Abbreviation	Variable
MGFT	Mean gross feature tally
MSW	Mean scratch width
MPP	Mean pit percentage
MPW	Mean pit width
MPL	Mean pit length
MOH	Mean orientation homogeneity

analysis, was derived by taking the mean microwear feature counts for each individual. Therefore, each datum in this variable is the mean microwear feature count for the casted teeth of an individual dentition. Gross feature tally was included in analysis because it has been shown in previous studies to vary according to the type and size of material processed (Mahoney, 2007; El-Zaatari, 2008).

Mean Scratch Width. The width of each scratch in each micrograph used in analysis was taken by delineating the widest point in the scratch using the MicroWare program and obtaining the program's measurement of the widest point in micrometers. The widest point was chosen because materials, depending upon how they are processed, can produce several different sizes of features (Fox and Frayer, 1997); thus, the widest point of a feature is more representative of the nature of the material than a narrower one. Each datum in this variable consists of the mean scratch width found in the casted teeth of a single individual.

Mean Pit Percentage. Pit percentage was taken for each micrograph used in analysis. The equation used to obtain pit percentage is as follows: # of pits/# of total features = pit percentage. This calculation was conducted for each representative micrograph of each casted tooth, and the mean taken for each individual. These individual means are the data points for this variable. This measurement was taken because, as noted above, pits and scratches are created from different processes and materials; thus, pit frequency has the potential to illustrate specific dental activity.

Mean Pit Width. The widest point of each pit in each micrograph used in analysis was delineated and quantified using MicroWare. The mean pit width was then obtained for each individual and each individual mean serves as a datum in analysis. Pit width was chosen as a variable because pit size can represent different materials and different processes.

Mean Pit Length. As a pit is most often defined in dental microwear research as a feature with a length to width ratio larger than 4:1, the axis with the larger micrometer measurement was chosen as pit length, and the remaining axis as pit width. The length of each pit in each micrograph used in analysis was delineated and quantified in micrometers using MicroWare. Mean pit lengths were taken for each individual, and this measurement comprises each data point. Pit length was included as a variable because in the processing of particles or materials, the length may express a property of the material that the width may not, and vice versa.

Mean Orientation Homogeneity. As features are delineated in MicroWare, the program calculates the tendency of the features to lie at a particular angle in relation to a 180^{o} plane and produces a numerical measure of homogeneity. This measurement can range from 0, indicating complete lack of angle dispersion homogeneity, to 1, indicating that every feature runs along the same angle as compared to the 180^{o} plane. This variable is of particular significance because a high homogeneity value (closer to 1 than to 0), that is, a micrograph displaying striations and pit long axes that appear to be basically parallel, have been implicated in cultural activity (Lukacs and Pastor, 1988; Fox, 1992). The variable used in analysis is the mean orientation homogeneity measurement for each individual, taken from the representative micrographs of the casted teeth.

Correlations

Five sets of variables displayed moderate or strong correlations that were significant at least at the $p \leq 0.05$ level. Most variables showed weak and non-significant correlations, suggesting weak linear relationships between most variables (see Table 3.2). In addition, a partial correlation analysis between age groups was conducted for the all variables (with the exception of feature plane index, as control and experimental groups were combined and mean orientation homogeneity is the comparable variable in this case), controlling for sex.

TABLE 3.2 Pearson correlation coefficients and *p* values within combined control and experimental groups.

(*N* = 27)	MPL	MPW	MOH	MPP	MSW
Mean gross feature tally	*r* = -0.524* *p* = 0.031	*r* = -0.558* *p* = 0.020	*r* = -0.405* *p* = 0.036	*r* = -0.107 *p* = 0.596	*r* = -0.132 *p* = 0.513
Mean scratch width	*r* = 0.292 *p* = 0.256	*r* = 0.350 *p* = 0.169	*r* = -0.052 *p* = 0.796	*r* = -0.010 *p* = 0.169	
Mean pit percentage	*r* = -0.115 *p* = 0.660	*r* = -0.175 *p* = 0.503	*r* = -0.093 *p* = 0.644		
Mean orientation homogeneity	*r* = 0.316 *p* = 0.217	*r* = 0.451 *p* = 0.069			

*Denotes significant correlation at the $p \leq 0.05$ level.

Mean Gross Feature Tally and Orientation Homogeneity. Using the measure of striation vector length generated by MicroWare, mean gross feature count and orientation homogeneity among combined control and experimental individuals showed a negative correlation of moderate strength, with $p = 0.036$ and $r = -0.405$ (see Figure 3.1). This correlation is significant at the $p \leq 0.05$ level (two-tailed).

Table 3.3. Partial correlation results for age controlling for sex within combined control and experimental groups.

(*N* = 20)	MGFT	MOH	MSW	MPP	MPW	MPL
Age	*r* = -0.416* *p* = 0.035	*r* = 0.163 *p* = 0.426	*r* = -0.091 *p* = 0.659	*r* = 0.166 *p* = 0.539	*r* = 0.056 *p* = 0.837	*r* = 0.129 *p* = 0.634

*Denotes significant correlation at the $p \leq 0.05$ level.

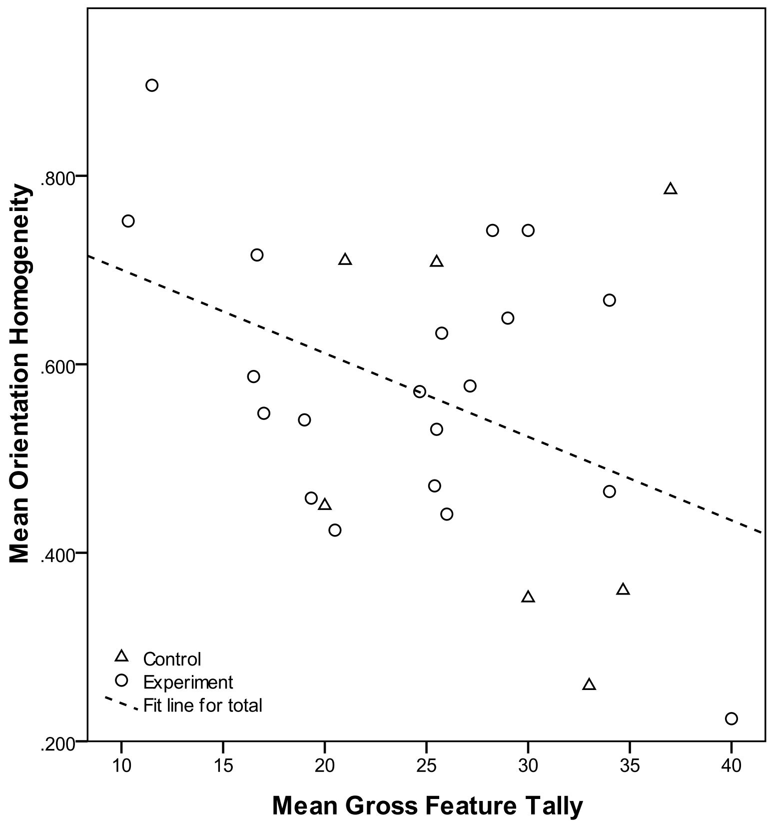


Figure 3.1. Scatterplot showing moderate negative correlation between mean gross feature tally and mean orientation homogeneity.

Partial Correlations. Only one microware variable correlated significantly with age when controlled for possible sex effects (see Table 3.3). Mean gross feature tally showed a negative correlation of moderate strength significant at the $p \leq 0.05$ level (r = -0.416, p = 0.035). As age increases, the mean number of microwear features decreases. Summary statistics by age group can be found in Table 3.4.

Between Control and Experimental Groups

Summary data is listed in Table 3.5, combining males and females of all ages and divided into control and experimental groups. Results of the two-tailed independent t-tests can be found in Table 3.6.

Mean Gross Feature Tally. An independent t-test was conducted to test for statistical significance in mean gross feature tally between the control and experimental groups. No significant difference was found (p = 0.162). Mean value was higher in the control group ($\bar{x}$ = 28.738; in the experimental group, $\bar{x}$ = 24.686). An eta^2 of 0.076 revealed a moderate effect size indicating that 7.6% of the variance in mean gross feature tally between the control and experimental groups can be explained by processes working upon the teeth in the experimental group. Although p was not significant, a moderate effect size suggests that significant differences may be found in a larger sample size with which more power can be given to an alpha level of 0.05.

Mean Orientation Homogeneity. An independent t-test for differences in mean orientation homogeneity between the control and experimental groups revealed no significant differences (p = 0.391). Mean value was higher in the experimental group ($\bar{x}$ = 0.582 as opposed to $\bar{x}$ = 0.518 in the control group) indicating that, on average, teeth in the experimental individuals (i.e. those with Grant features) showed a slightly more homogenous striation orientation. An eta^2 of 0.029 signified a small effect size, with only 2.9% of the differences between the control and experimental samples able to

Table 3.4. Descriptive data for microwear features by age group comparing control and experimental groups.

	MGFT	MSW (μm)	MPL (μm)	MPW (μm)	MPP	MOH
Control						
20-25						
Mean	29.291	1.490	7.175	4.615	2.143	0.576
SD	7.938	0.086	2.015	1.195	3.041	0.203
25-30*						
Mean	30.000	1.530	5.440	3.460	10.000	0.352
SD	-----	-----	-----	-----	-----	-----
35-40*						
Mean	33.000	1.680	-----	-----	0.000	0.259
SD	-----	-----	-----	-----	-----	-----
40-45*						
Mean	21.000	1.380	17.490	10.180	4.350	0.710
SD	-----	-----	-----	-----	-----	-----
Experimental						
20-25						
Mean	31.861	1.637	7.175	4.615	4.285	0.446
SD	7.566	0.271	2.015	3.062	3.061	0.313
25-30						
Mean	24.828	1.973	10.043	6.735	4.903	0.608
SD	5.749	0.324	5.019	3.389	3.815	0.096
30-35						
Mean	22.375	1.697	9.985	6.270	2.240	0.665
SD	8.309	0.493	3.613	2.234	0.225	0.110
35-40						
Mean	22.631	1.721	7.960	5.127	3.830	0.566
SD	8.693	0.244	1.812	1.763	2.815	0.111
40-45						
Mean	25.224	1.610	10.364	5.878	6.222	0.550
SD	3.610	0.296	4.035	2.480	3.262	0.127
50+*						
Mean	11.500	1.780	8.480	6.970	4.550	0.896
SD	-----	-----	-----	-----	-----	-----

*Denotes group consisting of a single individual.

Table 3.5. Descriptive data for control versus experimental groups.

	Control (n = 7)		Experimental (n = 20)	
	Mean	SD	Mean	SD
Mean gross feature tally	28.74	6.71	24.03	7.67
Mean scratch width (µm)	1.51	0.11	1.78	0.30
Mean pit percentage	5.73	3.35	4.38	2.87
Mean orientation homogeneity	0.52	0.21	0.58	0.15
Mean pit width (µm)	5.71	3.10	5.97	2.08
Mean pit length (µm)	9.32	5.63	9.33	2.79

be explained through scratch orientation. Therefore the null hypothesis is accepted: orientation homogeneity does not contribute significantly to dental wear patterns in ALA-329.

Mean Pit Percentage. An independent t-test revealed no significant differences between the control and experimental groups in mean pit percentage (p = 0.438). Mean value was higher in the control group ($\bar{x}$ = 3.274%; $\bar{x}$ = 2.845% in the experimental group), indicating that, on average, the microwear profiles of the control individuals exhibited a higher rate of pits to scratches than did the experimental group. An eta^2 of 0.003 signified a very small effect size. A small effect size and high p value prompts acceptance of the null hypothesis: the occurrence of pits does not significantly contribute to the dental macrowear found in ALA-329.

Mean Pit Length and Width. No significant differences were found in mean pit length between the control and experimental groups (p = 0.993). The experimental mean was slightly higher than the control mean ($\bar{x}$ = 5.942; $\bar{x}$ = 5.326 in the control group). An eta^2 of 5.4^{-6} signified an extremely small and insignificant effect size.

No significant differences were found in mean pit width between the control and experimental groups (*p* = 0.853). The experimental mean was slightly higher than the control mean ($\bar{x}$ = 3.716; $\bar{x}$ = 3.267 in the control group). An eta^2 of 0.002 signified a very small effect size. Effect sizes falling far on the extremely low end of the spectrum coupled with high *p* values is evidence that the null hypotheses are true: pit width and length do not significantly contribute to the high degree of dental macrowear found in ALA-329.

Mean Scratch Width. Significant differences were found in mean scratch width between the control and experimental groups (*p* = .002). A higher mean value was found in the experimental group ($\bar{x}$ = 1.78 μm; $\bar{x}$ = 1.51 μm in the control group). An eta^2 of 0.179 signified a large effect size, indicating that 17.9% of the variance in scratch width between the control and experimental groups can be explained by the processes working upon the experimental group. With a large effect size and significant *p* value, the research hypothesis is accepted: scratch width significantly contributes to the high degree of dental macrowear in ALA-329.

Table 3.6. Independent t-test results for microwear features between control and experimental groups (expressed in terms of means for each sample).

(n = 27)	*t*	df	Sig.	Mean difference	Confidence interval Lower	Upper
Gross feature tally	1.284	25	0.162	4.711	-4.409	13.831
Scratch width	-2.277	25	0.002*	-0.275	-0.604	0.053
Pit percentage	0.349	25	0.438	0.430	-3.636	4.496
Orientation homogeneity	-0.683	25	0.391	-0.064	-0.269	0.141
Pit width	-0.293	15	0.853	-0.250	-4.160	3.660
Pit length	-0.253	15	0.993	-0.018	-5.986	5.951

*Denotes significance at the $p \leq 0.01$ level.

Within Experimental Group

Independent t-tests were conducted to assess differences in the seven variables between males and females. Summary statistics comparing males and females within the experimental group can be found in Table 3.7. T-test results are summarized in Table 3.8.

Mean Gross Feature Tally. No significant difference was detected in an independent t-test of mean gross feature tally between males and females ($p = 0.130$). Males displayed a higher mean value ($\bar{x} = 26.398$; females, $\bar{x} = 22.333$). An eta^2 of 0.123 shows a moderate effect size, indicating that 12.3% of the variance in gross microfeature tally can be explained by sex-influenced processes. Although a substantial effect size exists, no statistically significant difference exists; therefore, the null hypothesis, that sex does not affect the number of microfeatures on each tooth, is accepted. A larger sample size may yield different results.

Table 3.7. Descriptive data for microwear features by sex comparing control and experimental groups.

	MGFT	MSW (μm)	MPL (μm)	MPW (μm)	MPP	MOH
Control						
Male						
Mean	29.333	1.503	11.465	6.820	4.783	0.616
SD	8.021	0.112	8.521	4.752	5.014	0.231
Female						
Mean	28.291	1.510	7.175	4.615	2.142	0.444
SD	6.816	0.122	2.015	1.195	3.041	0.192
Experimental						
Male						
Mean	26.398	1.822	9.895	6.268	1.516	0.509
SD	7.397	0.288	3.124	2.548	1.782	0.123
Female						
Mean	22.333	1.729	8.923	5.500	4.458	0.643
SD	6.855	0.350	2.855	1.822	3.981	0.115

Mean Scratch Width. An independent t-test revealed no significant difference in mean scratch width between males and females (p = 0.535). Males showed a slightly higher mean value ($\bar{x}$ = 1.822; females, $\bar{x}$ = 1.729). An eta^2 of 0.022 signifies a small effect size. With a trivial amount of variance being explained by sex and a non-significant result, the null hypothesis is accepted: sex does not affect scratch width.

Mean Pit Percentage. A significant difference was found in pit occurrence between males and females through an independent t-test at the $p \leq 0.05$ level (p = 0.032), but not at the $p \leq 0.01$ level. Females displayed a higher mean pit occurrence ($\bar{x}$ = 4.458%; males, $\bar{x}$ = 1.516). A large eta^2 of 0.331 signifies that 33.1% of the variance in pit percentage can be explained by sex-influenced processes. While a 99% confidence interval is the more trusted calculation with the small sample size involved in this study, a high effect size, substantial difference in central tendency, and significance at the $p \leq 0.05$ level suggests that a true difference does exist. Therefore, the research hypothesis is accepted: sex does affect pit occurrence in the teeth of ALA-329.

Mean Pit Length and Width. No significant differences were found in mean pit length ($p = 0.528$) or mean pit width ($p = 0.535$). Mean pit length and width were higher in males (respectively $\bar{x} = 9.895$ and $\bar{x} = 6.268$; females, $\bar{x} = 8.923$ and $\bar{x} = 5.500$). Small effect sizes (MPL = 0.037, MPW = 0.019) and non-significant results demand acceptance of the null hypothesis: pit size is not affected by sex-influenced activity.

Mean Orientation Homogeneity. A significant difference was found at the $p \leq 0.05$ level ($p = 0.012$) in mean orientation homogeneity between males and females. Females displayed a higher mean ($\bar{x} = 0.643$; males, $\bar{x} = 0.509$). An eta^2 of 0.025 indicates a small effect size, calling into question the strength of the results considering the small sample size. As results are typically interpreted at the $p \leq 0.01$ level in this study, and the results did not yield a significant result at this level, the null hypothesis is accepted: sex-related processes do not explain differences in mean orientation homogeneity. However, as the p value was extremely close to the $p \leq 0.01$ level, a larger sample size may yield a larger effect size and a more confidently significant result.

Table 3.8. Independent t-test results for microwear features between males and females within experimental group (expressed in terms of means for each sample).

(n = 20)	*t*	df	Sig.	Mean difference	Confidence interval Lower	Confidence interval Upper
Gross feature tally	1.588	18	0.130	5.268	-21.506	25.589
Scratch width (µm)	0.633	18	0.535	0.087	-0.309	0.484
Pit percentage	-2.332	11	0.032*	-2.951	-6.594	0.692
Orientation homogeneity	-0.683	18	0.012*	-0.163	-0.330	0.005
Pit width (µm)	0.466	11	0.650	0.558	-3.159	4.276
Pit length (µm)	0.651	11	0.528	1.035	-3.400	6.000

*Denotes significance at the $p \leq 0.05$ level.

4. DISCUSSION

In dental microwear studies, important data can be gathered through both statistical analysis and qualitative studies. It is therefore necessary to discuss visual observations and assessments, and then introduce the statistical results as they pertain to the qualitative data. The statistical analysis in this study is meant to assist in the discovery of trends in microwear deposition and thereby establish a platform for future studies. The following discussion will seek a thread connecting the various processes at work and compare dental microwear at ALA-329 to that of populations with similar and varying environments and cultural habits with the goal of distinguishing microwear patterns at ALA-329 as cultural or dietary.

Gross observation of the dental macrowear in ALA-329 reveals a severity and patterning that is unusual among prehistoric populations. Microwear patterns in the experimental and control individuals reflect their respective macrowear patterns. The control group exhibits microwear that is consistent with that observed in nutritional wear in past studies, while the experimental group exhibits microwear consistent with nonalimentary use. In particular, microwear in the experimental group is dominated by parallel scratches oriented in line with the macrowear feature in which they lie.

Males and females within the experimental sample exhibit macro- and microwear differences, but overall trends between the sexes are similar. This suggests that both males and females in the experimental sample were engaging in nonalimentary tooth use but with different materials and techniques.

When data from the control and experimental samples were considered together, a possible microwear threshold emerged. In early- to mid-adulthood, microwear patterns suggest a period of transition from primarily nutritional tooth use to more intensive nonalimentary use, possibly representing a period of skill acquisition. In later adulthood, typical nonalimentary microwear dominates, suggesting an intensification of cultural processing.

Macrowear in ALA-329

It is necessary to introduce a picture of the macrowear of ALA-329 for the reader to keep in mind throughout the following discussion of dental microwear. The macrowear present in these individuals is ultimately the composite of the microwear, and the visualization of one assists in the interpretation of the other.

Patterning Along the Dental Arcade. Upon gross inspection, it is immediately evident that adjacent teeth often display non-continuous patterns. Some studies have noted consistency in prehistoric populations with extreme levels of tooth wear; the dentition will follow a neat Monson plane, or the wear will consistently lean either buccally or lingually along the left or right side of the arcade (Butler, 1970; Kieser et al., 2001). In the experimental individuals of ALA-329, this is almost never the case, particularly among older individuals in which the typical wear pattern has had time to develop. A scoop feature leaning buccally will be adjacent to a slant feature oriented mesiodistally, which will be followed by a rounded premolar. A buccally slanting mandibular molar might be opposed by a maxillary molar with a mesiodistal slant, obstructing occlusion. In some cases, it appears as though two teeth may have served as a jointed platform for whatever process was wearing them down, for the wear plane of one tooth will continue in mirror opposition from the one next to it (Figure 4.1).

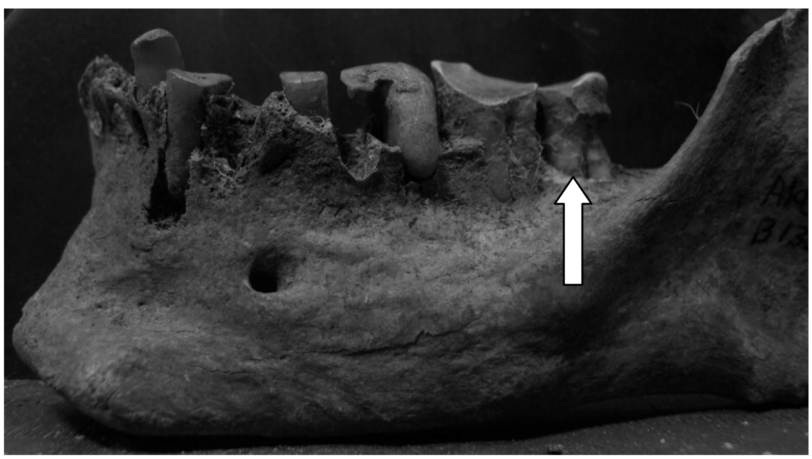


Figure 4.1. An example of a possible working platform in ALA-329 (Burial 135, LLM2, LLM3).

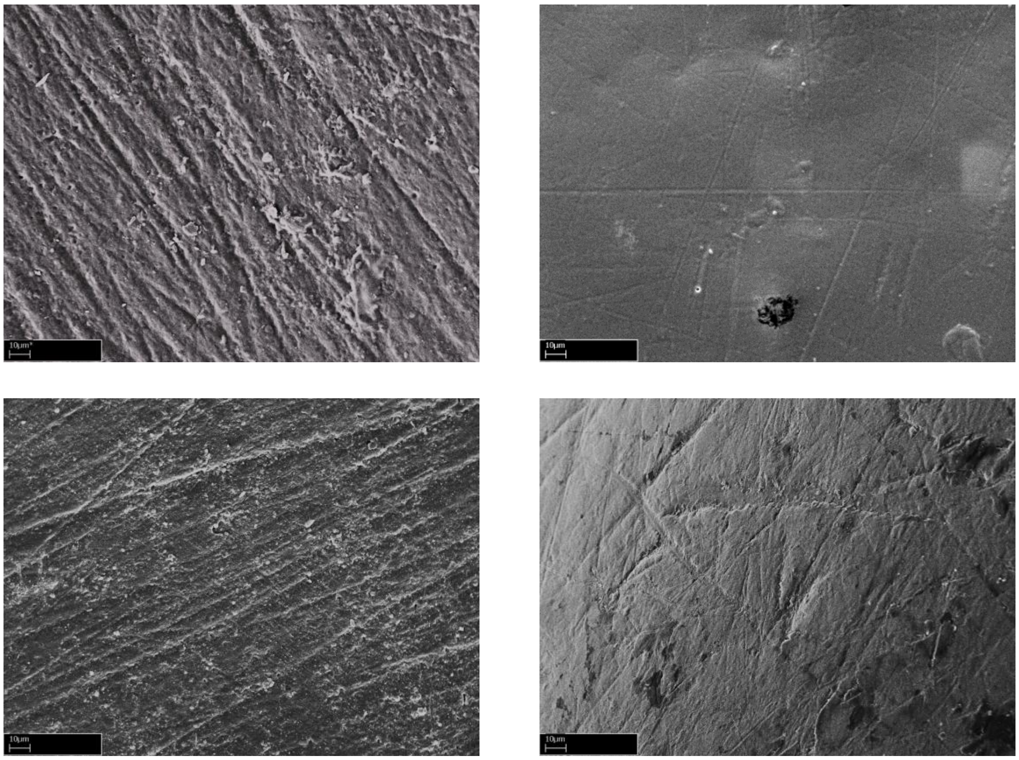
Frequency of Grant Features. Macrowear was characterized by the features described in the Grant scoring system. Most often observed in the posterior dentition was the slant featured, followed by the scoop feature. Rounding did occur in the molar row, but was primarily a feature of the anterior teeth. Only in two individuals in the experimental sample was a groove feature observed. These were male individuals aged 35-40 and 40-45 years at death. The groove in the former individual was located on the occlusal surface of a maxillary canine, while the latter individual displayed a groove on the distal interproximal surface of a mandibular second molar. Both scored as extreme under the Grant scoring system. The frequency of the groove feature has not been statistically addressed in this study, but it is interesting to note that the only groove observed in the experimental sample occurred in male individuals. This may hint at sex-specific fiber processing techniques in this population and is worth future study.

The ALA-329 Microwear Signature

To assign a particular signature to the individuals from ALA-329 is to combine visual observations and supporting data from statistical analysis in order to define what is typical of a population with similar cultural and dietary profiles. Not only can this definition assist future researchers, but it may contribute to the broader database of dental microwear studies by defining a regional and cultural typology of dental microwear. The following discussion describes the most likely etiologies of the microwear features of ALA-329.

Microwear Scratches and Pits. Micrographs of the teeth of control and experimental individuals differ visually in distinct ways. First, teeth from the experimental sample displayed most often one of three patterns: a single group of parallel scratches; two or more groups of parallel scratches running in different directions; or dentin exposure that made distinguishing individual microfeatures difficult. Upon scanning the occlusal surface of each experimental tooth, it was discovered that these three patterns tended to exist together on the surface of a single tooth. Teeth from the control group, however, typically displayed random crosshatching scratches. It was found during the scanning of the tooth surface under SEM that this trend continued across the occlusal surface. Patches of random crosshatching were less common in the experimental sample. Figure 4.2 shows micrographs that are representative of the visual difference between control and experimental teeth.

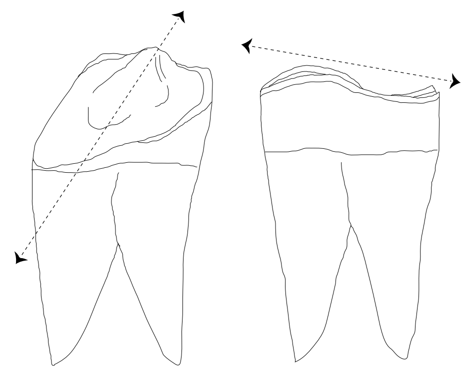
The most evident visual characteristic of the micrographs from the experimental individuals is the parallel orientation of scratches. Seventy percent of the experimental individuals in ALA-329 display a mean orientation homogeneity above 0.5, indicating that their feature landscape is dominated by a particular directional preference. In those individuals in the experimental sample who displayed high mean orientation homogeneity, it was observed that these parallel scratches ran parallel to the macrofeature in which they were found. For example, scoop features in ALA-329 individuals tended to run along the occlusal surface buccolingually, and it was found that the microscratches ran buccolingually and essentially parallel to the angle of the cupping feature as related to the dental arcade (see Figure 4.3).



A B

Figure 4.2. Micrographs depicting visual differences between control and experimental groups. A. Micrographs showing organized scratches and beginning of appearance of dentin layer in an experimental individual of 40-45 years. B. Micrographs showing the in-tact enamel layer of a younger control individual of 20-25, with finer, unorganized scratches. Note also the higher pit count in the (B) micrographs.

Another visual difference in the microwear between the control and experimental groups is the appearance of pits. No statistical significance was found in pit percentage between the control and experimental groups, but visual differences will be discussed. A high pit count has been associated with tooth-food-tooth contact during nutritional processing and also to exogenous and endogenous grit (Ryan, 1979; Schmidt, 2001).



A B

Figure 4.3. In order to be considered parallel to the orientation of the macrofeature, microfeatures must run in the directions shown above: A) as they would un respective to a slant, and B) as they would to a scoop.

Pitting occurs visibly more often in the control micrographs of ALA-329. The general profile of the control group consists of a higher pit occurrence coupled with low orientation homogeneity. No defining ratio of pits to scratches has been assigned to nutritional or to nonalimentary dental wear in previous studies, so it is reasonable to suggest that the higher mean pit percentage in the control group may indicate that these individuals were more often engaged in nutritional activities than in cultural ones. As for the experimental sample, pits are rare or either overwritten or nonexistent in the micrographs of male individuals in the experimental sample. Females in the experimental sample, hypothesized to exhibit the most typically nonalimentary microwear, exhibited a similar group pit percentage mean to the control sample. However, the standard deviations in this variable in each group represent a highly variable range of pit counts among individuals. A larger sample size may be needed to reconcile these observations.

Sex Differences

It has been found in ancient Californian populations that those on the coast exhibit the highest degree of tooth wear (Molnar, 1971a). Molnar (1971a) found that even in populations with lesser degrees of tooth wear, such as those in the Central Valley, males and females exhibit significant differences in their respective microwear patterns. Molnar suggests that a sexual division of labor may be the cause, particularly since such differences between male and female dentitions are not seen in agricultural populations. Among the ancestral Ohlone, both sexes were known to have produced cordage. Grant (2010) observed that males and females in central California exhibited similar degrees of severe wear, but with different patterns, and concluded that both males and females were using their teeth for non-nutritional purposes but for the manufacture of different items.

It is hypothesized in this study that the extreme dental wear in ALA-329 is the result of cultural processing, the most intensive having been basket weaving. As basket weaving was primarily a female occupation among the Ohlone, it was expected that males and females would exhibit different microwear patterns. Orientation homogeneity and pit percentage were significantly different between males and females. Some expected and unexpected results were found and are discussed below.

Microwear Observations Between Males and Females. In ALA-329, males exhibited a higher mean gross feature tally and a higher mean scratch width. Females showed a higher pit occurrence than males (although the pits found in male teeth were larger than those found in female teeth). Females also exhibited a higher mean orientation homogeneity. The difference in pit percentage was accepted as significant. While the mean orientation homogeneity was not significant at the 0.01 alpha level, the *p* value came close to this alpha level and the effect size was large enough to believe there may be potential in future studies to show a truly significant difference.n For the explorative purposes of this study, pit percentage and orientation homogeneity are the most statistically meaningful.

It is surprising that in general, males possess a higher scratch width alongside a higher feature tally (Figure 4.4). While mean scratch width is only slightly higher in males than that in females, the fact that males exhibit scratches at least as wide as do females while retaining a high feature count is a condition in conflict with what is expected from individuals participating in cultural tooth use: that is, wider scratches caused by fibrous material alongside a lower feature count due to a dentin canvas that registers most clearly the scratches made from forceful and patterned cultural processing.

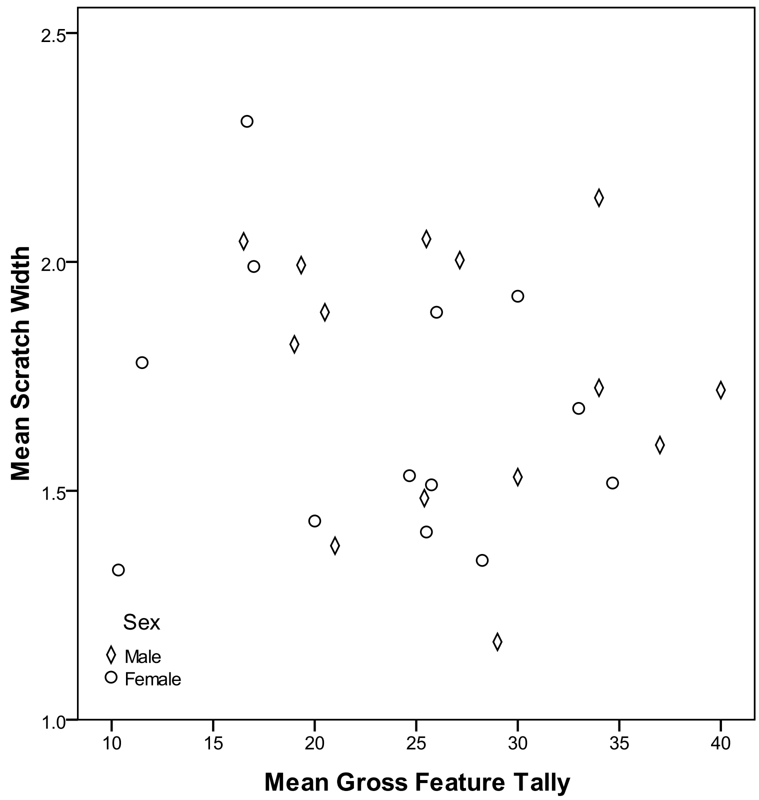


Figure 4.4. Scatterplot depicting the relationship between mean scratch width and mean gross feature count among males and females.

Possible Cultural Processing at ALA-329

Results of visual and statistical analysis give reason to accept that the individuals at ALA-329 were engaged in the dental cultural processing of materials. Analysis of scratch orientation suggests that repetitive, unidirectional manipulation of material occurred across the occlusal surfaces of the posterior teeth. Scratch width and frequency are suggestive of the material type used and of the force with which they were processed.

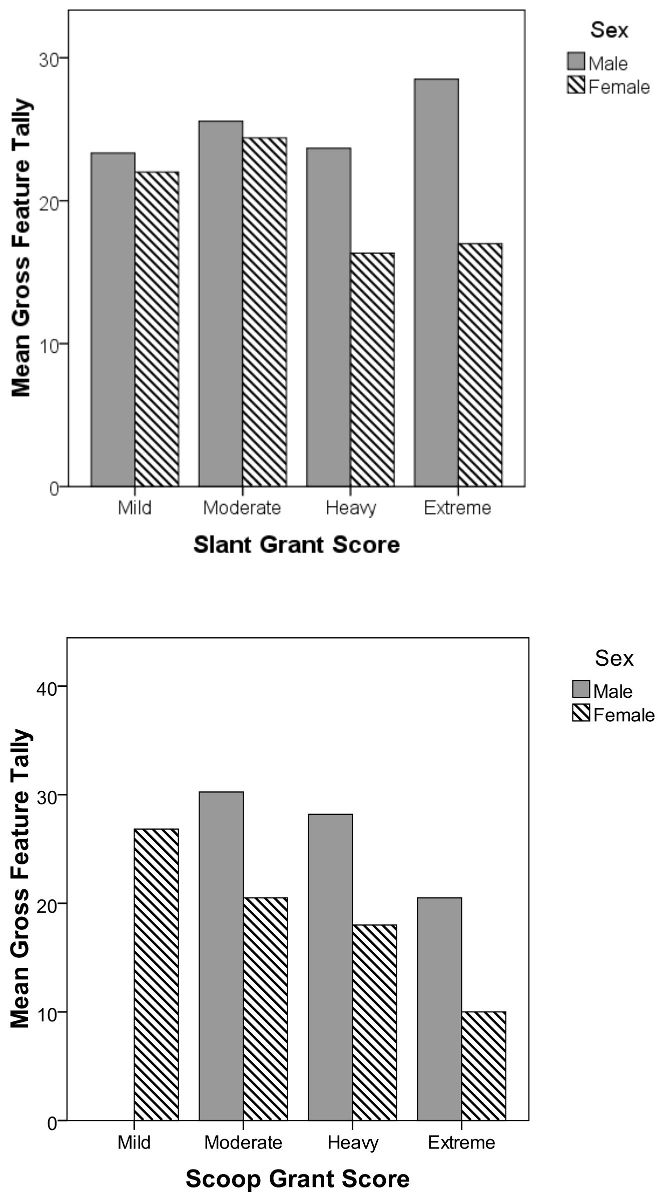


Figure 4.5. Above: depiction of mean gross feature tally between males and females in each stage of the slant feature. Below: in each stage of the scoop feature.

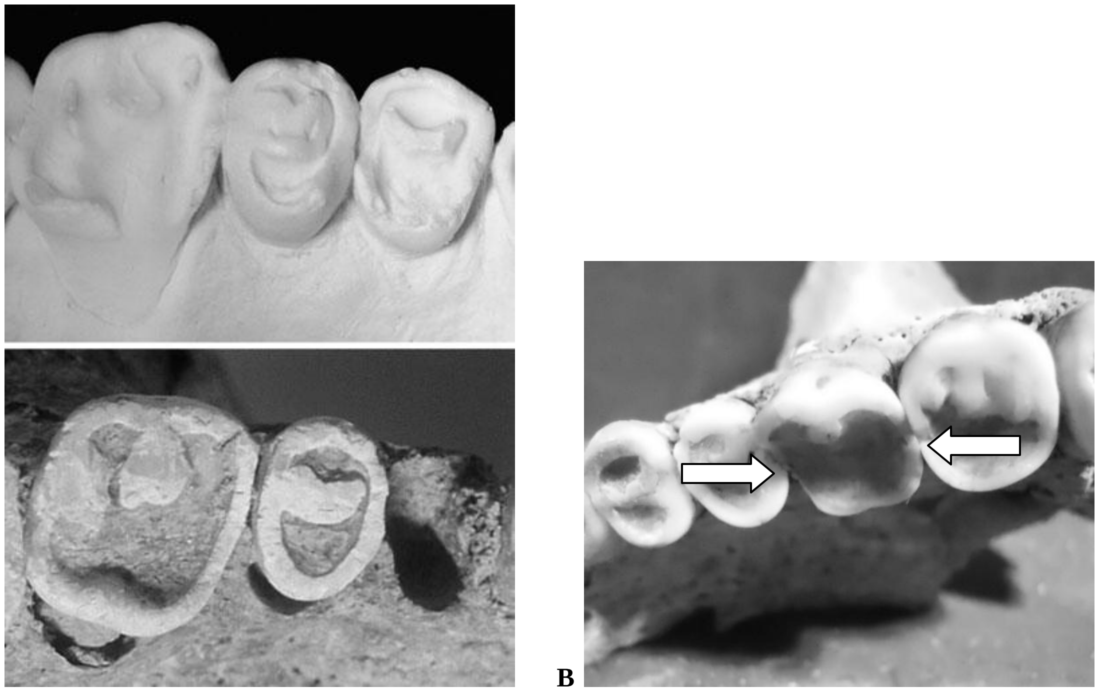
Alone suggestive of cultural processing, microwear features, when considered with the specific macrowear features in which they are found, indicate strongly that activities other than the consumption of a gritty diet contributed to the dental wear at ALA-329.

Directionality as an Agent of Tooth Wear. Parallel scratches have been associated with directionality in past studies. Fox (1992) assumes cultural activities in the role of creating parallel scratches, noting this pattern in the Inuit and in indigenous Tasmanians and Australians, three aboriginal groups who are known for dental sinew and fiber processing. Fox concludes that parallel scratches in the posterior dentition were created by grooming devices being applied habitually in the same back-and-forth motion. It can therefore be asserted that directionality has an observable and consistent influence upon dental microwear. Conversely, dietary processing has many directional influences from all sides – different mandibular and maxillary forces work against each other to reduce food from every angle, using every occlusal facet to grind material. It has even been suggested that the width of the mandibular corpus influences the size and shape of microwear features during masticatory processes (Mahoney, 2006). Whether factors such as occlusal facet, mandibular size and robusticity, and prism orientation bear upon cultural microwear remains to be seen. For the present, unidirectional evidence in the macro- and microwear in the experimental sample of ALA-329 is significantly more robust than that in the control sample.

Schulz (1977) noted in a prehistoric population from Sacramento, California that groove features exhibited microwear running parallel to the groove's orientation. Comparing the etiology of the groove feature to that of the enamel rim indentations in the scoop features of ALA-329 will support the argument that the repeated, uniform application of a material against the tooth likely creates parallel microfeatures. The enamel indentations in the scooping features lends them the appearance of having been created in a specific direction, while the cup-like features typically attributed to dietary grit appear to have been hollowed out from the center (see Figure 4.6). That grooves, often caused by repetitive, unidirectional activity such as picking, display parallel microscratches is support that the scoops of ALA-329 may indeed have been caused by deliberate cultural processing. Microscratches also run parallel to slanting and rounding features, arguing for cultural activity in teeth with these patterns as well. It is possible that fibrous materials were processed culturally on teeth with each type of macrofeature described by Grant, but through different techniques. Discerning the use of specific techniques through microwear is a highly suggested direction of future study.

Orientation homogeneity as an indicator of cultural dental activity has been contested. Bax and Ungar (1999) studied the microwear of different cultural groups who participated in different methods of nonalimentary tooth use and found no significant difference in mean orientation homogeneity. They concluded that orientation homogeneity is not an accurate measure of differences in cultural processes. However, they note that the low magnification used in the study is not adequate for assessing such differences, suggesting that nonalimentary microwear patterns may register more strongly at a finer feature level. The SEM phase of this study was conducted at a 500X magnification level, enough to define striations narrower than a single micrometer. Closer magnification may offer different data, but a 500X magnification is considered sufficient for the purposes of this study.

The effect of orientation homogeneity upon dental wear in ALA-329 was not statistically significant, but the visual observations presented above argue for a cultural etiology of parallel scratches in ALA-329. However, confounding factors must be considered. Three out of seven individuals from the control sample show a mean orientation homogeneity of above 0.5. It is acknowledged by the author that the control individuals are mostly in the 20-25 age-at-death category; this is because they were the few who did not exhibit extreme macrowear. It is possible that these individuals were not yet engaged as intensely in the cultural processes that may have created the extreme wear in older individuals, but that they may have been learning the art and producing some of the same wear patterns. The control individuals' value lies in the fact that they have enough enamel still intact that it is possible to observe dietary patterns that may not



A B

Figure 4.6. Cupping wear as found in dietary erosion as opposed to scooping wear in ALA-329. A) cupping wear (Ganss et al. 2002); B) scooped wear (arrows point to the characteristic complimentary indentations in the enamel rim).

register on the exposed dentin of older individuals. Statistical results will undoubtedly suffer from these inevitable fluctuations of the occlusal surface.

The process of obliteration is also a concern. The dental microwear phenomenon of obliteration is a confounding factor in both visual and statistical analyses. Any hiatus in cultural dental processing would mean that the microwear left by the previous weaving session was left vulnerable to erasure through the processes of subsequent meals. Teaford (1994) found in *in vitro* studies that within one week, the dental wear landscape on a particular tooth had been nearly entirely altered. This process can skew data in each of the six variables used in this analysis. Baskets were essential to Ohlone survival; weaving them was a skill that required years of practice and was called upon regularly for several habitual activities. Therefore, it is expected that a number of individuals participating habitually in basket weaving would exhibit cultural features as the last marks made upon their teeth and that the data set in this analysis was not affected significantly by the superimposition of nutritional wear onto cultural patterns. However, even taking the process of obliteration into account, a habitual activity superimposing itself over wear created by previous occasions of the same activity conducted in the same way and in the same place would logically produce something similar to that seen in image (A) of Figure 4.2.

Here, a question arises. How can it be asserted that these parallel microscratches were created through a repetitive process when microwear is representative only of the last activities performed immediately before death? Microwear change occurs quickly in dietary wear, but it can occur over the course of one week. It is unlikely that dietary processing, which has been shown to be characterized by random placement of features (and in gritty diets such as that at ALA-329, high pit count), would create a similar pattern of parallel scratches and low pit count such as that seen repeatedly in the experimental sample. It is more likely that something deliberate and repetitive worked over the course of a week to stamp such a regular pattern onto the tooth. Alternately, if the weaving of a basket or the manufacture of a cordage mat was an intensive process on which an individual would spend a day, then the formation of the parallel microwear pattern would possibly be created more quickly.

The Role of Grit in ALA-329. Micropitting has been most commonly attributed to the direct maxillary to mandibular cusp contact that occurs in the processing of hard objects such as seeds, and in the dentitions of frugivores, who habitually participate in less dental stripping motion than do folivores (Teaford and Ungar, 2000). Ryan (1979) demonstrated that tooth-food contact resulted in an occlusal surface characterized by scratches surrounded by pits. The high amount of grit in the prehistoric Ohlone diet can explain the presence of pits and random scratches in the control sample. The pitting seen in the control sample in this study can be logically attributed to high dietary grit; however, dietary grit cannot alone explain the dental wear seen in the experimental sample of ALA-329. This assertion can be supported by the difference in macrowear between ALA-329 experimental individuals and comparative populations known for gritty diets, whose members do not exhibit features such as scoops or a combination of different features in succession. Lukacs (1988) suggests that these same gritty particles, when dragged across the tooth surface, caused many of the microscratches observed along the occupational grooves of Neolithic Mehrgarh, offering an etiology of sinew and fiber processing using a dragging motion for these grooves. The high amount of grit present in the mouth of the Ohlone individual may have caused pits in the initial contact of occlusal surfaces to material, and subsequently been taken up by fibers being culturally processed and dragged along by the pulling motions used to manipulate the material, resulting in scratches. Grit was indeed present and can account for the combined presence of pits and parallel scratches in the control individuals. The fact that parallel scratches begin to obscure pits or preclude pit formation in individuals with more extreme wear may indicate that grit actually did play as big a part in tooth wear as most researchers believe; however, it may have done so through directional processing rather than dietary or salivary contact with the teeth. It is likely that any pitting present in ALA-329 was not caused by activities that can be attributed specifically to cultural processing, but that they were caused by dietary processing or by incidental motions in the transitional moments of cultural processing.

Microwear in Specific Macrowear Features. Heavily cupped dental wear is typically associated with agricultural groups (Hinton, 1981). However, agricultural populations exhibit cupped wear with a complete circumferential enamel rim. Cupped wear in ALA-329, labeled "scoops" by Grant, is characterized by two opposing indentations in the enamel rim. It is plausible that these indentations represent the two points at which material was habitually placed into contact with the tooth and between which material was worked in dental processing. Often in ALA-329, the scoop feature, with increased extremity, displays characteristics of both a slant and a scoop; that is, the indented enamel rim and cupping of the dentin are still apparent, but one side of the tooth (typically the buccal side) becomes worn to a lower level than the other. Kieser and colleagues (2001) suggest that heavy cupping wear in the pre-contact Maori, who, like the Ohlone, consumed gritty shellfish, was initialized by abrasion from the grit and accelerated by intrinsic and extrinsic acid erosion. The cupping wear in this population did not include the enamel rim indentations found in ALA-329, so already it is apparent that the scoops in the Ohlone dentition have a different etiology than simply dietary grit and acid. Cupping wear to the extreme found in the Ohlone is not an absolute result of coastal life, as demonstrated by other coastal populations lacking such features, such as prehistoric Alaskans (El-Zaatari, 2008). The scoop features in ALA-329 cannot have been caused expressly by grit-induced dentin wear.

It is tempting to suggest that the scoop feature is most likely caused by cultural processing while the slant feature is simply a typical Monson plane and can be explained by dietary use. However, the microwear in both types of macrofeature shows parallel striations and no predilection for higher orientation homogeneity exists in the data for either type of feature. The scoop feature does not appear in ALA-329 individuals until the age of thirty years at death, similar to the prehistoric central Californian individuals in Grant's study. This is further evidence of an etiology particular to this feature – a technique that requires repetition over a number of years.

Rounding is also a feature that appears later in life. In the current sample, in posterior tooth positions, the feature is restricted to females above 40 years of age at death. Lukacs and Pastor (1988:396) attribute this feature to "very forceful pulling of material through tightly clenched anterior teeth". Hinton adds a possible etiology of increased stress upon the anterior dentition in maize-cultivating populations due to molar loss through carious processes (1981). ALA-329 displays an atypically low caries rate for Native American populations, so this is an unlikely cause of added stress on any tooth position. The rounding wear of a supernumerary tooth from ALA-329 is suggestive of a dietary grit etiology, as the tooth is positioned in such a manner as to be awkward in any nonalimentary attempt. However, the presence of rounding wear on the adjacent normally erupted premolar, as well as alveolar resorption on the opposing right maxillary fourth premolar suggestive of heavy use and subsequent loss may be evidence of the repetitive processing of fiber through the coronal plane. An example of parallel striations in a premolar from ALA-329 exhibiting rounding wear can be found in Figure 4.7. In light of the above, it is suggested that the scoop feature is most representative of the singular wear patterning found in prehistoric central Californian individuals, and should be the subject of more focused study in the future.

Scratch Width as Evidence of Cultural Fiber Processing. The width of microscratches has been related to material type, force applied to the tooth surface, and the tendencies of enamel and dentin to wear at different rates (Danielson and Reinhard, 1998; Lozano et al., 2008). Schmidt (2010) suggests that pits have little impact upon the degree of macrowear present compared to scratch width. In ALA-329, the experimental individuals exhibited a wider mean scratch width than did the control individuals (see Figure 4.8). Even with the small sample size, the difference between the two was

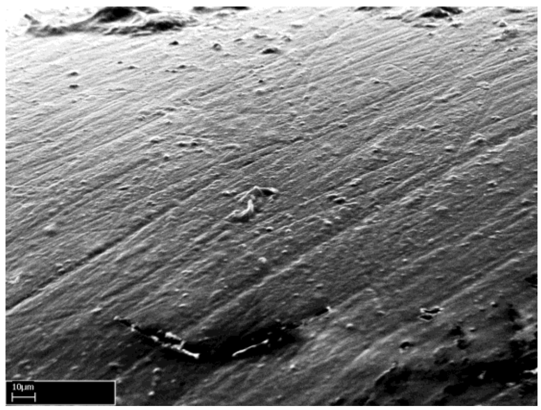


Figure 4.7. Microwear of an upper premolar exhibiting rounding wear. Note the parallel striations running in the direction of rounding toward the edge of the occlusal surface toward the lingual border (bottom left).

strongly significant at the 0.01 alpha level. Aside from orientation homogeneity, this variable has the most informative potential regarding the differences between nutritional and nonnutritional microwear.

Even the widest scratches in ALA-329 are narrower than what has often been characterized as cultural-use microwear. Fox (1992) set a tentative standard of cultural scratch width of at least 46 micrometers, a standard that was broadened in a publication with Frayer (1997) to 10-46 micrometers. These studies were conducted at a much lower magnification than that used in the current study, so any patterns involving finer scratches would have been missed. The presence of phytoliths in plant materials is a possible cause of these finer scratches. While not considered in-depth in this study, phytoliths nevertheless exist in fibrous material and must be considered here at least as an abrasive agent. Phytoliths range from 10-100 micrometers, and particles of three vastly different sizes – Fox (1992) gives the example of particles measuring 73, 23, and 14 micrometers – can produce scratches with widths from 1.8-6 micrometers. Fox and Frayer note that some activities, such as the use of a hard toothbrush or fiber processing, can produce fine striations similar in width to the normal diet striations.

A B

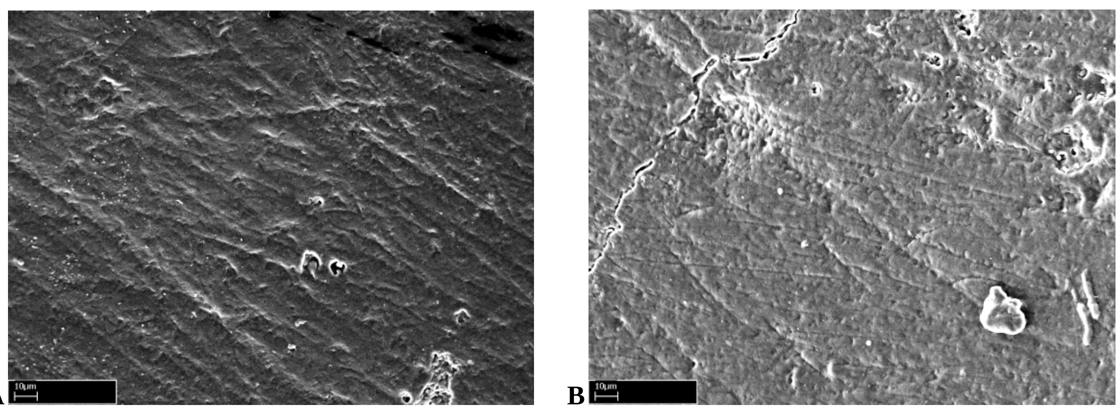


Figure 4.8. Scratch width as compared between control and experimental groups. A) experimental sample displaying wider scratches; B) control sample displaying narrower scratches.

Microwear in the ALA-329 experimental individuals resembles that of nonhuman primate habitual leaf-strippers. The average scratch width in the microwear of a gorilla is less than two micrometers, which is in the range of ALA-329 microfeatures (Teaford, 1994). Until further work is done on exact phytolith size of different plant genera, then it is not likely that we can determine whether the material, the process, or a combination thereof that is producing similar microwear between leaf-strippers and ALA-329; and it is also possible that fine grit such as that found in earth ovens used by the Ohlone is responsible. But then, the etiology of the parallel scratch pattern becomes the question, particularly as the ALA-329 control sample also displays fine scratches but not the distinct parallel pattern of the experimental sample.

Leaf-stripping has not been documented in the Ohlone as a dietary strategy; therefore, it is reasonable to examine microwear features resembling that of leaf-strippers through a cultural lens. Ryan and Johanson (1989) argued that *Australopitecus afarensis* had a mosaic of gorilla-like fine wear striae, indicating the use of incisors to strip gritty plant parts such as seeds, roots, and rhizomes. Teaford and Ungar (2000) note that folivores have a high occurrence of long, narrow scratches on their molars, with frugivores showing more pitting and hard-object feeders the most pitting.

The parallel scratches seen in the experimental sample are much finer than the range tentatively established for determining cultural microwear. However, if the materials that these individuals were processing were of the type that have been proven to create finer scratches, (e.g. plant fibers as opposed to sinew), then it is possible that the parallel scratch patterns in ALA-329 are the result of cultural processing. Parallel scratches found in teeth with extreme wear are also the wider ones, suggestive of cultural processing in ALA-329.

Mahoney (2007) argues that frequent long scratches in the posterior dentition of individuals from Ohalo with an aquatic-based diet suggest shearing rather than a hard brittle diet involving the highly direct, compressive forces needed to produce pits. This condition of microwear and diet closely resembles the ALA-329 profile. Material remains from Mahoney's site include plant foods, grinding stones and remains of aquatic foods, similar to the archaeological finds at ALA-329. Mahoney does not attribute the microwear at Ohalo to cultural tooth use, but to dietary shearing forces. If the Ohalo were not using their teeth as tools, the conditions in this population may serve as evidence against cultural use in ALA-329. However, as stated above, leaves and leaf-stripping are not featured in the available data for the prehistoric Ohlone diet. Also, while Manhoney's data shows a pit breadth and scratch breadth similar to that in the ALA-329 experimental sample, ALA-329 individuals exhibit far lower pit percentages. Mahoney also found a positive correlation between pit and scratch width, and believes that they were therefore caused by similar agents. If this is indication that leaf stripping can create the occasional pit, then Mahoney's finds can in fact support the cultural tooth use hypothesis for ALA-329. Taking the above discussion into consideration, the cultural processing of plant fibers is a valid candidate for the cause of the microwear signature of ALA-329.

In order to wear enamel away to such severity and at such young age (in comparison to agricultural and industrial populations) as is seen in ALA-329, forces inflicted upon the tooth must pass beyond the threshold of the enamel's resistance more rapidly. As Burak and colleagues (1999) noted, after a certain force load is reached, enamel wear rates rise as force rises. More muscular force being applied to a material that is run along the surface of the tooth likely means that more of the surface of the material is pressed onto and dragged along the enamel and dentin. Whatever abrasive agents are creating microwear features would be spread further and possibly compound the enamel's tendency to wear faster with greater force and create a wider scratch. Even if equal force is used to process materials culturally and to masticate gritty foods, the pattern associated with cultural wear in past studies is present in ALA-329.

The relationship between scratch width and feature frequency has been informative in such studies as an unpublished one by Schmidt (population unspecified), who found a significant negative correlation between the two variables. Schmidt related these results as a warning that microwear variables tend to covary, thereby violating the assumption of independence in many parametric tests. (This relationship appears very weakly in ALA-329 and not at a statistically significant level, but may appear more strongly with a larger sample.) However, where the quality of the features is concerned, this correlation can still be illustrative of the progression of nonalimentary tooth wear: as more forceful, wider scratches are created through repetitive action, fewer features created randomly and more fleetingly are allowed to make their mark.

The discussion of width leads to a note about pit width. Pit width and length both show a strong significant negative correlation with feature tally. (As the upper ratio limit for a pit is 4:1, the variables PW and PL are essentially the same.) This correlation makes sense when one considers that a rise in feature tally is associated with more exposure of the dentin layer. Dentin is softer than enamel; therefore, a particle capable of creating a pit most likely would create a larger pit in a softer material. This correlation can be best interpreted as a function of dentin exposure and not as a indicator of different material or activity.

Different Cultural Tooth Use Between Sexes. Both males and females exhibited scratches that ran parallel to their respective macrofeatures and that were within the range of the accepted width for culturally processed plant fibers. However, males and females exhibited different values in each of the Grant features present. Only the slant and scoop features were observed in both sexes, with rounding features in the posterior dentition observed only in females and grooves in the posterior dentition observed only in males.

Mean scratch tally was examined among Grant scores as this variable was unexpectedly high in males. This comparison is illustrated in Figure 4.5. Evidence from Grant (2010) that males and females exhibited different macrowear patterns suggests that each sex was participating in unique dental activities. While not significantly different between the sexes, mean scratch tally was higher in males in each Grant score. This may be a result of the processing of different materials; males manufacturing an arrow shaft and processing the necessary plant fibers and sinew may likely inflict different wear upon the enamel than a female processing rhizomes for a basket.

If males and females in the experimental sample were using their teeth as tools, then males may have been doing so less often than females, with enough dentin remaining untouched by tool use to be able to register the more randomly placed dietary microwear features. It is also possible that a different motion was employed in the respective nonalimentary activities of each sex, involving different use of the occlusal platform with a corresponding increase in tally and width, perhaps due to prism orientation as it acts with direction of applied force. The most likely explanation is the use of different materials, which may explain the difference in scratch width and the impact on the tooth in the form of frequency of features lain. Each variety of plant fiber has a unique phytolith size, with each able to produce a wide spectrum of scratch widths; the size of the phytolith type in each plant may correspond to its frequency, for example smaller phytoliths occurring in larger numbers throughout the plant but still capable of producing a scratch within the larger end of the range of a larger phytolith, and vice versa. The use of different materials can also account for the difference in pit percentage between the sexes, with different materials containing different levels of grit, or requiring more force to process, either of which would produce different pit frequencies. These phenomena would account for the fact that males exhibit parallel scratch patterns but females show a significantly higher orientation homogeneity.

It has been suggested that tooth wear studies, including dental microwear studies, can elucidate socioeconomic roles (Teaford, 1994; Hogue and Melsheimer, 2008). Menstrual taboos among the Ohlone forbade the consumption of meat for the duration of menses and in some cases, up to a year after childbirth (Harrington, 1942; Jacknis, 2004). In some Californian cultures, men were discouraged from meat consumption before and during a big hunt (Harrington, 1942). These hiatuses may have altered the microwear landscape prior to death enough to create different means among variables, but not enough to appear significant in statistical analyses.

A Possible Threshold of Dental Microwear Patterning. Patterns in the microwear data show that males and females experience similar changes in tooth wear at similar ages. When feature tally is observed in the context of overall severity of wear (i.e. Molnar's scale), it is seen that in both males and females, feature tally drops corresponding to initial dentin exposure (a score of 4), rises once again with a score of 5, and steadily drops with each increasing increment of severity (see Figure 4.9). Tooth wear reaches moderate wear status in the mid-20s. Scoops do not appear until the 30s. There may be some connection between enamel loss and microwear signals. Orientation homogeneity rises until the 30-35 age group, drops in the 35-40 group, then rises steadily until elderly age (50+). Feature tally and orientation homogeneity have a significant negative correlation of moderate strength. This may represent a threshold in the laying down of microwear features. Identification of a threshold phenomenon can contribute to the knowledge of the nature of how dental microwear is produced, providing guidance for future studies.

In the early stages of wear when most of the crown is present, features accumulate, then are obscured once the softer dentin is exposed, making features less distinctive and more difficult to count. However, once dentin becomes a significant portion of the occlusal platform, feature tally rises. This may correspond to an increase in the intensity of cultural dental use as more demand is made upon the individual to produce as he or she becomes skilled. It may also represent a compensatory process; once dentin is exposed, it may take more effort to achieve the same effect on a material, resulting in more force and more wear upon the tooth. Once enamel is worn away by nutritional and non-nutritional processes in the late twenties and early thirties, then feature tally drops because the many random patterns made in chewing are replaced by the more controlled, direct application of materials characteristic of cultural processing; orientation homogeneity rises because heavier force over more occlusal surface makes cultural scratches that obliterate nutritional ones. The negative correlation between mean orientation homogeneity and gross feature count was expected, and corresponds to the phenomenon discussed above. As features become more organized, feature count drops, and this corresponds with an increase in macrowear

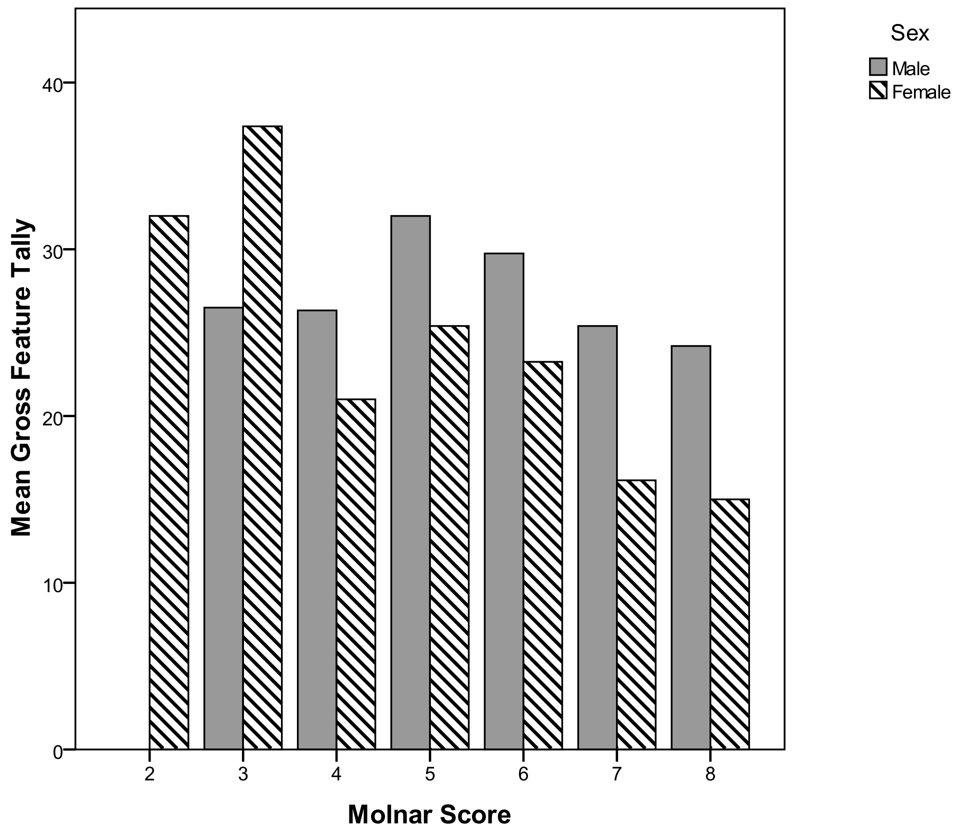


Figure 4.9. Depiction of mean gross feature tally in each stage of the Molnar (1971a) occlusal wear scale. Features build up through the third and fourth decades of life; then, as enamel wears away, and dentin becomes the canvas for microwear, random features become less visible. This represents a possible threshold able to be employed in the observation and prediction of microwear behavior.

(see Figure 4.10). This suggests that when the occlusal platform becomes softer and less responsive to random wear, the pattern that dominates is that asserted in many studies to be indicative of cultural wear and which is found in the ALA-329 experimental sample.

Summary of Findings. It is evident that the microwear in ALA-329 is most likely the result of a focused, repeated processing of material between the posterior teeth. This is most apparent in the relationship of scratches to macrowear features in the experimental sample. While dietary grit may exacerbate the effects of cultural processing, it is strongly

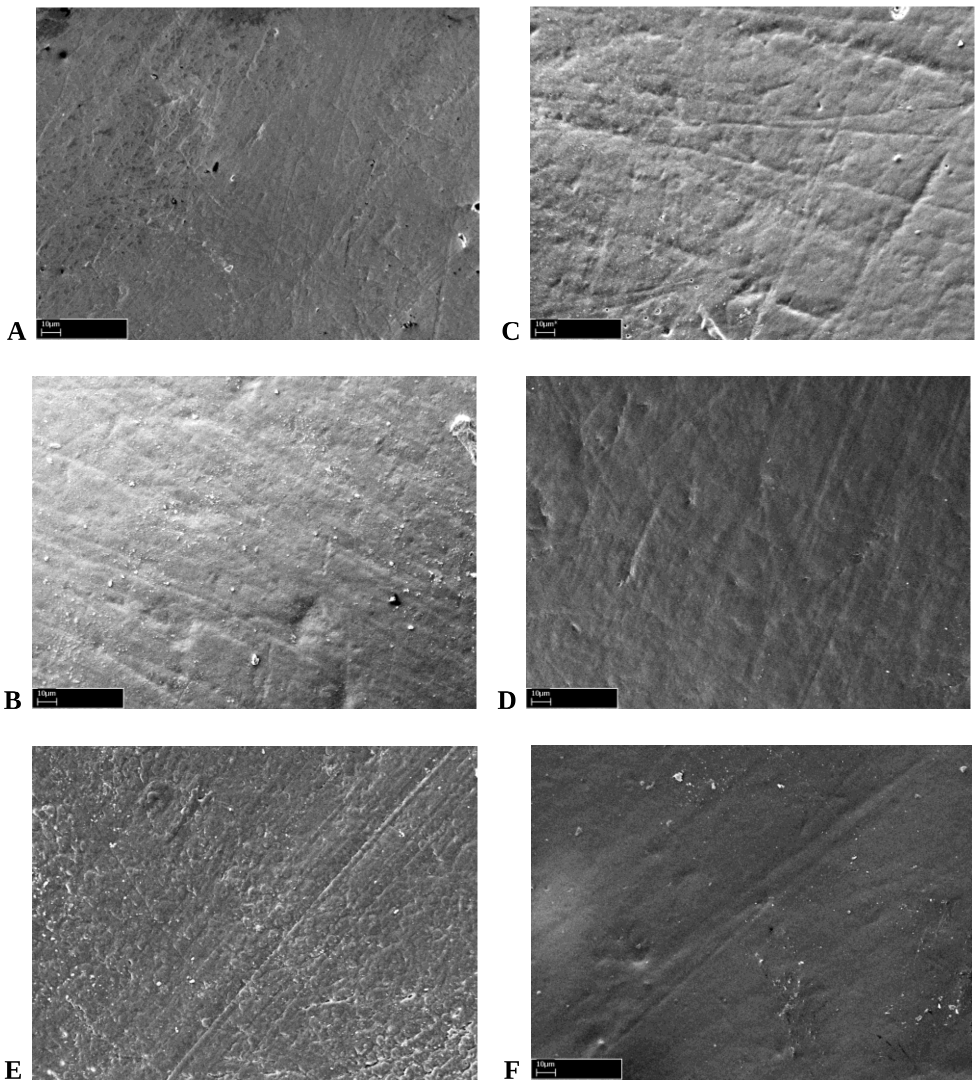


Figure 4.10. An example of the progression of the suggested threshold pattern in ALA-329 through age groups. By the fourth decade of life, feature tally begins to drop and features become more organized. A) 20-25; B)25-30; C) 30-35; D) 35-40 E) 40-45; F) 50+.

asserted based on the above evidence that grit is not the primary etiology of the tooth wear in ALA-329. Differences between males and females are found not in the overall pattern of microwear, but in the expression of this pattern through different values in feature frequency and pit percentage. These intra-group differences are specific within an established pattern in the experimental sample, while inter-group differences between the control and experimental samples reveal that each group exhibits a unique pattern. This indicates that experimental males and females were likely both participating in a practice that the control individuals were not, but through different methods.

5. CONCLUSIONS

The objective of this study is to introduce the application of dental microwear into central Californian physical anthropology and to contribute a data set to which future studies may be compared. A qualitative and quantitative study of the dental microwear of prehistoric Californian individuals in ALA-329 was conducted and revealed some expected and unexpected results.

Microwear in ALA-329 revealed features attributed to cultural processing in past studies. While macrowear in ALA-329 is singular in severity and patterning, visual assessment of the microwear within each feature revealed form and direction that, when considered intuitively, could have worn the occlusal surface into that feature. For example, wider and more organized scratches form a scoop feature in the direction in which they run, while random scratches and pitting result in a less extremely and more evenly worn flat occlusal surface.

A visual assessment of the micrographs from both groups revealed clear differences between the control and experimental individuals. Both groups exhibit wear typical of cultural tooth use, which includes organized scratches and a low pit percentage. However, these patterns appear much more consistently and dominantly in the experimental sample. Experimental individuals exhibit primarily striations that run parallel to the orientation of the macrofeature in which they were observed. While this was seen occasionally in the micrographs of the control group, these individuals more frequently exhibit random crosshatching patterns most typically attributed to dietary wear.

Statistical analysis of the data revealed differences between the control sample and experimental sample as well as between males and females within the experimental sample. A significant negative correlation between feature tally and orientation homogeneity in the combined control and experimental samples indicates that as unidirectional activity increases, the frequency of randomly placed features decreases. This suggests that a repeated, forceful contact of material against the tooth in a consistent direction is taking place in such a manner as to erase microfeatures created by dietary use. In order to obliterate features created by such a frequent activity as eating, in particular a rough, grit-heavy diet, the activity overwriting them must have been forceful and intensive.

It was found also that feature tally steadily decreases with age. Since microwear is easily replaced with each subsequent dietary or nonalimentary dental activity, the fact that the experimental sample individuals exhibited mostly organized striations running parallel with the macrofeature shortly before death is indicative of an intense participation in a consistent activity. Scratch width in the experimental sample is consistent with that commonly attributed to plant food consumption in humans and leaf-stripping in nonhuman primates. These findings suggest deliberate manipulation of the direction of fibers across the occlusal surfaces of the teeth. Wider scratches in the experimental sample and narrower scratches in the control sample suggests a possible combination of force and material in the experimental sample that differs from normal dietary wear. It is most likely that plant fibers as opposed to animal sinew constituted the bulk of materials being processed, as the width and orientation of microscratches coupled with pit characteristics mirror those found in populations with nonalimentary traditions similar to those presumed of the Ohlone, such as neighboring Sacramento groups as well as aboriginal hunter-gatherers in Australia and Tasmania.

The repetitive, unidirectional force cited in the etiology of groove features in past studies is here cited as the most likely cause of the unique scoop feature common in ALA-329. This is most evident upon examination of the structure of the enamel rim remaining in extreme expressions of the scoop feature, in which opposing indentations interrupt an otherwise encompassing border. The scoop feature can be reasonably asserted to be related to the groove, arising from similar directionality but perhaps different technique and material, as evidenced not only by macro-inspection but by parallel, organized microwear. The scoop feature is the most unique among an amalgamation of macrofeatures in ALA-329, and is suggested here to be the most defining of central Californian tooth wear.

Nonalimentary activity likely varied between males and females, as suggested by the shared presence of microwear features indicative of cultural wear and the significant differences between the sexes in pit percentage and orientation homogeneity. Macrowear features in males and females differed as well, with rounded wear in the posterior dentition found primarily in females and grooves in the posterior dentition found only in males. Statistical analysis was particularly useful when assessing intragroup sex differences, as the visual assessment methods employed in comparison between the control and experimental groups could not detect meaningful differences within the experimental group. Statistical tests suggested that males and females in the experimental sample used either different techniques, different materials, or both. A significant difference in pit percentage between the sexes, with the higher percentage occurring in females, is suggestive of sex-specific specialization, as pits are known to be created by the processing of gritty materials as well as tooth-on-tooth contact. While pits were most often found to be characteristic of dietary wear in past studies, the presence of pits in the experimental sample does not derail the acceptance of the research hypothesis, as past studies have shown that pits are rarely absent in microwear profiles, be they dietary or non-dietary.

Males and females exhibited similar scratch widths, but gross feature tally was higher in males. This result is interpreted as a function of dentin exposure, wherein males retain more enamel on the occlusal surface throughout the life of the tooth, providing a canvas better able to display fine features. Females may have been using a technique that more aggressively etched features, obliterating the finer ones, or were more frequently engaging in nonalimentary tooth use and were more likely to have lain a cultural feature landscape immediately before death. The significant difference in pit percentage and the differences in feature tally are suggestive of either division of labor, the observance of cultural taboos regarding meat consumption, or a combination of these factors.

A possible threshold of microwear formation was identified upon examination of the pace of Molnar and Grant occlusal wear throughout life. Microwear feature tally increases in the third and fourth decades of life, then drops in subsequent years, seen in both Molnar dentin exposure standards as well as Grant feature expression. As the scores in each of these scales increase beyond the Molnar score of 4 and the moderate Grant expression, feature tally begins to drop after a lifetime of buildup. This shows that feature tally drops with dentin exposure, a fact that helps to define the nature of nonalimentary tooth wear and may assist future studies in predicting microwear patterns in cases of missing data.

The data gathered in this study is valuable to the larger debate regarding a gritty diet as the primary cause of California tooth wear. Grit was introduced into the mouth from many sources in ancient California, particularly around the coast and the bay. However, the rarity of pits, the narrow range of scratch width, and the organization of microscratches argues for a process more focused and deliberate than the dietary processing of grit. Gritty foods and exogenous grit from underground ovens, stone boiling, and stone grinding may likely have exacerbated the effects of cultural tooth processing, and while not expressly the cause of wear in ALA-329, the effects of grit should remain in consideration in future studies.

That the microwear landscape in the experimental sample is dominated by organized striations running parallel to the macrofeatures in which they occur, that the statistical evidence supports a difference in microwear between with the group with heavy occlusal wear and that with light occlusal wear, and that the differences between males and females can be supported by Ohlone ethnographic literature compels acceptance of the research hypothesis: examination of the dental microwear in ALA-329 does demonstrate nonalimentary tooth use.

As ethnographic literature notes the similarities in cordage and weaving culture between the neighboring Miwok populations and what little is known of the Ohlone, it is expected that the findings of this study can be used as supporting material in similar arguments made for other prehistoric central Californian populations. It is of utmost significance in future studies of this nature that the role of different levels of force applied to the occlusal surface of the tooth be examined more closely, both in *in vitro* studies and among modern individuals participating in traditional weaving and cordage techniques. Study of the size of phytoliths in those plant species used by ancient central Californians and the range of wear created by each type will be extremely beneficial. The study of microwear as it occurs between the junction of two teeth involved in a macroscopically observable working platform will be valuable in order to better indentify such relationships between adjacent teeth. Observation of modern weavers in the process of basket and cordage manufacture will not only be invaluable to dental wear studies but also to the archaeological and ethnographic records.

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APPENDIX A

Microwear Data by Individual

Burial #	Gross Feature Tally	Vector Length	Scratch Width (μm)	Pit Percentage	Pit Width (μm)	Pit Length (μm)
ALA-329						
5	25.500	0.785	2.050	5.26	10.200	14.340
6	37.000	0.531	1.600	0.00	----	----
10	34.000	0.465	1.725	2.24	4.310	7.460
12	26.000	0.441	1.890	11.56	4.660	8.570
15	17.000	0.548	1.990	0.00	----	----
19	19.000	0.541	1.820	2.17	7.150	9.970
23	16.500	0.587	2.045	2.42	7.850	12.540
65	19.333	0.458	1.993	0.00	----	----
69	27.143	0.577	2.004	1.02	4.220	5.960
70	25.500	0.708	1.410	0.00	----	----
92	34.667	0.360	1.517	2.12	3.770	5.750
93	30.000	0.742	1.925	4.55	5.400	7.540
94	34.000	0.668	2.140	0.00	----	----
111	25.750	0.633	1.513	7.08	3.920	6.450
113	20.000	0.450	1.434	6.45	5.460	8.600
135	20.500	0.424	1.890	3.57	3.880	9.10
145	40.000	0.224	1.720	0.00	----	----
158	28.250	0.742	1.348	2.06	4.690	7.43
177	25.400	0.471	1.484	0.00	----	----
192	11.500	0.896	1.780	4.55	6.970	8.48
217	24.666	0.571	1.533	7.08	5.270	9.12
251	16.667	0.716	2.307	3.33	9.060	14.43
254	29.000	0.649	1.170	0.00	----	----
269	10.333	0.752	1.327	0.00	----	----
SCL-867						
1	21.000	0.710	1.380	4.350	10.180	17.490
SCL-30/H						
3	30.000	0.352	1.530	10.00	3.460	5.440

APPENDIX B

Grant Scale Scores for Posterior Dentitions of ALA-329 Experimental Group by Individual

SCORE
1 = Stage 1
2 = Stage 2
3 = Stage 3
4 = Stage 4

ORIENTATION
MD = mesiodistal
BL = buccolingual

Burial #, Sex	Tooth	Slant	Scoop	Rounding	Groove	Orientation
5, male	LLP3		2			MD
	LLM1		4			MD
	LLM2		4			MD
	LRP3		2			MD
	LRP4		3			MD
	LRM1		4			MD
	LRM2		4			MD
	ULP3	2				BL
	ULP4	2				BL
	ULM1	4				BL
	ULM2	3				BL
	URP3	2				BL
	URP4	2				BL
	URM1	4				BL
	URM2	3				BL
10, male	LLP3			4		BL
	LLM1		3			MD
	LLM2		3			MD
	LRP3			3		BL
	LRM1		3			MD
	LRM2		3			MD
	LRM3		4			MD
	ULP3	4				BL
	ULP4	4				BL
	ULM1	4				BL
	UL (super-numerary)	3				BL
	ULM2	4				BL

Burial #	Tooth	Slant	Scoop	Rounding	Groove	Orientation
10, male	URC1				4	BL
	URP4	4			2	MD, BL
	URM2	4				BL
	URM3	3				BL
12, female	LRM2			3		BL
	ULP3	4				BL
	URP3	3				BL
15, female	LLP3	3				MD
	LLM1	2				BL
	LLM2	2				BL
	LLM3		2			MD
	LRM1			3		BL
19, male	LLP3	4				BL
	LLP4	4				BL
	LLM1		2			MD
	LLM2		3			MD
	LRP3			1		BL
	LRP4		2			BL
	LRM1	3				BL
	LRM2		4			BL
	LRM3		3			BL
23, male	LLP3	2				BL
	LLM1			1		BL
	LLM2	2				BL
	ULP3	2				BL
	ULP4	3				BL
	ULM1	2				BL
	ULM2	2				BL
	URP3	3				BL
	URP4	3				BL
	URM1	2				BL
	URM2	2				BL
65, male	LLP4	3				BL
	LLM1		2			MD
	LLM2		2			MD
	LLM3		2			MD
	LRP4	1				BL
	LRM1	2				BL
	LRM2		2			MD
	LRM3		2			MD
	ULP4	2				BL
	ULM1			3		BL
	ULM2	3				BL
	ULM3	2				MD
	URP4	2				BL
	URM1			3		BL

Burial #	Tooth	Slant	Scoop	Rounding	Groove	Orientation
65, male	URM2	2				BL
	URM3	1				MD
69, male	LLP4	1				BL
	LLM2	2				BL
	LRP3		2			BL
	LRP4	2				BL
	LRM1		4			MD
	LRM2		3			MD
	ULP4		2			MD
	ULM1	2				BL
	ULM2	1				BL
	URM1	2				BL
	URM2	1				BL
93, female	LLP4			3		BL
	LLM2	4				BL
	LLM3	4				BL
	LRP4			4		BL
	LRM1			3		BL
	LRM2	3				BL
	LRM3	4				BL
94, male	LLM1		4			MD
	LLM2		4			MD
	LRP3		1			MD
	LRP4		2			MD
	LRM1		4			MD
	LRM2		3			MD
	LRM3		2			MD
	ULP4	3				BL
	ULM1	3				BL
	ULM2	3				BL
	URM1	3				BL
	URM2	3				BL
111, female	LLM1		3			MD
	LLM2		3			MD
	LRM1		2			MD
	LRM2		2			MD
	ULP3	2				BL
	ULM1	2				BL
	ULM2	2				BL
	URP3	2				BL
	URP4	2				BL
	URM1	2				BL
	URM2	2				BL
135, male	LLP4			1		BL
	LLM1			3		BL

Burial #	Tooth	Slant	Scoop	Rounding	Groove	Orientation
135, male	LLM2		4			MD
	LLM3		4			MD
	LRM2		3			MD
	LRM3		3			MD
145, male	ULM1	2				BL
158, female	LLP3	1				BL
	LLM1		2			MD
	LLM2		2			MD
	LRM1		1			MD
	LRM2		1			MD
	ULM1		1			MD
	ULM2		1			MD
	URM1		1			MD
	URM2		1			MD
177, male	LLP3	2				BL
	LLP4	3				BL
	LLM1		3			MD
	LLM2		3			MD
	LLM3		4			MD
192, female	LLM1			3		BL
	LLM2	3				BL
	LLM3	3				BL
	LRM1			3		BL
	LRM2	2				BL
	LRM3	1				BL
217, female	LLP3		1			MD
	LLP4		1			MD
	LRP3		1			MD
	LRP4		1			MD
	LRM1		3			MD
	LRM2		1			MD
	LRM3		1			MD
251, female	LLP4		1			MD
	LLM1		1			MD
	LLM2		1			MD
	LRP3		1			MD
	LRP4		1			MD
	LRM1		2			MD
	LRM2		2			MD
	LRM3		1			MD
	ULP3	1				BL
	ULP4	1				BL
	ULM1	3				BL
	ULM2	2				BL
	URP3	1				BL
	URM1	3				BL
	URM2	3				BL

Burial #	Tooth	Slant	Scoop	Rounding	Groove	Orientation
254, male	LLM1	2				BL
	LLM2		4		4	MD, distal interproximal
	LRM1			3		BL
	LRM2	3				BL
	ULM3	2				BL
269, female	LLP3			3		BL
	LLP4			2		BL
	LLM1	3				MD
	LLM2	2				MD
	LLM3		4			MD
	LRP3			3		BL
	LRP4			3		BL
	LRM1	1				MD
	LRM2		3			MD
	LRM3		3			MD
	ULP3	2	2			BL
	ULP4	1				BL
	ULM1			2		BL
	ULM2	3				MD
	ULM3	2				BL
	URP3	3				BL
	URP4	3				BL
	URM2	2				BL