# A COMPLEX SYSTEMS THEORY OF TECHNOLOGICAL CHANGE: A CASE STUDY INVOLVING A MORPHOMETRICS ANALYSIS OF STONE AGE FLAKE DEBITAGE FROM THE HORN OF AFRICA


By

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This document is dedicated to my family and friends for their continued support.  Thank you all.

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This thesis provides theoretical, archaeological and experimental archaeological evidence to support a complex systems framework for identifying and explaining lithic technological change within the Stone Age of the Horn of Africa. Complex systems theory is used to provide an interpretation of the process of technological change by describing the proximal effects of individuals on larger, longer-term technological systems via multi-scalar spatial and temporal dynamics, temporal continuity, recognition of material and non-material archaeological culture, and the intentional and un-intentional actions of technological producers. Technological change is proposed here to be found in the modification of "ideal types," which describe how a technology is produced and used by members of a technological system.

To support a complex systems theory approach to technological change, this thesis presents the analysis of two Stone Age sites from the Horn of Africa. Each of the two Stone Age sites was analyzed using computer-assisted morphometrics—the study of

shape—to identify the changes in flake shape through time. Changes to flake shape are correlated with modifications to the ideal type of the technology and are taken to represent technological change through time.

The results of the morphometrics analysis suggest that this method is a useful research tool. In particular, the morphometrics analyses are able to identify technological changes and technological variations within the lithic technological systems at both Stone Age study sites. Using complex systems theory to interpret these results, it appears that there were several independent technological changes at each site that may correlate to changes in the "ideal types" of these technological systems.

# CHAPTER 1
# TECHNOLOGY, STONE TOOLS AND THE HORN OF AFRICA

## Introduction

Stone Age African archaeology research has held a long-standing relationship with the cultural historical method since Wayland applied culture historical ideas to his "pluvial sequence" in the early twentieth century (Robertshaw 1993:20, 79). Wayland believed that the pluvial method was a way to examine the relationship between African and European cultures by recording the localized pluvial episodes at an archaeological site. Each African pluvial data was compared against European glacial sequences because it was believed that this would provide a relative dating method for African archaeology (for example, see Wayland 1930).

Louis Leakey also used a culture historic method through his application of the pluvial method. Leakey's use of the pluvial method is now referred to as the "organic model" because of his general conception of cultures as organic forms (Robertshaw 1993:80). In particular, Leakey defined cultures based on highly specific artifact types, disregarded functional explanations, considered change to be exogenous, believed that variability was a product of temporal differences, and narrowly associated different human types with specific cultures (Robertshaw 1993:81).

Perhaps the most prominent application of culture historicism in African archaeology is the current rendition of the three-age sequence developed by A.J.H. Goodwin and Clarence van Riet Lowe (1929). The development of their sequence was contemporaneous with Wayland's pluvial sequence but instead of relying on extra-

African data sources, such as European glacial sequences, Goodwin and Lowe's classification was based primarily on locally recovered (South African) technological material culture (McBrearty and Brooks 2000:456).

However, the use of culture history today presents two major problems to contemporary theories of technological change within African Stone Age archaeology: interpretation and continuity. First, culture history does provide a useful methodology to organize large bodies of data by using trait lists to create large scale typological classes. This is especially useful in the Horn of Africa where the archaeological record of stone tool use is temporally greater than anywhere else in the world and may span more than 2.5 million years (cf. Semaw 2000). And when compounded by an equally great spatial area, the culture historical approach presents a useful system to manage an incredible diverse (spatio-temporal) body of lithic archaeological data in the Horn of Africa (i.e., the three-age sequence developed by Goodwin and Lowe 1929).

On the other hand, the culture historical method also limits the interpretations of data and may also distort actual trends within a dataset. When an archaeological site is studied, a culture historical approach creates massive potential for the misinterpretation of archaeological data because it relies on over-generalized, large-scale chronostratigraphic trait lists. McBrearty (1988) notes that the assignment of connotation-laden chronostratigraphic periods (i.e., Early Stone Age, Middle Stone Age, and Late Stone Age) to artifacts based on techno-typological characteristics is dangerous and even misleading. Poorly studied data may be identified into a culture historical typology that, by definition, has to have a substantial amount of referential meaning attached to each typological class. As a result, these data are directly associated with the particular meanings of the typological classification regardless if the typology is truly accurate or not (cf. McBrearty 1988).

Second, culture history presents a non-dynamic and discontinuous conception of time and change because the use of essentialism restricts any idea of change to a series of distinct periods or phases without any leeway to consider continuity through time. The essentialism of culture history requires that the traits used to create typologies are considered real and unique, and are manifest in artifacts and representative of only a single "cultural" or "technological" type or time period. Therefore, each trait must fall into only one category. Due to this very problem, the Third Pan-African Congress (Clark 1957) introduced the use of "transitional periods" because certain Stone Age industries (i.e., Sangoan) showed features characteristic of two different periods and thus proved difficult to place into one specific classification (McBrearty and Brooks 2000).

Therefore, in order to model technological change as a continuous process through time, and be able to measure these changes accurately, the preexisting application of culture historical essentialism and methodology to study the African Stone Age must be re-worked. Before this model can be developed, however, certain problems within contemporary theories of technological change must also be addressed.

**Impetus for this Research**

The impetus for this thesis is a reaction to perceived deficiencies in the predominant application of culture historical methodology in current African Stone Age archaeological research and existing theories of technological change. This thesis focuses on the application of complex systems theory (CST), which is a non-reductionist theory to explain multi-scalar interaction within historically contingent systems (Bentley and Maschner 2003) to interpret the process of technological change as it is observed in the prehistoric archaeological record in the Horn of Africa. In particular, CST is used to interpret the process of technological change identified using computer assisted shape analysis (morphometrics) to identify lithic technological change through time with specific focus on the Middle and Late Stone Age transition within Ethiopia and Somalia.

Complex systems theory is rooted in chaos and non-linear theory and has several core principles (Bentley and Maschner 2003; see also McGlade and Van der Leeuw 1997; Van der Leeuw and Torrence 1989). These principles include the reliance on an open systems model recognizing the free flow of energy into and out of the system including the constant creation of diversity, non-equilibrium, and continuous systemic fluctuations operating at different scales, multi-scalar interaction including agentive and extra-agentive processes and influences, short and long term systemic dynamics, historical contingency, and intentional and non-intentional technological changes.

Although genres of CST have been applied within archaeology (cf. Bentley and Maschner 2003; McGlade and Van der Leeuw 1997; Roux 2003; Van der Leeuw and Torrence 1989), the theory itself was not developed for the social sciences. As a result I have associated new ideas with base principles of CST in order to account for the actions and ideas of people within a theory of technological change. These ideas focus on my assumption of an essentialist metaphysic underlying the process of technological change as interpreted using CST. The adoption of an essentialist position may seem contradictory to a reaction against culture historical research. However, the essentialist position maintained within culture history research creates strict limitations on interpreting change and variation because the normative characteristics underlying typologies are knowable and unchanging throughout the entire spatial or temporal extent of the typological class or period under question.

I assume that there are underlying essential ideas that direct our actions in creating technological products, but I reject the ability to know the exact ideal characteristics of an object now or in the past. This idea does condone a Cartesian mind-body dichotomy, but only to differentiate between the ideas directing actions and the actions themselves. Therefore, by rejecting the ability to ever observe or define the essential qualities of an object I hope to measure instead the variation of many objects around a hypothesized ideal type thereby creating a bridge between thoughts and actions.

In addition, I emphasize five primary theoretical and methodological aspects of CST within this thesis. First, emphasis is placed on multi-scalar spatial and temporal influences in order to account for the different scales of lithic technological change. Second, emphasis is also given to multi-scalar individual and group level influences in order to account for the creation of lithic technological change at all scales within a technological system. These first two attributes are specifically addressed at moving beyond seamless and linear sequences of time as well as the general inability of other theoretical approaches to operate within different scales of research. Third, technological change within a lithic technological system is conceived as a continuous process operating at all scales of the system. By conceptualizing technological change as a continuous process it resists the synchrony of the culture historical approach. Furthermore, if technological change is recognized as a multi-scalar process this equalizes the effects of both small and large scale systemic processes and introduces the capability that both endogenous and exogenous influences can affect the technological system. Fourth, the visible effects of prehistoric behaviors (i.e., material culture) must be explored, but the fifth, and final, characteristic must be the equally important reliance on the materially invisible cognitive and symbolic correlates of Stone Age lithic material culture. These final two characteristics seek to move beyond the blinding reliance on materialism inherent in prehistoric Stone Age archaeology, specifically studies of prehistoric technological change. The following chapters, therefore, are an intellectual journey as I play out this theoretical position in an attempt to measure the variation in flake morphology assumed to be directly related by one or more ideas that underlay the actions of individuals in the past that created the artifacts.

**Problems Associated with the Study of Technological Change**

"Change" is defined by the *Oxford English Dictionary* (2004) as "to become different, undergo alteration, alter, vary." The ontology of this definition suggests that "change" is the mechanism for movement between multiple states of being within the object under observation. The epistemological quality of "change," however, is much more important to the study of archaeology because it provides the contrast and comparison between the multiple states of being within the study object. The epistemological recognition of "change" compels us, as contemporarily situated researchers creating and interpreting archaeological data in the present (cf. Hodder 1991:30, 1999:72; Thomas 2000:4; Tilley 1991:115) to differentiate between the "current" state of the world and the interpretation of the state of the world as it existed at some point in the past.

The study of "change", though, is much too generic. Therefore, this thesis focuses upon the phenomena of "change" as it is applied to the study of "technology". The *American Heritage Dictionary* (2000) provides a robust and delimited definition of "technology" stating that technology is "the body of knowledge available to a society that is of use in fashioning implements, practicing manual arts and skills, and extracting or collecting materials." This definition recognizes material products and their non-material correlates, and it does not differentiate for western industrialism. From this definition of "technology", and that given above for "change", the study of "technological change" can be "variations and alterations in the body of knowledge available to a society that is of use in fashioning implements, practicing manual arts and skills, and extracting or collecting materials" (cf. American Heritage Dictionary 2000) However, this definition of technological change still lacks recognition of technological knowledge and skills for the symbolic and visual arts such as religious and other graphic representation including body decoration. Therefore, within this thesis "technological change" is defined as the study of the "variations and alterations in the body of knowledge available to a society that is of use in fashioning implements, practicing manual, symbolic, and visual arts and skills, and extracting or collecting materials" (cf. American Heritage Dictionary 2000).

Although the study of technological change in archaeology is not new, there is a renewed interest in the mechanisms of the process of change within technological systems (for example, Bentley and Maschner 2003; McGlade and Van der Leeuw 1997; Roux 2003; Van der Leeuw and Torrence 1989). A technological system describes the dynamic and open interrelations of the material and behavioral components that serve to classify knowledge and techniques for the production of a specific technology. This definition of "technological systems" incorporates specific elements utilized by French cultural technologists (i.e., technological systems as a network of chaînes opératoires practiced by a group) (Lemonnier 1992; Roux 2003) as well as other researchers who employ a complex systems approach (i.e., open systems model and non-equilibrium) (Bentley and Maschner 2003; Van der Leeuw and Torrence 1989).

The principle problem with current, and past, interests in technological systems is an over-reliance on using discrete events to explain changes over time in a technological system without adequately describing the actual processes involved (cf. Van der Leeuw 1989:3). According to McGlade (1999:141), the lack of study into the processes of technological change is because time was considered to be self-evident. The linear theories of the twentieth century objectified time, quantified it, and structured it in a way to provide seamless historical narratives (Bailey 1983; Binford 1981; Fabian 1983; McGlade 1999; Raper 2001). When an attempt was made to provide an explanation for technological change, the answer commonly was a rather mundane and cursory description of the (mostly exogenous) factors involved in technological change, and not the actual process, with the inevitable outcome being something "better" than before. For example, a common contemporary explanation of technological change is that it is the product of fitness enhancing or goal-oriented solutions either at the society or individual levels (see Fitzhugh 2001; Kim 2001; Mokyr 2000; Pfaffenberger 1992). But, these ideas do little to explain the actual processes involved in the change itself and merely describe the ability to increase energy efficiency or productivity.

Another noteworthy issue within technology studies is the scalar difference between the myriad ideas of technological change. Evolutionary and evolutionary ecological approaches take a broad view of technology with specific focus upon the origins of a technology rather than look at technology systems as a whole over time (see; Fitzhugh 2001; Mokyr 2000; O'Brian and Lymen 2000:ch.2; Ziman 2000a).

Functionalist approaches also view technology in a holistic fashion, but focus upon technological change more as a disequilibrium effect to particular environmental influences or stress rather than a continuous process of change through time (see Binford 1965; Kuhn and Stiner 1998:152; Pfaffenberger 1992:429-492, 508; Watson et al. 1971:74). As a result of scalar differences within these approaches, prior and contemporary research into technological systems is nearly incompatible. And yet without each scale of research together, the study of technology and technological change would seem wholly incomplete.

A final issue within contemporary studies of technological change is the lack of discussion concerning unintentional technological changes. The archaeological literature that specifically addresses ideas of technological change consistently lacks any substantial discussion of the effects or process of unintentional technological changes in lieu of a reliance on intentionality to create technological change (for example see Lemonnier 1992, 1993; McGlade and Van der Leeuw 1997; Roux 2003; Schiffer 2001; Schiffer and Skibo 1987; Torrence and van der Leeuw 1989; Pfaffenberger 1992; Ziman 2000b). A research agenda that combines intentional and unintentional technological changes, however, would provide a more robust conception of the nature of technological change. Such an agenda would incorporate the punctuated events of directed and purposeful action (i.e., intentional change) in association with the constant acquisition of unanticipated techniques, tool characteristics, tool types, or technological knowledge in general acquired during the directed and purposeful events of intentional technological change (i.e., unintentional change).

### Resolving the Problems of Prehistoric Technological Change in the Archaeology of the Horn of Africa

A solution to these deficiencies in culture history and theories of technological change would be a theory of technological change that accounts for dynamic processes rather than just origins or discreet periods and also integrates the small-scale events of individuals (cf. Lemonnier 1992) with large-scale events operating over hundreds, if not thousands of years or more (Allen 1997:40; cf. Braudel 1980:27; Roux 2003:12).

Although there have been previous attempts to move between different scales of research (cf. Braudel 1980) these attempts have been more descriptive accounts of the processes involved rather than operationalized methods, thus leaving the user still unable to dynamically move between multiple scales of research. In order to overcome the limitations of contemporary, mostly culture historical, archaeology in the Horn of Africa and emplace it within a more diverse framework, a theoretical and methodological approach must be employed that has the capabilities to: 1) maneuver between, and link logically, individual and group level dynamics, 2) maneuver between, and link logically, multi-scalar spatial and temporal extents, 3) rely on a model for continuous and dynamic changes, and 4) employ both the visible effects of prehistoric behaviors (i.e., material culture) as well as their materially invisible cognitive and symbolic correlates.

These ideas still do not resolve the initial dilemma that the spatio-temporal expanse in African archaeology is too great and the number of researchers too small to afford each and every archaeological site the requisite attention it deserves. Therefore, a fifth criterion must be a methodology that brings control to the archaeological record using particular data to identify the temporal extent of a site, and its particular characteristics therein, without relying initially, or solely, on generalized trait lists. The explicit purpose of this criterion should only address the expedient initial summation of a site, or region, as a means for more accurately proceeding with more detailed methods of research in the future and not simply as a standalone tool for archaeological data collecting.

The benefits these recommendations provide to prehistoric African archaeology include the abilities to 1) quickly identify cultural and temporal characteristics of a site for excavation, heritage protection, management, or salvage without relying on generalized trait lists, 2) study regional/large scale trends while concurrently being able to study 3) small scale trends such as individual or group actions including technological variations, 4) mediate between large and small scale processes within a continuous dynamic framework of change and not as a discontinuous series of time periods, and 5) utilize material culture but also recognize and begin to interpret its non-material behavioral, symbolic, and cognitive correlates. Effectively, this method would facilitate a more holistic research agenda for the documentation of archaeological sites to enable archaeologists to comprehend and manage better the prehistoric record and employ a more expansive array of theoretical ideas and particular archaeological methodologies. And as a further endeavor, the application of CST, in conjunction with the addition of an essentialist metaphysic, may provide a more robust interpretive schema with which to infer the development of modern human behavior in the late Pleistocene or early Holocene. This, however, is outside the realm of discussion here and will only be touched upon briefly in the concluding chapter.

## Conclusion

This thesis will use CST in association with an essentialist metaphysic to explore the process of lithic technological change during the Middle to Late Stone Age transition within Ethiopia and Somalia. Changes in lithic technology will be identified using morphometrics. The implementation of this particular theory and method should provide a more robust conception of technological change that is multi-scalar, continuous, and links ideas within people's heads with materialized actions. In turn, this will provide an avenue of research around perceived deficiencies within culture history and other theories of technological change.

The thesis is structured as follows: Chapter 2 provides a succinct synopsis of complex systems, chaos, and non-linear theories and further discusses their application here within a theory of technological change. Chapter 3 introduces computer assisted morphometry and discusses the methodology and techniques used to perform a morphometrics analysis. Chapter 4 begins with a discussion of the Gilgel Gibe morphometrics lithic analysis and draws upon the theoretical ideas discussed in chapter two. It also introduces the Gogoshiis Qabe morphometrics analysis as a comparative study with the Gilgel Gibe analysis to assess the morphometrics method. In the conclusion of this thesis I summarize my ideas and provide direction for future research.

# CHAPTER 2
# COMPLEX SYSTEMS THEORY

## Introduction

Complex systems theory (CST) is not applied by mainstream archaeology. The reason for this may be due to an overall misrepresentation that the application of this theory requires substantial high level mathematical knowledge. In fact, it is easy to reach such an idea as many discussions using a CST, and its related concepts non-linearity and chaos, in archaeology contain page after page of mathematical jargon not decipherable to the non-mathematically specialized archaeologist. But, this is a fallacy as the concepts of CST can be usefully applied to interpret archaeological problems without the need for complex mathematical modeling. Therefore, the focus of this chapter is to discuss the history of CST, its relationship with non-linear and chaos theory, and describe how the concepts of CST will be applied to understand technological change within this thesis. This chapter will also present the concepts of ideal types and unintentional technological change in association with the basic framework of a complex systems theory.

## Complex Systems Theory, Chaos Theory, and Non-linear Theory: Relationships and Characteristics

Complex systems theory is grounded in chaos and non-linear theory (Bentley and Maschner 2003; see also McGlade and Van der Leeuw 1997; Van der Leeuw and Torrence 1989). The foundation of chaos theory can be traced as far back as the late nineteenth century to James Clerk Maxwell's research on long-term unpredictability and sensitivity to initial conditions (Williams 1997:17). During the early twentieth century researchers developed other key components of chaos theory including the concept of entropy. Much of the current interest in chaos can be traced to a 1963 paper written by Edward Lorenz; however, it was the advent of affordable, high-power computers in the 1970s that brought about the wide-spread application of chaos theory to the physical and social sciences (Williams 1997:18).

Chaos is a theoretical idea that seeks to explain changes over time within long-term, naturally occurring systems. In particular, it is designed fundamentally to interpret temporal changes strictly within deterministic, complex, nonlinear dynamic systems. Characteristics of chaos include: 1) determinism (mathematical laws underlying systemic processes), 2) sensitivity to initial conditions (two slightly different initial inputs can create two vastly different results), 3) emergence (ability of the system to create new, more complex levels of order over time) and self-organization (ability of the system to create order from irregularity without external influences), 4) dynamics (changes through time), and 5) non-linearity (definitions adapted from Williams 1997).

According to Williams (1997:14), the benefits of using chaos theory include 1) the ability to identify randomness within a system and explore systemic determinism (see also Bentley and Maschner 2003:2), 2) greater accuracy for short-term predictions, and 3) the ability to identify time-limits for reliable predictions. However, chaos theory does lack the ability to reveal particular details of any underlying physical laws in nature (Williams 1997:15).

Non-linearity is a component of chaos theory that describes systemic dynamics—movement and readjustment—through disproportional changes between variables and reactions within a complex system. A non-linear equation does not plot a straight line on a graph or take on the proportional, linear equation form $y = mx + b$ where x and y are variables and m and b are coefficients. Non-linearity is useful for describing systemic fluctuations (Allen 1989:272; Allen 1997:42; McGlade 1999; see also Torrence and Van der Leeuw 1989:8; Van der Leeuw and McGlade 1997:334) and non-equilibrium, including the historical dependency of these fluctuations (McGlade and Van der Leeuw 1997:2), long-term systemic unpredictability via unaccountable or changing systemic variables (McGlade 1999:151), and the capacity of the system to change (Allen 1997:40).

Complex systems theory, also known as "complexity theory", is a recent term used to describe multi-scalar intra-systemic interactions whose future trajectory is dependent upon its history (Bentley and Maschner 2003) via the interactions of "particular-like units or 'agents' " (Williams 1997:234). In particular, CST focuses on the emergence of new levels of order (self-organization) within systems that exhibit non-linear and chaotic characteristics (Williams 1997:234).

**Characteristics of Complex Systems Theory**

Williams (1997:449 emphases original) defines complexity as "a type of dynamical behavior in which many independent agents continually interact in novel ways, spontaneously organizing and reorganizing themselves into larger and more complicated patterns over time." Based on this definition, a complex system relies on five basic qualities:

1. An open systems model to describe the influx of new matter and energy into the system (i.e., births of children, creation of new artifacts) (Bentley 2003:9; Bentley and Maschner 2003:2).

2. Non-linearity to describe dynamics (movement) of the system via the continuous fluctuation of systemic energy (non-equilibrium) (Bentley and Maschner 2003:2). In association with an open systems model, long-term systemic prediction is unable to be made (Allen 1989:272; Allen 1997:42; McGlade 1999; Torrence and Van der Leeuw 1989:8). As a result, the focus changes to predicting the capacity to change

within the system through sensitivity dependence on initial conditions thereby introducing the ability for creativity, innovation, and multiple results (Allen 1997:40).

3. Determinism (governance by underlying laws). However, because of non-linear systemic dynamics and an open systems model, the history of the system, and the laws that regulate it, may be impossible to physically identify or predict (Bentley and Maschner 2003:2; Williams 1997:15)

4. Sensitivity to initial conditions (slight alterations in initial conditions creates two or more vastly different trajectories) (Williams 1997:466). Sensitivity to initial conditions is related to the concepts of the "critical path network" that Allen (1989:249) describes as "a scheduling technique for portraying a group of interrelated steps which make up a whole process" and "contingency", which describes how similar events at different times can trigger vastly different reactions within a complex system because the current setting could not sustain the appropriate chain of events (Bentley and Maschner 2003:2; see also McGlade and Van der Leeuw 1997:2)

5. Emergence (ability of the system to create new, more complex levels of order over time) through self-organization (ability of the system to create order from irregularity without external influences) (McGlade 1999; Van der Leeuw and McGlade 1997:334; Williams 1997:234)

The most important aspect of CST, however, is the capability to maneuver between numerous scales of reference when the theory is implemented (cf. McGlade 2003:116). Multi-scalar analysis is vitally important to this approach because CST views systems as highly complex, interlinked events occurringat any possible scale (Bentley and Maschner 2003; Williams 1997). And true to its non-linear and chaotic roots, CST posits that the most microscopic event can generate disproportionately greater, or different, macroscopic events (Bentley and Maschner 2003:5). In particular, Bentley and Maschner (2004:5) note that one of the goals of CST research is to "discover how movements at a small scale translate into emergent phenomena at a larger scale or at least what emergent phenomena can be expected."

The scale of analysis within CST is variable. CST attempts to bridge both reductionist and constructionist methodologies (Bentley and Maschner 2003:1) by observing how small scale events can create disproportionately larger macro-scale events within complex dynamical systems (Allen 1997:40; Bentley and Maschner 2003:5). In particular, Williams (1997:234) emphasizes a socially situated (micro) scale of analysis by suggesting that complexity research focuses on the interaction of "particle-like agents" including the "hierarchical progression in the evolution of rules and structures." In this thesis, the use of the term "agents" does connote individuals but refers more generally to human and non-human agents of change including people, ideas, and objects.

**Context within Technological Systems**

Complex systems theorists describe context through "sensitivity to initial conditions" and "contingency". "Sensitivity to initial conditions" specifically refers to the reliance of the system upon historical events such that a miniscule action in the past can translate into disproportionately larger events in the future actions of the system (Williams 1997). "Sensitivity to initial conditions" also refers to the particular trajectory of a complex system due to its unique suite of initial conditions (ibid).

"Contingency" on the other hand, describes how similar events at different times can trigger vastly different reactions within a complex system (Bentley and Maschner 2003:2; McGlade and Van der Leeuw 1997:2). "Contingency" also refers to the concept of the "critical path network" that Allen (1989:249) describes as "a scheduling technique for portraying a group of interrelated steps which make up a whole process."

Relying strictly on the complex systems theory terminology described above, "context" refers specifically to 1) historical actions, 2) contemporary setting, and 3) sequences of events, both historical and current, within a complex system. However, these concepts only describe the mechanical setting and processes of the system and do little to discern the socially situated nature, or meaning, of a complex technological system that is being investigated here.

A more meaningful approach to study past context within complex technological systems can be found within the various themes of interpretive archaeology. The specific epistemology of interpretive archaeology can provide explicit boundaries on what meaning can or cannot be discerned from the archaeological record, especially considering the meaning drawn from lithic debitage relating to underlying ideals.

Accordingly, these phenomenologically inclined ideas place a great deal of responsibility upon the contemporary interpreter, and their actions, to understand past social processes because it is assumed that only through the interpreter's present and past subjective experiences are possible any identifications of meaning (cf. Hodder 1991:30; Hodder 1999:72; Knapp 1996:143; Shanks and Hodder 1995:5; Thomas 2000:4; Tilley 1991:115; Tilley 1993:3,7). As such, these positions are less concerned with the explanation of events than with creating an understanding of the event, as a product of contemporary subjective knowledge (cf. Whitley 1998:13).

Although not explicitly discussed throughout this thesis, the recognition of an underlying essentialist metaphysic guiding a technological system ultimately is concerned with meaning. The assumption of ideals guiding technological systems entails the assumption that these ideals connote specific and subjective social meanings to the individuals who employ them. However, it is beyond the scope of this thesis to address these issues in great detail. Suffice to say, the conception of ideals (i.e., ideal types) here is assumed to never be directly identifiable or materialized by those in the past who employ them or those of us in the present who wish to study them. I assume instead an underlying essentialist metaphysic guiding the production of technological objects but deny the ability to know and utilize these ideals to classify these products. As a result, I hope to measure the variation of many technological objects around a hypothesized ideal type thereby creating a bridge between thoughts and actions, the technological society and the individual. Ultimately, we may be able to hypothesize individual and social meaning of these variations around certain ideal types. For now, however, I simply assume that the creation and maintenance of ideal types by a technological community connotes some sense of shared meaning between individuals about how to produce and use the technology, which in turn creates homogeneity within a technological system.

Thus, the employment of interpretive archaeological epistemology may significantly enhance the concept of "context" within complex technological systems by moving beyond a description of mechanical settings and processes and elaborating on the meaning of the essentialized properties of technological systems and technological products. An interpretive archaeological epistemology facilitates the contemporary creation, and elaboration, of a past technological system through contemporary social actions and knowledge. As such I assume that by relying on socially situated actions, historical and contemporary sequences of technological events can be more fully described in terms of the human and non-human agents creating the action, the complex interrelations between agents within the technological system, and how these agents recursively create, and are influenced, by the larger technological system as a whole.

**Technological Change within Complex Systems**

Within a complex systems approach, technological change is described through individual and group level behavior (Allen 1997; McGlade 1999; Roux 2003; Spratt 1989; Van der Leeuw 1997:34) adapting to particular environmental influences resulting in non-equilibrium systemic processes and subsequent re-organization of the system (Allen 1989:273; McGlade 1999:150; Roux 2003:6; Torrence and Van der Leeuw 1989:7-8; Van der Leeuw and McGlade 1997:339). For example:

> It is the existence of processes such as reproduction, cooperation and competition at the interface of individual and community levels which can, under specific conditions of amplification, generate unstable and potentially transformative behaviour. (McGlade 1999:150)

> Adaptability and change come from the interplay of internal variability, system structure, and environmental conditions. (Allen 1989:273)

> The non-linear coupling of a relatively structured, slow environmental dynamic and a more rapid and stochastic human one generates bifurcation behaviour. (Van der Leeuw and McGlade 1997:339)

This thesis, however, applies an essentialist position advocating ideal types to describe technological change. This position suggests that ideas direct the actions of active agents who manipulate their available resources and knowledge within a pre-conceived (but not necessarily achieved) prediction of his/her consequences in order to gauge the value in retaining or discarding technological elements for future use. As a result changes in the ideal type affect changes in the technological system, but these changes are instituted only through the discursive and contextualized choices of technological agents.

**Ideal Types**

A “type” is nothing more than a “general character or structure held in common by a number of people or things considered as a group or class” (American Heritage Dictionary 2000). In particular, ideal types are mental representations an individual or society has as to the appropriate form a technological product should have for a specific function. This section discusses the use of ideal type within this thesis and other research and suggests two reasons why the use of ideal types within technology studies is important.

The use of types is essentialist and normative. However, the primary difference between the uses of ideal types in this thesis compared to prior research is assumed inability of past and current individuals to ever identify the ideal type or produce it perfectly in material form. This is different from culture historical research where normative values are used by a researcher to classify and compare one culture against another through the use of trait lists (Trigger 1989). The use of types in culture historical research suggests that any person is able to know, and materially express, their shared normative values. In contrast, the employment of ideal types here is employed strictly as a heuristic to describe general similarities in thinking among members of a technological system, and it is the variation around ideal types with which we can infer change.

Many other theories allow for mental or cognitive contributions to technology, but references to ideal types within technology studies seem to be highly variable. Lemonnier (1993:3-4) suggests that there are underlying mental processes directing our actions. Roux (2003), following Lemonnier and others, suggests that the compromise between formal and ideal properties of artifacts advocated by the behaviorist approach (cf. Schiffer and Skibo 1997; Skibo and Schiffer 2001) creates an over-simplified linear sequence of change and unrealistic duality between technology and society. In addition, through their recognition that choices can be used to improve an artifact's performance characteristics and that those creating a technological product have a conception of optimum levels of performance, Schiffer and Skibo (1987), imply the existence of ideas that direct actions, but not an explicit conception of ideal, shared form types:

> ideally then, the tinkering artisan tries out different technical choices, attempting to optimize an artifact's activity relevant performance characteristics. In practice, however, many performance characteristics fall short of optimal levels because of their complex causal relationships with technical choices and formal properties. (Schiffer and Skibo 1987:599)

Others recognize ideal types but misrepresent its use. For example, Rolland and Dibble (1990:483) note that

> any of the retouched tools found in Middle Paleolithic assemblages represent worn-out, discarded objects rather than intentional end products . . . in this case it would not be true that the lithic types represent deliberately shaped objects reflecting normative values

Rolland and Dibble are absolutely correct to state that the original "normative value" may not be preserved in the final morphology of the tool. However, contra Rolland and Dibble (1990:483), from a heuristic point of view there are normative ideal types in the final morphology of a lithic tool; they are just different from the original "normative value" of the tool. An idealist basis for technology requires that the ideas must always precede actions. Even later modification events conform to some "ideal" characterization.

This section has, up until this point, concentrated on a discussion of the infrequent and implicit use of ideal types within other research. In spite of the lack of use within contemporary technology studies, and a common opinion throughout the discipline of archaeology that essentialist ideas are outdated and largely rejected, I still intend to argue for two benefits that an essentialist conception of ideal types can offer a theory of technological change. First, the ideal types privileges the mental conceptions of a technology held within the minds of the technological agents. Second, the ideal type is the foci of the technological system creating similarity within its materialized effects (artifacts).

First, my use of ideal types only privileges the mental conceptions of a technological form held within the minds of the technological agents. The materialized effects of a technology (i.e., artifacts) are simply the by-products of the process that attempts to recreate—but never attain—the "ideal tool" materially based on the mental conceptions of the "ideal type." Technological change, therefore, is found within variations of materialized tool form around an ideal type as well as alterations of the ideal type itself held within the minds of the technological agents and secondarily manifest in the materialized by-products of that technological system. Precisely for this reason I hope to move beyond prior conceptions, and use, of essentialist ideas and ally it more closely with a materialist metaphysic that allows for measurable variation of change through time.

Second, the ideal type becomes the foci of a technological system allowing for similarity within its materialized effects (artifacts). Using CST terminology, the ideal type can be likened to the convergence of a system towards an "attractor" (cf. Williams 1997:447). However, the state of systemic equilibrium also associated with the concept of an attractor can never be achieved using my concept of ideal types because the type is assumed to never be achievable. This presumption creates a constant and dynamic locomotion of change within the technological system. The drive of innumerable technological agents to invent the "ideal tool" creates a technological system that is constantly in the processes of non-linear and seemingly chaotic action.

This action, what I see as a gravitational movement around the ideal type, is perturbation. Perturbation is a "displacement in a trajectory or any difference between two neighboring trajectories or observations at any given time" (Williams 1997:169). It is a means for describing the movements of a technological system over time though self-organizing fluctuations (cf. McGlade 1999; Torrence and Van der Leeuw 1989:8; Van der Leeuw and McGlade 1997:334) that are essential to the survival of complex and non-linear systems (Van der Leeuw and McGlade 1997:338).

Perturbation is directly associated with the sensitivity to initial conditions (cf. Williams 1997:466), contingency (cf. Bentley and Maschner 2003:2; see also, McGlade and Van der Leeuw 1997:2) and critical path (cf. Allen 1989:249) of a technological system. Allen (1989:269) notes "because of fluctuations the real system is always, in fact, probing the stability of the particular situation and, depending on which fluctuation occurs at a critical moment, the system will move to one or another of the stable behaviors which are possible."

However, perturbation by itself is an incomplete concept to describe how technological changes occur because perturbation only describes movement in a trajectory. The origin of technological change is always with the technological producer. In particular, within my model technological changes result from the recognition and decision to implement intentional and unintentional changes through a technological producer's available knowledge base and conception of the ideal type for that particular technological system. The next section introduces the concepts of intentional and unintentional changes. Particular attention is focused on unintentional changes as the primary catalyst for technological changes.

Ideal types are a critical component of this thesis' interpretation and application of CST as it pertains to technological systems. The ideal type is the foci of a technological system providing continuity in form and function of what is produced and it is the locus of technological change because as the ideal type changes so too does the technological system as a whole. But, the ideal type is just the focus of technological change. The actual means by which technological systems change is more precisely described through the processes of intentional and unintentional changes incurred through the process of technological production and the influence of technological agents.

**Intentional and Unintentional Changes**

The predominance of intentional technological change within archaeologically-based research restricts the ability to conceive of technological changes in any other way (however, see McGlade 1999:152; Schiffer and Skibo 1987:597; Torrence and Van der Leeuw 1989:10). Equally important, however, is the idea of unintentional technological change. This section describes the differences between intentional and unintentional technological changes and advocates a research agenda that utilizes both concepts of technological change. In addition, Appendix A presents the results of an experimental archaeological project designed to investigate the process of intentional and unintentional technological changes.

A research agenda that combines intentional and unintentional changes is useful for two reasons. First, a combined research agenda incorporates the punctuated events of directed and purposeful action (intentional change) in association with the acquisition of unanticipated techniques, tool characteristics, tool types, or technological knowledge in general acquired during the directed and purposeful events of technological change (unintentional change). Second, intentional technological change facilitates an open systems model of complex systems because unintentional changes are hypothesized to occur constantly as a source of diversity but are only recognized infrequently. In addition, the concepts of sensitivity to initial conditions, critical path, and contingency describe the incorporation of unintentional changes into a technological system. The adoption of unintentional changes requires first the recognition of the variation based on the contingency of the situation and critical path of the person's knowledge base, and second the emergence of a qualitatively modified technological system through self-organization in order to incorporate the new technique, tool characteristic, tool type, or technological knowledge into the pre-existing conception of the ideal type.

The concept of "intentional change" describes the active and directed process of technological creation and invention. This position, which I call "intentionalist," maintains that technological changes occur as the result of the purposeful and conscious influence of directed individuals (for example see Fairtlough 2000; Lemonnier 1993; Martin 2000:99; Schiffer 2001b; Schiffer and Skibo 1987:599), larger technological systems (for example see Pfaffenberger 1992; Roux 2003), or even creativity (Boden 1998; Hodder 1998; Kuhn and Stiner 1998). In particular, the intentionalist position relies on the direct reproduction of the forms and techniques that structure the creation of technological products (cf. Roux 2003:5; Schiffer and Skibo 1987:597; Ziman 2000:5a). Examples of the intentionalist position are found in Hodder (1998:62 emphasis added) who notes that creativity is "associated with the more active process of problem solving, imagination, and invention" and Schiffer (2001b:217) who succinctly sums up the intentionalist position by suggesting simply "in the invention process, people create…"

On the other hand, unintentional technological change refers specifically to the decision to implement unanticipated techniques, tool characteristics, or tool types achieved during the intentional production of technological products that alter the ideal type through its design strategy and use. The basis of unintentional technological change is associated directly with the inability to create a perfect one-to-one relationship between the mental conception and physical production of a technological product (cf. Ziman 2000:7a). The imperfect reproduction of a similar material product, or production of a new idea, is a result of the inherent qualities in raw material and the influences of various social, ideological, and physical contexts of both the technological product and producer. As a result, the process of technological production can be more accurately described as "production-in-kind" whereby the technological agent assesses any identifiable unintended variations based on the current ideal type and reorganizes his or her knowledge to accept or reject these variations.

Underlying the concept of unintentional technological change is the idea that unintentional changes occur constantly during every act of technological production or modification. However, a technological agent may not identify any constantly occurring unintentional changes until some later date. The ability to identify, and assess the potential of, unintentional changes is directly linked to the socially situated current context of the technological agents including the critical path (cf. Allen 1989:249) and contingency (Bentley and Maschner 2003:2) of their technological knowledge. The critical path of the knowledge available to a technological agent is essential for identifying potential in the unintended variation. A technological agent will discard an unintended variation if they have no extant knowledge to identify any usefulness of a technological variation into an existing technology or aid in the development of a new technology.

A preliminary experimental archaeology project studying the ability of nine volunteers with no knowledge of stone tool production or use to make and use stone tools underlines the duality of intentional and unintentional technological change and the role knowledge and context serves to identify and implement these changes (Appendix A). The results of this experiment provide verbal and visual evidence that each group did rely on pre-conceived ideas to direct their actions. Furthermore, during the course of intentional, directed actions to make a specific stone tool, unintentional variations were observed to occur frequently and when identified and adopted had the potential to change the ideal conception of a certain tool for the group. Finally, direct observation of each of nine participants as they adopted unintentional technological changes suggests that this process is controlled by the individual's knowledge critical path to see potential within the variation as well as how the variation can be applied within the contingency of current actions.

The contingency of a technological system concerns the social and historical situation and knowledge base of a technological system and it is crucial to both intentional and unintentional technological changes (Bentley and Maschner 2003:2; see also McGlade and Van der Leeuw 1997:2). In particular, contingency is a tool to describe how the context of a technological system must be capable to sustain sufficiently an unintentional technological change because the incorporation of unintended variations can initiate rapid and punctuated changes within a technological system.

A prime example of contingency within a technological system is the Fairbanks Morse (FM) H-20-44 Trainmaster diesel locomotive. According to the foreman of the machine shop at FM during the time the Trainmaster was unveiled (Kenneth Bunnell, 2004) and Ingles (1996), the Trainmaster was introduced on the market in 1953 and was considered to be decades ahead of its time in terms of technological efficiency. The

Trainmaster was hailed as the single greatest improvement in diesel engines since World War II. The 2400 HP Trainmaster was the first diesel locomotive to have six individual traction motors operating each of its six axles, and it was also the first locomotive to have an engine with aluminum bushings. But, the feature that has had the greatest impact on the railroading industry was the automation built into the control of the locomotive. This automation meant that one person could operate the engine instead of the standard three persons on other types of locomotives.

From the Trainmaster's technological superiority versus contemporary diesel locomotives, it seems logical that the Trainmaster would have been readily accepted by the railroading industry. Certainly, there would be more than just one of these engines remaining today. However, efficiency and superior technological qualities are meaningless unless the social context is receptive to the technology. Soon after introducing the Trainmaster, FM entered into negotiations with the New York Central (NYC) railroad for the purchase of 100 Trainmaster units. However, the NYC was concurrently also in contract negotiations with the railroading unions. The unions, fearful of the three-quarters job loss the Trainmaster would bring with it, offered to accept the NYC contract proposals so long as the NYC did not accept the FM Trainmaster contract. As an unintentional consequence of the efficiency of the Trainmaster, the NYC did not buy any new Trainmasters. Three years later, the NYC filed for bankruptcy from having to pay high personnel salaries and the chairman of the NYC railroad committed suicide. In addition to this debacle of contingency, Fairbanks-Morse, a once grandiose company among the railroading industry, was effectively cut out because they had hoped the Trainmaster would save them from impending financial ruin. The railroading industry eventually implemented many of the technological changes forecasted in the Trainmaster once the context was receptive to these changes thereby transforming the technology of railroading in the process.

Furthermore, the intentional development of the Trainmaster had specific unintentional consequences as a result of the contingency of the then current social context. It was not how the Trainmaster changed FM or the railroading industry directly, but how the Trainmaster was unable to be maintained that was contingently important; the Trainmaster was just too far ahead of its time for its social and technological context and this caused radical unintentional change throughout the railroading community.

A technological system must qualitatively reorganize itself to accommodate the changes incurred following the identification and adoption of both intentional and unintentional technological changes. In particular, the ideal type of a technology must be reconsidered and modified in order to institute the technological change. Often, the qualitative shift in the ideal type is no more than a reconsideration of the creation and use of a particular technological product since ideal types are no more than a concept held in the minds of technological agents. As for the Trainmaster example above, there were several scalar qualitative shifts in the enormously large railroading technological system. At a proximate scale, Fairbanks-Morse stopped producing railroad locomotives and focused on engines for marine or other applications. On a much larger scale, the American railroading system saw the potential, and problems, of the Trainmaster and eventually developed engines with greater personnel and mechanical efficiency.

## The Technological Life Cycle

No discussion of technological change is complete without due consideration for the macroscopic, long term changes affecting technological systems. In particular, when discussing technological changes occurring over a long period of time there must be some discussion as to how one particular technology ends and another begins in its stead. Up until now, this discussion has focused on the explanation of proximate technological events and processes. This section has one primary objective. By focusing on the long term development and eventual end of technological systems as a whole entity, this section presents a model to discuss the origin, development, peak, and decline of a complex technological system over the long term.

**The Trajectory of Long Term Technological Systems**

Due to the sensitivity to initial conditions of any technological system (cf. Williams 1997:466), no two technological systems will follow the same trajectory. Though some technological systems may appear more analogous than others, the underlying chaotic principles of any complex technological system dictates that the slightest alterations in initial conditions of any complex system create vastly different systemic trajectories. Add to this that the critical path of knowledge (cf. Allen 1989:249) and contingency (cf. Bentley and Maschner 2003:2) of any technological system creates a unique set of influences and each technological system then, by definition, is exclusive.

All technological systems, however, do follow a very similar, though much generalized, pathway from initial conception, growth, peak, decline, and abandonment. This model describes the crucial relationship between two sequential technological systems, one system succeeding the other. Furthermore, the application of complex system theory to this model provides ample ability to maneuver between the large scale, long-term processes of a technological system and the small scale, short-term dynamics between a technological agent and a technological system.

Ideally, the generalized, long-term trajectory of a technological system is best represented by a logistic curve. Logistic curves are capable of describing the origin and development of a complex technological system over time, including the limitation of systemic growth and eventual systemic decline. The natural growth pattern for a logistic system is through the S-shaped logistic curve. According to Modis (2003), the beginning of any log curve is exponential. This suggests that two users of a technology would pass on the idea to two other users, and they would pass on the technology to two other users each, and so on and so forth.

Exponential systems, however, require an equally exponential amount of resources to sustain the rapid growth of the system. Therefore, exponential systems cannot last indefinitely because of the limitations imposed by the availability of resources. Once a technological system reaches its maximum capacity of resources, the growth rates begin to slow down and eventually stabilize. McGlade and McGlade (1989:283) show that the adoption of a technology in a society follows a logistic curve in response to the initial adopters of a system, those that adopt after some delay, and the "laggards" adopting the technology after much delay. The underlying mechanism to their model is diffusion (ibid). Modis (2003) also discusses the potential of logistic curves in technological systems although he relies upon competition as being the underlying factor in the model.

**Growth and Complexity of a Technological System**

In figure 2-1, 'A' is the genesis of technology '1'. The rise in the curve (B) represents the exponentially based rate of adoption for a technology by technological users. In the past, technological adoption has been perceived to be a product of the effectiveness of a technology (Torrence and Van der Leeuw 1989:10), the representation between technology and society (Pfaffenberger 1992; Roux 2003 following Lemonnier

1989, 1993), extra-technological factors (Schiffer and Skibo 1987), and the perceived future benefits, costs, and risks of adopting the technology (Kim 2001). Technological adoption is seen here as a product of each of these factors because these variables establish the natural and social limitations with which to gauge any new technology.

Following adoption of a technology, the increase in technological users expands the capability for variation within the technological system. The expansion of the possible variation that can occur during production likewise increases the possibility of introducing greater complexity into the technological system. Complexity is a contested and speculative subject. Modis (2003:29) notes that complexity cannot be quantified. Instead he argues that the relative amount of complexity can be calculated by determining the importance of an event as directly proportional to the complexity it introduces into the system, and also by the length of the stasis preceding the next event. According to Modis' (2003) formula, a more important event would then introduce more complexity into the system, and also have a longer period of stasis following the event, than a less important event.

However, Modis' definition of technological complexity would be very difficult to apply to the African Stone Age because neither the important event nor the resulting stasis may be archaeologically visible. Therefore, instead of trying to quantify "complexity" in this thesis (*sensu* Modis 2003), I suggest that it is more appropriate to discuss the "approximation of the degree of complexity" as proportional to the frequency of technological users sharing a similar ideal type for employing, creating, and modifying a technology. As the number of users within a technological system increases, the possibility for more variation within the system is likewise increased, thereby introducing the likelihood for greater systemic and technological complexity. This idea of complexity does assume a direct correlation between quantity of individuals within a technological system and the quantity of variation within that system, but with future research this premise could be tested archaeologically.

**Peak**

The peak in the technological life cycle (Figure 2-1 label C) is a direct result of the introduction of a competing technology, and like the approximation of the degree of complexity, the peak of the technological life cycle also refers to the frequency of use of that technology. The assumption of this model is that this peak is brought on by a competing technology that draws away users of the current technological system holding other variables such as population or material resource availability constant. This limits the amount of resources and energy available to the current technological system because these resources are being redirected towards the competing system. A viable competing technology must have significant qualities that make it more appealing to the technological users, and also have the ability to operate within the users' social contexts. The new technological system must also possess enough similarity to the existing technological system to be positively recognized and received by a society. The example given earlier in this discussion of the Fairbanks-Morse corporations showed exactly this concept; the Trainmaster was too far ahead of its time, therefore, it was ill-received and greatly affected the railroading industry at that time.

**Decline**

If two technological systems are in direct competition then the adoption of a new technological system causes the decline of the existing technological system (Figure 2-1 label D). The use of the term "decline" here does not suggest the immediate eradication of the former technological system. The adoption and decline between two competing technological systems is simply a shift in the predominant application of resources, knowledge, and use from one system to another. As this shift occurs, the former technological system becomes less and less utilized. The loss of users limits the amount of variation (i.e., the approximation of the degree of complexity) within the technological system thereby restricting the frequency of future intentional and unintentional systemic changes.

Ideal types are assumed here to structure the process of decline. While in decline, the innumerable variations and knowledge attributed into the technological system will be lost (i.e., unable to be maintained) until all that remains is only enough knowledge to accomplish the task set forth by the ideal type. The removal of technological attributes during the decline of the technological life cycle is simply just another qualitative change to the ideal type and nothing more. In essence, the ideal type has changed yet again while the system is in decline, and it is in no way comparable in terms of quality, quantity, or character to prior and future states of the ideal type because of the contingency and critical path of the system's history, and ever-changing contemporary influences on the system which may seek to propel the system in new and unpredictable directions.

## Conclusion

This chapter has introduced several new concepts into CST and its application to a theory of technological change. First, I have introduced an underlying essentialist metaphysic of ideal types controlling the process of technological change. Second, I redefined context using interpretive archaeological hermeneutic and phenomenological theories in order to allow for the experiential and relativist recognition of meaning in past technological systems. I assume that ideal types imply a shared sense of meaning about how to produce and use a technological product and that this definition of context brings together thoughts and actions, the technological society and the individual. Third, I have introduced the conception of unintentional technological change drawing from the assumed inability of a technological producer to ever identify and create a perfect copy of the preconceived mental conception (i.e., ideal type) and physical production of a technological product. Fourth, I have introduced a model of long-term growth, peak, and decline of technological systems including the creation of complexity within a technological system.

Therefore, using CST, as I have modified it here, I believe that human actions and internal and external influences can be appropriately modeled through the device of a system. In particular, this modified Complex Systems Approach is aptly suited for modeling technological systems because it facilitates dynamic events that can abruptly alter the trajectory of a technological system while also accounting for the contemporary and historical context of the technological system. Furthermore, the multi-scalar capability of CST easily allows for descriptions of technological influences and change on both micro and macroscopic levels. By far the most advantageous quality of CST, as it is applied within this thesis, is its ability to incorporate both material culture and non-material cognitive ideas and behaviors of individuals to explain the changes within a technological system.

Thus, I believe that the application of CST within studies of technological change has the potential to provide significant improvements in the way technological change is identified and described. The following chapters move beyond a purely theoretical discussion of CST within technological change and provide a methodology for operationalizing this theoretical approach within archaeological and ethnoarchaeological research. To do this, chapter three introduces the application of computer assisted shape analysis (morphometrics) to analyze morphological changes in archaeological flake debitage. Finally, chapter four presents the results of a morphometrics analysis of two Stone Age sites from the Horn of Africa and applies CST, as described in this chapter, to interpret the results.

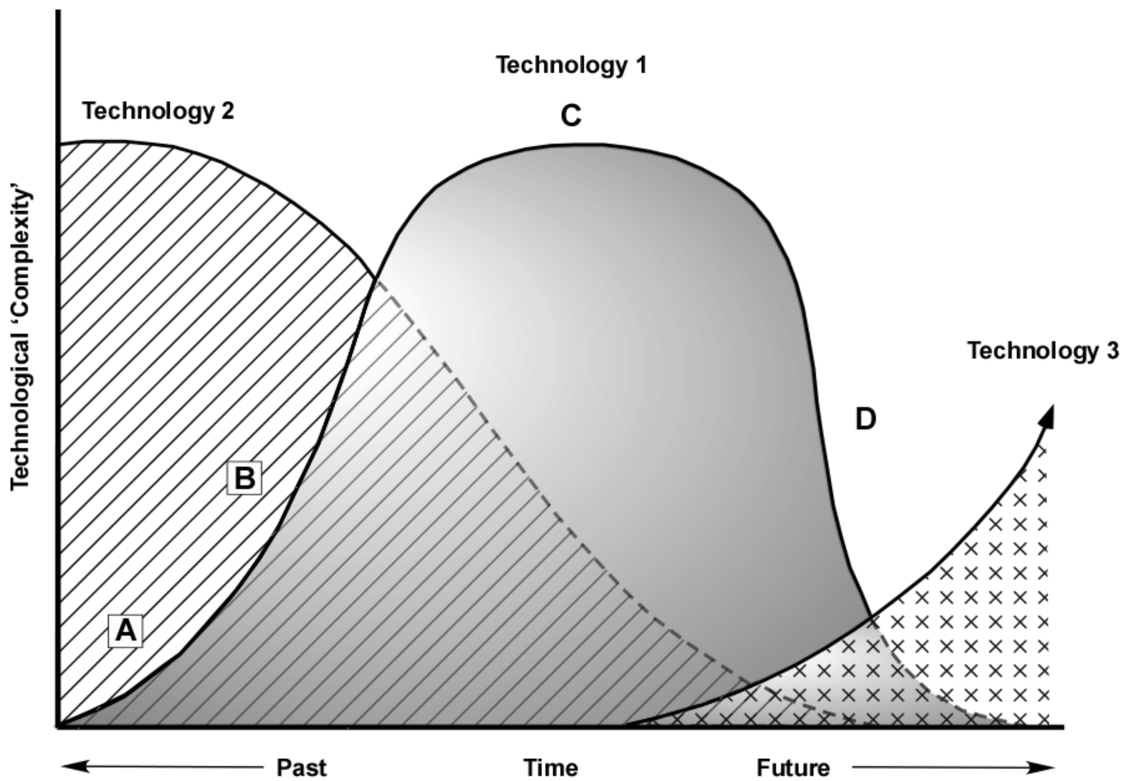


Figure 2-1 The technological life cycle of three different technological systems. Technology 1 is a complete life cycle representing the genesis, adoption, stasis, and decline of any technological system. Technology 2 represents a technological system in decline and Technology 3 represents the genesis of a technological system competing with Technology 1 and 2 for technological users and other resources.

# CHAPTER 3
# PUTTING A SHAPE ON TECHNOLOGY

Until now, this thesis has focused primarily on the theoretical background for a complex systems approach to technological change. The task is now to show how a complex technological system, relying on the assumed cognitive ideal types posited in the theory, can be identified in the real world. This chapter seeks to find a method to answer the following questions: 1) how can we observe technological change in the archaeological record using computer-assisted shape analysis and interpret these changes using a complex systems approach, 2) how can we identify the variations around cognitively-based ideal types through an analysis of form in the archaeological record, and 3) how can we observe the changes of ideal types through time?

## Morphometrics

In my model I propose that the process of technological change is measured in terms of the attempts to replicate the ideal conception of a particular tool based on a specific function and context. However, because of deterring factors found in the somatic actions of the technological agents, properties of the raw materials, and extrasomatic influences such as the spatio-temporal environment, the ideal type can actually never be materialized. Thus, according to this model technological change is found in the shifts of the ideal type over time as evidenced by the always imperfect materialization of the ideal type. Therefore, if the ideal type consists of a configuration of specific fundamental formal properties of a technological product, as I have suggested, then it is plausible that the morphometry of the materialized technological products should provide an avenue to study the variations around an ideal type through time and the change from one ideal type to another. The pursuit of this theoretical model further requires methods that can identify the relative shapes of the ideal types and map their changes over time.

Morphometrics is the study of the shape, or more general morphology, of an object. The analysis of shape has been a research topic in anthropology for a great deal of time. In particular, the use of shape to classify stone tools has existed since the early 20th century. Black and Weer (1936) presented a lithic typology that identifies the basic form of the object by classifying it either as “rectanguloid”, “trianguloid”, or “circuloid.” Currently, many lithic analyses commonly categorize artifacts based on their cross-section, profile, and plan-view. However, the problem with such terminology, and application methodology, is the inherent subjectivity and ambiguity found in the distinctions between one shape type and another (cf. Gero and Mazullo 1984:317; Rovner 1995). What is “sub-rectangular,” and how is it different from “rectangular” or “square,” for example? The problem lies in the ordinal nature of this system. Shape is not based on an objective and pre-defined reference point. Rather shape is defined based on the degree of difference from another similar shape (Gero and Mazullo 1984:317). For example, rectangular is more elongated than “sub-rectangular,” which is more elongated than “square,” “sub-circular,” or “circular[1].” Although the classes of shapes such as “square,” “rectangular,” or “circular” may be used with explicit definition, the gradations between these classes are ambiguous. Furthermore, shapes of actual artifacts rarely, if

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[1] Here, square refers to an object with four equidistant planes connected through rights angles. ‘Rectangular’ refers to an object with two pairs of equidistant planes connected through right triangles whereby one pair of planes is longer than the other. ‘Circle’ refers to a plane curve equidistant from a fixed point.

ever, conform to easily classifiable shapes such as “square” or “circle.” As a result this system of morphometry does not provide an adequate method to differentiate objectively between categories of shapes either qualitatively or quantitatively.

There is also currently no well-defined standard of shape or measurement in the analysis of stone tools; ten different projects can have ten different systems to describe shape and record measurements. Quantitative systems of measurement, which might be perceived as objective and straight-forward, actually contain a great deal of ambiguity and subjectivity. Take the measurement of flake “length,” for example. Andrefsky (1998: ch. 5, 85-109) devotes an entire chapter on measuring stone tools, including several pages describing solely how to measure flakes. According to him (ibid: 97), one method to measure a flake is by orientation. In this method the recorded length of a flake can actually be shorter than the “actual” length of the flake if that flake is oriented so that the line perpendicular to the striking platform intersects a lateral margin before reaching the distal end (Figure 3-1a). Andrefsky (1998:98) also mentions two other methods to measure flake length including length perpendicular to striking platform width (Figure 3-1b) and length as the maximum distance from the proximal to dorsal ends (Figure 3-1c). Rovner (1995) also argues that mathematically the greatest length of a flake is not parallel to the axis of the flake but is, in fact, diagonal to the proximal and distal edges (Figure 3-1d).

**Standardization**

There has been scant research designed to transcend the lack of standardization and subjectivity found in lithic shape analysis and dimensions measurement. Gero and Mazullo (1984) discuss the use of a Fourier test to objectify the shape of a flake, while Dibble and Chase (1981) employ a parallel scale to measure ten points on an artifact.

Yet, in spite of solutions such as these, contemporary lithic analysis still has not adopted a less-subjective and standardized methodology to record the shape and dimensions of stone artifacts. Therefore, to move beyond this perceived deficiency, I have employed computer-assisted imagery analysis as a method to provide an objective measure for lithic archaeological research.

Computer-assisted imagery analysis uses computers to measure the shapes of objects using digitized raster images taken of the objects. Any object can be digitized, and simple digitization can be achieved using a digital camera, scanner, or video recorder. Digital images are recorded in a pixel-based Raster format. In this format each pixel in the image has a particular value corresponding to its color displayed on the screen. The Raster format is significant because it introduces the possibility of mathematically analyzing and manipulating the pixels in an image. There is a primary drawback to this method, however. Raster images are dependent on the pixel resolution of the image. Therefore diagonal lines have to proceed over and down around the borders of specific pixels. If the resolution of an image is set too low, then the pixelation of the object could potentially alter an analysis.

The computer assisted imagery package used in this research was the Image Processing Toolkit® version 5 (IPTK) developed by Reindeer Graphics, Inc. As shown in figure 3-2, after digitizing an image, the necessary next step transforms this image into binary raster format. Color images can contain millions of colors and thus an equally great amount of values for its pixels. Programs such as the IPTK have the ability to isolate each pixel value, but this does not identify the actual object in the image. In essence, the program cannot sense the forest from the trees. Therefore, the user must first select each object intended for analysis within an image (Figure 3-2a). Within Adobe Photoshop®, objects within an image are selected using the Magic Wand tool. This tool selects a range of pixels with similar digital number values based on the input pixel value. The conversion to binary format isolates each selected feature within an image and reclassifies the value of pixels contained within its area as '1'. All other pixel values are reclassified as '0'. The end result of a binary transformation is a white image with a series of black silhouettes of the objects that were selected (Figure 3-2b). Although this process eliminates all other color information embedded within the image, by reclassifying pixels as either '1' or '0' (i.e., "on" or "off"), it also provides the ability to accurately employ mathematical calculations of shape and dimension on the silhouetted objects within the image.

Morphometrics analysis has several primary benefits. First, hundreds of artifacts can be digitized in an expedient manner providing more time for an analysis or the collection of more data in the same amount of time. Second, morphometrics increases the efficiency of data collection because more than one object can be represented within a single image (for example see Figure 3-2a). Personal experience has shown that up to sixty flakes can be included within one digital image without variations in morphometric statistical results within four significant digits. However, as noted above the pixel resolution of the image is a significant constraint in the ability to record many objects in one image. Although pixel resolution can be increased, this also increases the size of the computer file. Therefore, the researcher must first decide on the relation between pixel resolution and image size versus recorded area and number of objects. Third, the entire analysis process from image procurement, binary conversion, and tabular data output rarely takes longer than a few minutes. For example, as will be discusses in chapter four, in preparation for this thesis research, I was able to analyze morphometrically over 1800 flakes in two weeks' time.

By far the most advantageous aspect in employing computer assisted morphometrics is the ability to ensure a measure of objectivity and standardization within lithic morphometry. Computer-assisted image analysis programs such as the IPTK come with a pre-set suite of shape and dimension functions based on contemporary morphometrics techniques. The only subjectivity within computer assisted shape analysis is found in the relationship between the real world shape of the object and its pixelized raster image. The techniques used to measure the shape and dimension of objects quantitatively provided in morphometrics programs are not subjective. Computer-assisted shape analysis is objective because the program does not analyze shapes as "shapes" per se rather it simply quantifies the patterns of pixels with a value of '1'.

**Measures of Shape and Dimension**

The standardization and limited subjectivity of computer assisted shape analysis is linked to the methods the program employs to measure the selected objects. Among the many measures of shape and dimension that the IPTK records are area, perimeter, "x-feret," "y-feret," length, and width. Unlike the ambiguity discussed earlier for measuring the length and breadth of an object, computer-assisted analysis works around this issue by relying on only two distinct and predefined measures of length and breadth. The first measure of length and breadth, for example, is called "X-Feret" and "Y-Feret." These are measures of the widest points of an object on the x and y axes respectively. These measures are dependent upon the orientation of the object relative to the x and y axes

(Figure 3-3). Values for "X-Feret" and "Y-Feret" are recorded in pixels. In contrast, the measure for "Length" records the distance of the longest arc between two points within an object (maximum caliper distance) whereas "Breadth" measures the minimum caliper distance (Figure 3-4) (Russ 2002; Rovner 1995). Both "Length" and "Breadth" operate independent of object orientation.

The IPTK software outputs a text file of over 20 different calculations of shape and dimension. Not all of these values were used in this research. Therefore, this discussion will be limited strictly to those measures used to analyze lithic flakes. In particular, I will discuss the use of "formfactor," "roundness," "aspect ratio," and "elongation" in conjunction with a separate measure that records the ratio of the "formfactor" and "roundness" values of an object.

Formfactor, roundness, aspect ratio, and elongation are dimensionless measures. This means that they record similar values depending on the shape of an object irregardless of size. The mathematical formulas for these measures are shown in Appendix B. Formfactor measures the changes in the perimeter of an object irrespective of the elongation of the object (Russ 2002; Rovner 1995). Essentially, the formfactor measures the edge roughness of an object. Roundness, on the other hand, measures how round an object is independent of the object's perimeter roughness (ibid). Used together, the formfactor and roundness indices provide a very descriptive analysis of the shape of an object. Both of these measures are calibrated against a perfect circle which has a value of '1'. Within both measures, greater values indicate the degree of departure from a perfect circle. Figure 3-5a shows several "generic" shapes including a circle, square, rectangle, and triangle and their corresponding formfactor, roundness, elongation, and formfactor divided by roundness values for comparison. Figure 3-5b shows these same morphometrics measures for more amorphous shapes. In particular, figures 3-5a and 3-5b illustrate the differential change in formfactor and roundness values as the perimeter (irregularity) and roundness (elongation) diverge more and more from a perfect circle.

The quantification of shape is certainly a benefit for objectivity and standardization in analysis, but it is also a problem as well. If I told another person that an object is "sub-circular" then that other person might have a rough indication of what shape I am discussing albeit most likely with slight subjective differences from what I think is "sub-circular." However, if I were to tell this same person that a specific object had a formfactor and roundness value of '0.89' this most likely would not connote that I have actually just described a very similar "sub-circular" shape because we do not use numbers to classify shapes in everyday activities. The ability to use this quantitative shape analysis, therefore, hinges on a firm understanding of how the measures operate because the values themselves have little relevance to everyday activities.

The other two default measures of shape introduced earlier are elongation and aspect ratio. Elongation measures the skeleton length of an object divided by the mean fiber width (Russ 2002; Rovner 1995). Skeleton length is the length of the centerline of the object. The skeleton is created by removing all pixels in an object except those that make up the midline. Mean fiber width measures the mean distance from all pixels in the object skeleton. Aspect ratio is essentially the same measure as cephalic index and it measures the length of an object divided by its breadth (ibid). Figures 3-5a and 3-5b illustrate the properties of elongation using similar shapes as formfactor and roundness.

Finally, the Formfactor divided by Roundness was used to provide a relative index of the irregularity of an object versus its roundness. A perfect circle still has a value of ‘1’. However, as the perimeter increases relative to the elongation (greater irregularity in the shape of the perimeter) the morphometry values will be lower. In contrast, an object with a low perimeter irregularity and a high elongation will have a larger number (Figure 3-5a and 3-5b).

**Flakes**

The whole purpose of employing a morphometrics approach in this research is to identify the relative patterns of the shape of stone tools over time and interpret the process of these patterns using a Complex System Theory and cognitive ideal types. At first it seems logical to analyze the actual tools that embody directly the thoughts and actions of technological producers. Such shaped tools theoretically reference the ideal type in their very shape; that is, their shape reflects the ideas people held about how to produce the tool as best they can. Other researchers have also focused on the shape analysis of formal tools as well (Rovner 1995). However, it is widely known that the morphology of formal tools is modified over time through use, repair, and modification (Frison 1968; Jelinek 1976; Rolland and Dibble 1990). If it could be reasonably ascertained that a formally designed tool was not modified throughout its use life then this would be an appropriate line of investigation. However, while formal tools approach a direct one-plus representation of the ideal type of the technological agent, the debitage produced to make these formal tools should in fact be an “inverse representation" of the ideal type. To phrase this another way, stone tool production debitage reflects those characteristics that are inversely associated with the ideal type. Essentially, this method is akin to analyzing Michelangelo’s David by only studying the shapes of the bits of rock that he chipped off the main block. Predominantly (because there are always mistakes and unintended variations), the debitage produced during the sculpting of stone (i.e., flaking) was removed because the producer consciously seeks to remove characteristics incompatible with their ideal end type conception.

During the analysis of the data for this research, I have relied on whole flakes as the primary morphological data source. I believe that flakes are the by-products of an intentional and predetermined process by the toolmaker and when analyzed together they represent the generalized underlying intentions of the technological system referenced to create that assemblage of artifacts. Primary, secondary, and tertiary flakes, as well as stage of manufacture to produce flake debitage may prove morphometrically identifiable with future research. However, this study group encompasses all of these groups into just one category—flakes—as a representation of the overall inverse ideal type. The incorporation of a statistically significant sample size of flakes should then represent an average ideal type conception for the range of tools used during one specific time period. Changes in the shapes of the flakes should then correspond with changes in the conceptions of the ideal tool forms, intentionally or unintentionally. For example, if a lithic technological system is modified to produce more elongated tool forms than were produced prior, the flake debitage should show a related altered morphology to facilitate these changes. If the changes in the conceptions of tool forms represent a gradual and continuous process of technological change as I have suggested previously then the application of morphometrics to a study of flakes should show trends of gradual technological change within the archaeological record.

## Conclusion

Computer-assisted shape analysis is a unique technique to study the morphometrics of objects. It provides standardization within an analysis and a means to analyze large datasets relatively quickly. Morphometrics is also relatively inexpensive. By applying a morphometrics analysis to study flake debitage, and explaining this data using a Complex Systems approach, the next chapter will explore how this method and theory combination usefully identifies technological changes within two sets of data.

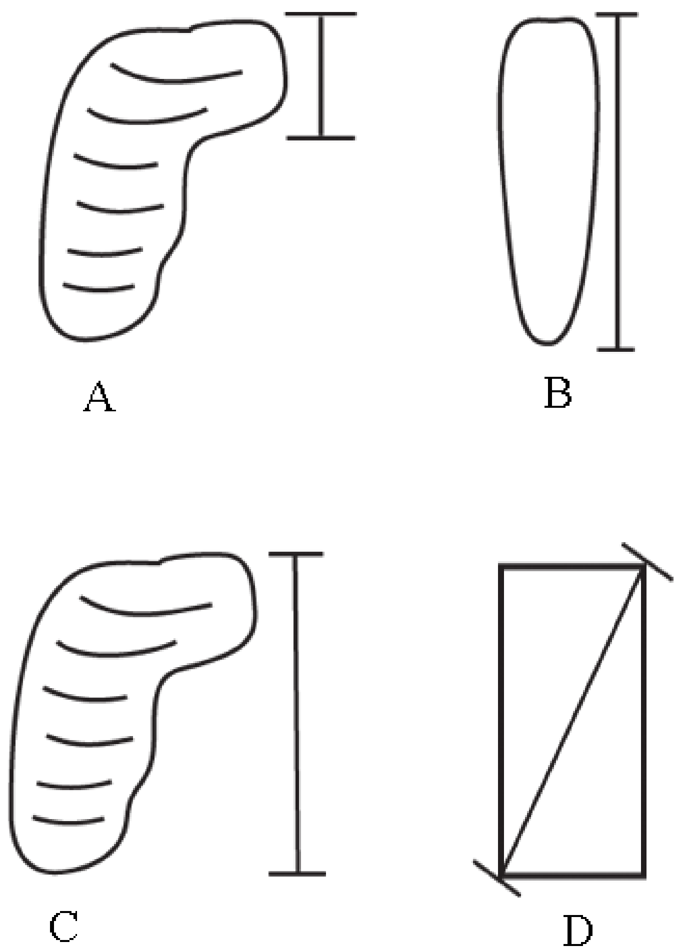



Figure 3-1 Measurement of flake “length” varies based on the methods used. In Figure 3-1A, flake length is the intersection with a lateral margin of the flake prior to reaching the distal edge of the flake. Figure 3-1B represents flake length perpendicular to striking platform width. Figure 3-1C represents how the flake shape of Figure 1A also can be measured as the maximum length from the proximal to dorsal flake ends irregardless of lateral margins. Figure 3-1D, however, shows that mathematically the greatest length of any rectangular flake is actually diagonal to the proximal and distal flake edges.

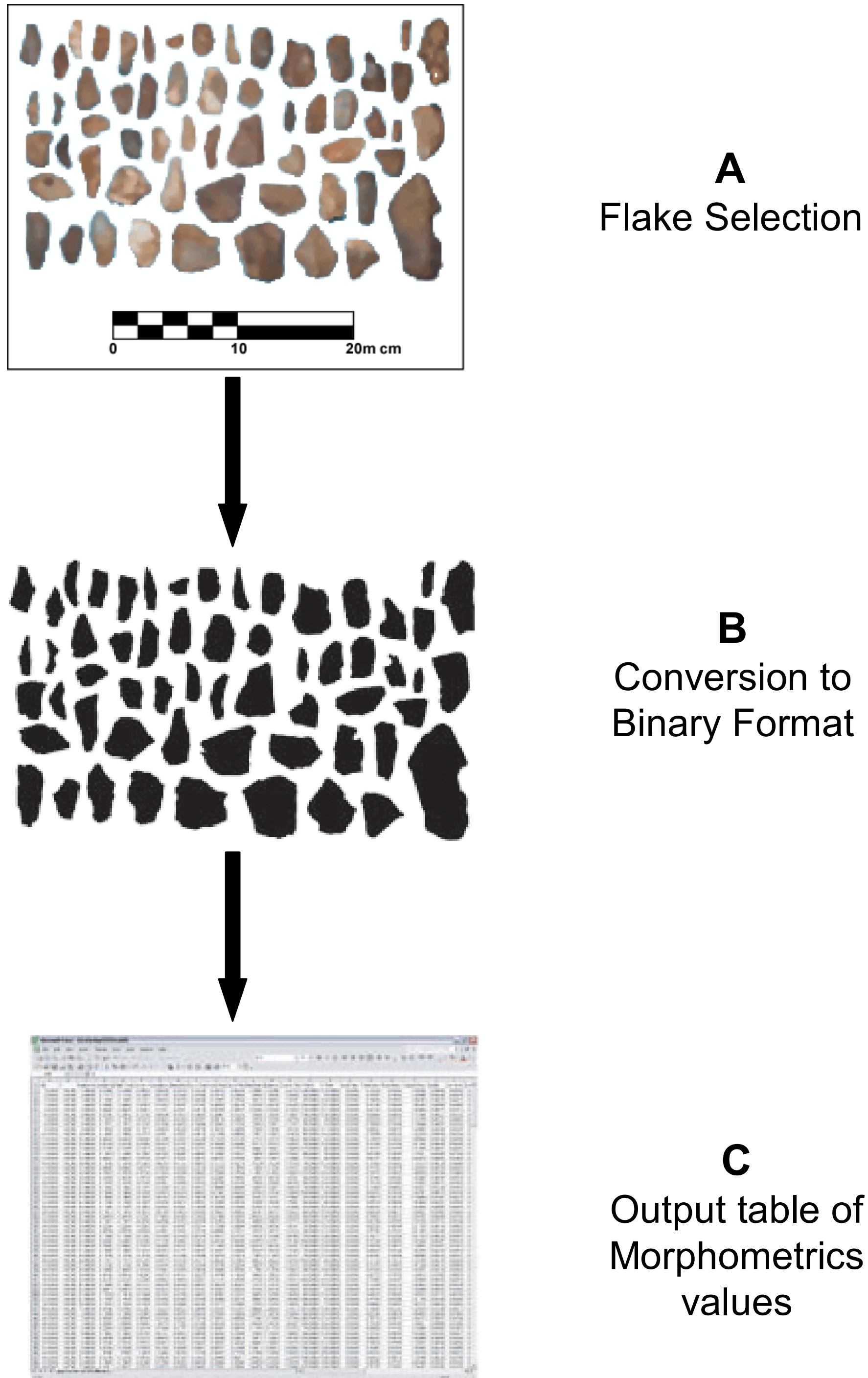



Figure 3-2 The steps necessary to conduct a morphometrics analysis using computer-assisted shape software. Flakes must first be positioned within a photograph and then selected using a graphics program. Next, the selected flakes are converted into binary format. Finally, after running the morphometrics software the program creates a table of morphometrics values.

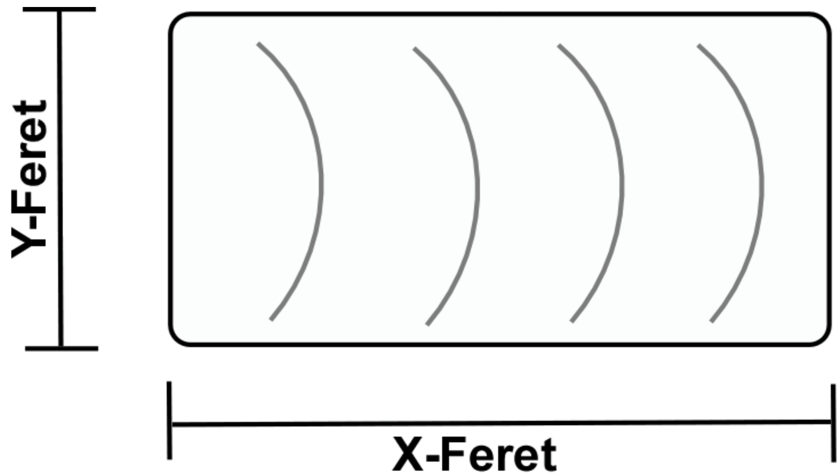



Figure 3-3 X-Feret and Y-Feret represent measure the widest points of an object dependent upon an object's orientation to the X and Y axis.

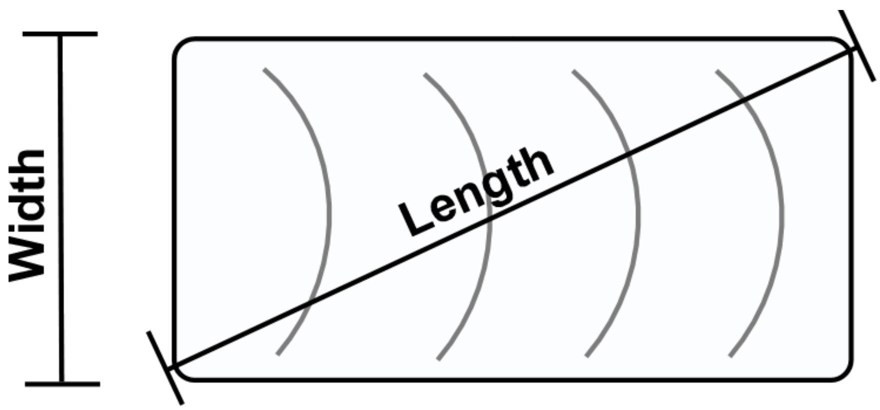



Figure 3-4 In contrast to X and Y-Feret (figure 2-4), Figure 3-5 illustrates how the Image Processing Toolkit represents "length" and "breadth" of an object. Here, length represents the distance of the longest arc within an object (maximum caliper distance) whereas the breadth measures the minimum caliper distance of an object.

| | | | | | |
|---|---|---|---|---|---|
| **Formfactor** | **0.929** | **0.767** | **0.789** | **0.662** | **0.595** |
| **Roundness** | **0.986** | **0.485** | **0.646** | **0.464** | **0.570** |
| **Elongation** | **1.007** | **2.294** | **1.009** | **2.334** | **5.103** |
| **FF / RR** | **0.942** | **1.583** | **1.221** | **1.428** | **1.043** |

A

| | | | |
|---|---|---|---|
| **Formfactor** | **0.368** | **0.302** | **0.171** |
| **Roundness** | **0.631** | **0.389** | **0.169** |
| **Elongation** | **9.909** | **12.236** | **21.819** |
| **FF / RR** | **0.582** | **0.776** | **1.011** |

B

Figure 3-5 How different morphometrics statistics measure different shapes of objects. Figure A illustrates how the formfactor, roundness, elongation and formfactor divided by roundness statistics characterize common shapes. Figure B represents the same morphometrics statistics applied to more amorphous shapes. Figure B adapted from Rovner 1995.

# CHAPTER 4
# THE GILGEL GIBE AND GOGOSHIIS QABE MORPHOMETRICS ANALYSES

## Introduction

Computer-assisted morphometrics analysis was presented in the preceding chapter as a means for identifying technological changes within the archaeological record using flake debitage. Morphometrics analyzes the shapes of object, such as flakes, and can provide a clear indication as to how shapes of objects change through time.

Flake debitage is especially useful to study within a morphometrics analysis for three reasons. First, flakes are frequently found at archaeological sites, many times being the most prevalent artifact type. Second, whole and unmodified flakes, unlike shaped tools, do not change morphology during their use-life. There may or may not be a correlation between flake debitage shape and stage of manufacture for the tool being produced, between primary, secondary, tertiary, and retouch flakes, and even raw material. However, this analysis assumes that grouping all whole, unmodified flakes into one category, and measuring the total variation of flake shape within this generalized group, will provide an overall measure of the flake shape per assemblage. Third, in spite of being unable to determine reliably the exact stage of manufacture of a shaped tool, an analysis of flakes provides an alternative window into the technological system. Instead of looking directly at final tool forms, analyzing the debitage removed to create such tools provides an inverse portrait of the ideas and intentions within the minds of prehistoric technological producers using a reductionist process. As noted in chapter four, a morphometrics analysis of flakes is akin to studying Michelangelo's David by studying only the debris removed from the final shaped form; the key element—the sculpture itself—can not be clearly discerned, but by studying what was removed to make that sculpture, we can acquire some idea of what it may have represented.

Therefore, the focus of this chapter is the application of morphometrics analysis on flakes from the two Stone Age sites of Liben Bore in southwestern Ethiopia and Gogoshiis Qabe, southern Somalia. Drawing upon CST, particular emphasis is given towards identifying long term technological change within each dataset and describing the perturbative actions of the lithic technological system around the assumed existence of ideal types. At the conclusion of each section, each dataset is compared against current culture historical sequences within each area in order to discern more particular technological characteristics within the data and also provide some measure of unification with currently employed chronological methods.

## Liben Bore

Between 1999 and 2002, archaeologists from the Gilgel Gibe Archaeological Project (GGAP) conducted a series of emergency surveys and site excavations in the Gilgel Gibe River Basin of Southwestern Ethiopia in conjunction with the Ethiopian government's plan to construct a major hydroelectric dam and reservoir (Brandt 2000; Kinahan 2004). GGAP identified and recorded many archaeological sites, including GG35, an open air site situated 30 meters west of a small river that feeds into the Gilgel Gibe River, but unfortunately directly in the path of a new road to be built around the edge of the reservoir. First identified by a lithic and ceramic surface scatter, two $1m^2$ test units were excavated at Liben Bore, followed by four 1x2 m units taken down in 10 cm spits. These excavations exposed over two meters of stone and ceramic artifacts embedded within silty clay deposits thereby revealing the deepest archaeological sequence in southern and western Ethiopia and the second deepest sequence in all of Ethiopia.

Since no faunal remains and only very small amounts of charcoal from the uppermost levels were recovered from the homogeneous silty clay deposits, radiocarbon dating of the sequence has not been possible. Furthermore, the homogenous clay deposits of Liben Bore have not as yet lent themselves to OSL dating. Typologically, occupation of the site appears to span more than 30,000 years from the late Middle Stone Age/early Later Stone Age through the Iron Age, and may span the Pleistocene/Holocene transition as there appears to be no evidence of a depositional hiatus or disconformity. Excavations revealed three major litho-stratigraphic units from surface to bedrock:

- LSU1 occurs from the surface to 20cm below surface (surface to excavation level 1) and is a very dark brown clay encompassing Later Stone Age, Neolithic or Iron Age lithics and ceramics.
- LSU2 occurs from about 20cm to 60cm below surface (excavation level 1 to level 3). LSU2 is a reddish brown clay containing Later Stone Age/Neolithic lithics and ceramics. Lithics increase in quantity within this unit.
- LSU3 occurs from 60cm to 200cm below surface (excavation level 4 to level 18). This unit is a dark reddish brown clay. At approximately 100cm below surface pottery disappears and only lithics remain. At this time new elements in lithics appear including higher frequencies of blades and unifacial and bifacial points.

The analysis of the Liben Bore artifacts was undertaken at the National Museum in Addis Ababa, Ethiopia. A. Negash (2004) recently completed an attribute analysis of the Liben Bore shaped and unshaped tools and cores, while B. Kimura (2003) has analyzed the Liben Bore ceramics. Due to time constraints, I focused largely upon the morphometric and techno-typological analysis of flakes from two excavation units (S14W1 and S23W1).

Prior to GGAP, very little was known about the Stone Age archaeology of the Gilgel Gibe area, or for that matter Southwestern Ethiopia. It was this precise lack of knowledge for this large area that provided the impetus to search for new and more expedient methodologies (i.e., morphometrics) that might help resolve the inadequacies of culture historical typologies.

**Morphometrics Analysis**

Morphometric analysis of the flakes included a series of measurements such as formfactor, roundness, elongation, aspect ratio, and X-Feret and Y-Feret. Before any descriptive statistics are generated from the data, the data are further represented graphically by plotting the excavation levels of the entire dataset on the X-axis and the particular morphometric value on the Y-axis (Figure 4-1 to 4-6a and b). Visual analysis of these graphs is an essential first step in the analysis of this data because it provides the analyst the opportunity to observe how the data changes and note any possible patterns within the dataset. Within this analysis, initial pattern recognition was based on the changes in the mean morphometrics value between excavation levels, changes in the standard deviations of morphometrics values between excavation levels, and the changes in the extreme upper and lower morphometrics values between excavation levels. Particular emphasis was also given to rapid changes (i.e., between one or two contiguous excavation levels) in the variance of morphometrics values between excavation levels.

There are two initial observations of the Liben Bore morphometrics data based only on the visual analysis of the data. First, the flakes represented within the morphometrics graphs appear to change shape through time. Since there appears to be no evidence of disconformities in the depositional sequence, the Liben Bore flakes appear to change shape gradually. Second, there appear to be three different patterns observable within the

Liben Bore sequence. These patterns correlate with excavation levels 1 to excavation level 8 (pattern 1), excavation level 9 to excavation level 14 (pattern 2), and excavation level 15 to excavation level 26 (pattern 3). Of the total flakes within the dataset, pattern one contains 11.55%, pattern two contains 49.31%, and pattern three contains 39.14%. The trends within and between patterns suggest that pattern three, the oldest and lowermost pattern of the dataset, contains flakes that are distinctly ovate and lack much elongation (Figure 4-4) or edge irregularity (Figure 4-1) than the rest of the dataset. By comparison, in pattern two flake shape is much more elongated and has greater edge irregularity. In pattern one the flake shape has transitioned back to a less elongated form than in period two but does not appear as ovate as seen in period three. Because each morphometrics measure is independent of other morphometrics measures, the patterns noted visually within each morphometrics measure (n= 6) of the dataset are suggestive of several lines of independent evidence of specific patterns within the data

Therefore, the inter-pattern differences and trends within the dataset were further identified using quantitative statistical analysis including analysis of descriptive statistics, t-test, and cluster analysis. In order to quantify each pattern, the mean, minimum, maximum and standard deviation of each morphometrics measures per excavation level was first calculated. These data were then used to calculate the average standard deviation, minimum, maximum and mean values per pattern range within the data. The results of this analysis suggest that pattern three has a mean aspect ratio of 1.5384, a mean formfactor of 0.6895 and a mean roundness of 0.6104. The aspect ratio value suggests a slightly elongated form, the roundness value also suggests a slightly elongated shape but also fairly ovate, and the formfactor indicates a low level of edge irregularity (refer to Figures 4-1, 4-2, and 4-3 comparison).

The values for pattern two, however, contrast markedly with pattern three values. Pattern two has a greater mean aspect ratio value (1.760) indicating more elongation, a lower formfactor value (0.655) indicating more edge irregularity, and a lower roundness value (0.551) indicating these flakes are less round than flakes in pattern three. In particular, the aspect ratio (Figure 4-3) in pattern two is greater than pattern three by a value of 0.222. This suggests that the flakes in pattern two are much more elongated than flakes in pattern three. When this value difference is compared to the mean aspect ratio of flakes in pattern one (1.613) it indicates that the flakes in pattern two are the most elongated of the entire dataset.

Pattern one is relatively similar to pattern three in terms of having a more ovate flake shape with decreased edge irregularity. In particular, the mean aspect ratio value (1.613) for flakes in pattern one indicates a more elongated form than the flakes in pattern three (1.538) though by no means as elongated as flakes in pattern two (1.760).

A t-test was further conducted on this data to determine the statistical difference between the inter-pattern mean values within the dataset (Table 4-1). According to this test, there is no statistical difference between the mean values for pattern one or pattern two, there is a small difference between mean values in pattern one and pattern three, and the mean values for pattern two are statistically different than each of the other two patterns. The alpha value for this test was set at 0.05.

A cluster analysis of the Liben Bore data using the standard deviation and mean values per excavation level for the roundness, aspect ratio, and formfactor measures also supports the differentiation of period two from periods one and three (Figure 4-7). According to these results, most of the excavation levels identified earlier into pattern two (excavation level 9 to level 14) as well as levels 6, 8, 17, and 18 cluster together at a rescaled cluster case distance of 25. The remaining excavation levels cluster together into another main group with small sub-clusters at differing scaled cluster distances. The significance of these results will be discussed below.

**Understanding the Liben Bore Data**

Although it is still unknown when certain technological changes occurred precisely at Liben Bore, the morphometrics analysis of the Liben Bore flakes suggests evidence for technological change within the 26 excavation levels of units S14W1 and S23W1 at this site.

The Liben Bore dataset represents three morphologically different technological patterns during the times of occupation at this site. Theoretically speaking, and ignoring other potential sources of variation, the analysis of the morphometrics data suggests that pattern three (excavation levels 26 to level 15) is characterized by an ideal type emphasizing the production of ovate flakes with little edge irregularity or tools requiring the removal of ovate flakes for proper tool production. The flakes in pattern two (excavation levels 14 to level 9) indicate a much different ideal type. Here, the technological system emphasizes the production of more elongated flake forms, which may be indicative of more elongated tool forms. In pattern one, however, the ideal type changes yet again, this time back to a more ovate shape reminiscent of pattern three.

Drawing upon the theoretical discussion of the technological life cycle presented in chapter two, the Liben Bore dataset could represent the peak and initial decline of the lithic technological system within the Gilgel Gibe region of Ethiopia. If this is an accurate assumption, pattern three would represent a still-developing lithic technological system while pattern two represents the peak of the lithic technological system within this area.

The end of pattern two (level 9) or the beginning of pattern one (level 8) may further represent the introduction of a competing technological system as perceived from the conception of complexity, which reflects the number of users of a technological system and emphasizes the ability for more intentional and unintentional variations within a technological system for greater technological variability. Technological variability is identified within the Liben Bore dataset by calculating the standard deviation of each morphometrics statistic per excavation level. Excavation levels with less flake shape variability are assumed to correlate with less technological complexity, and should exhibit a lower standard deviation than excavation levels with greater s technological complexity.

Once the standard deviation values of each morphometrics statistic are calculated and grouped into the three patterns, the mean of these values is taken and then used to compare against each of the other two patterns. In comparison against the mean standard deviation for the formfactor, aspect ratio, and roundness of pattern one and pattern three, pattern two has a much greater standard deviation than either the other two patterns (table 4-2). If standard deviation is an accurate representation of the degree of perturbation due to the complexity of a technological system, then it can be concluded that pattern two has possibly the greatest technological variability and technological complexity of the entire dataset.

Furthermore, a separate technological system, in the form of ceramics, may have directly or indirectly influenced the local lithic technological system. Analysis of the ceramics recovered at Liben Bore suggests that ceramics are first introduced to this site around level 8. Negash (2004) has suggested that the introduction and adoption of ceramics most likely also entailed the restructuring of food procurement strategies and group mobility (Negash 2004). Therefore, the shift in procurement strategies and group mobility may have inadvertently enacted changes to the predominant application of certain technological resources including knowledge, technological producers, and users from the lithic technological system. This does not deny that a lithic technological system still occurred during and after the adoption of ceramics. However, based on the model of complexity advocated within this thesis, the lithic technological system would exhibit less variability following the adoption of a competing technological system and would be in a state of decline because the shift in subsistence strategies and mobility would re-direct the application of knowledge and resources to produce and maintain certain technologies.

The possible loss of technological producers within pattern one also would create a technological system incapable of maintaining existing technological variability or creating new variability. Unnecessary variations were discarded leaving in place only those variations necessary for the fundamental application of lithic technology. As a result, the remaining vestige of the lithic technological system within trend one assumed the appearance of a less complex and less variable technological system. Due to similar levels of complexity, trend one and trend three should appear similar. The t-test and cluster analysis results of the morphometrics values do suggest that pattern one and pattern two are statistically similar to one another and cluster together when compared to pattern two. However, any such similarities between pattern one and pattern three are purely superficial as the essential character—that is the ideal type—in pattern one is qualitatively different than the ideal type in pattern three; pattern one merely represents the continuation of qualitative change to the ideal type and technological system via the technological life cycle.

Thus far, the morphometrics analysis has been able to identify three patterns within the Liben Bore dataset, statistically differentiate these patterns, and identify the morphology of the flakes within each pattern that are indicative of the ideal types. Furthermore, this analysis has suggested how to measure the perturbation around ideal types and the technological changes between each pattern via alterations to underlying ideal types. Given the limitations and restrictions of the model, this analysis has been able to identify technological change through time based only on a shape analysis of flakes.

Morphometrics analysis, however, is not a standalone method. If only a morphometrics analysis on flakes was conducted for a site, this leaves out vast bodies of data including shape tool analyses. Concurrent with the Liben Bore morphometrics analysis, which analyzed 1,810 flakes, this author also conducted a techno-typological analysis of the shaped tools (n > 1,900) recovered from excavation unit S14W1 at Liben Bore. This analysis was followed with a similar analysis (n = 2,555) by A. Negash who analyzed Liben Bore units S23W1 and S23E1 in conjunction with the prior analysis results from S14W1.

From these analyses, a much more coherent picture can be made of the Liben Bore data. As a whole, the dataset is scraper-dominated in all three excavation units with a large quantity of points also at S14W1 (n = 19) (cf. Negash 2004). Negash (2004) subdivides the Liben Bore data into two distinct time periods based on the introduction of pottery in level 8 and the more apparent expedient nature of the lithic assemblage between level 8 and level 1. The expedient nature of the lithic assemblage between level 8 and level 1 could indicate a more sedentary lifestyle as a result of changed technological, economic, and associated mobility patterns. Furthermore, Negash (2004) recognizes that the earliest levels in the Liben Bore sequence, which contain the Levallois technique, may in fact also represent another separate time period.

Based on the very similar results from the morphometrics and techno-typological analyses, it seems very likely that at least one, if not more, technological shifts did occur during the time of occupation at Liben Bore. Regardless, both analyses identify a technological shift in level 8 possibly due to the introduction of ceramics thereby issuing more substance to the claim that level 8 represents the introduction of a competing technological system (i.e., pottery) and subsequent decline of the lithic technological system. In fact, the expediency of shaped tools that Negash notes between level 8 and level 1 can be interpreted to reflect changing ideal types enacted by a shift in the predominant application of technological knowledge, resources and users. According to the model, these changes created less technological variation, loss of prior specific technological characteristics, and resulted in the subsequent appearance of a lithic technological system lacking any significant technological complexity at this time.

## Gogoshiis Qabe

Gogoshiis Qabe (GQ) is a rockshelter located in the inter-riverine Buur Heybe region of southern Somalia (Brandt 1988). The site was first excavated by P. Graziosi in 1935. Further excavations by the Buur Ecological and Archaeological Project (BEAP) in 1983 and 1985 found the burials of fourteen individuals providing the earliest evidence of mortuary practice in the Horn of Africa. In total, the BEAP project excavated thirty-two contiguous $1m^2$ units in 5cm levels (ibid).

The primary goal of the Gogoshiis Qabe morphometrics analysis was to test the reliability of the morphometrics approach because of an overall concern that the Liben Bore analysis could have been misleading due to previous knowledge of the site. Since the Liben Bore morphometric analysis was conducted simultaneously with a techno-typological lithics analysis, in spite of the persistent lack of information about the site in particular, this nonetheless allowed for direct questioning of the reliability of the morphometrics method itself. In particular, the question at hand was which analysis led the other; the results of the morphometrics method might only have been reached through a priori conclusions and observations based on the techno-typological lithics analysis. Therefore, the Gogoshiis Qabe morphometrics analysis was conducted without any prior knowledge of the technological characteristics or prior conclusions reached of the GQ assemblage, temporal periods, or precise spatial distribution of the materials. For this reason, more detailed background data for Gogoshiis Qabe will be given following the discussion of the morphometrics analysis.

### Morphometrics Analysis

The GQ dataset has been very difficult to explain in spite of being relatively easy to interpret. The GQ dataset is composed of flakes spanning thirty-six 5cm excavation levels. Unfortunately, at the time of this analysis several excavation levels were unavailable for analysis because their storage bags had disintegrated allowing the artifacts to mix together (e.g., excavation level 17 and level 18). Based on the formfactor and roundness values, the GQ dataset does not exhibit any marked differences indicative of technological changes when graphed against their excavation levels (Figures 4-8 and 4-9). There are some notable constrictions in the range of formfactor and roundness values around level 7 and level 27 but this more likely represents poor sample size and not actual restriction of technological variation.

However, a different picture emerges when the elongation values are graphed by their excavation levels (Figure 4-10). This graph clearly shows a distinction between the elongation of the flakes from level 1 to level 16 and the flakes in level 19 to level 36. According to this graph, the flakes from level 19 to level 36 have a much greater range of elongation, if not more elongated as a whole.

When the aspect ratio is similarly graphed (Figure 4-11), the trend noted in the elongation graph again disappears. Though elongation and aspect ratio are both dimensionless measures of the elongation of an object, they operate differently. Aspect ratio measures the length of the object against its breadth. In particular, the "length" measured in the aspect ratio is independent of orientation and is simply a measure of the longest arc length within an object. Width conversely is the measure perpendicular to the length. Therefore, if an object has a greater width than length (e.g., a side-struck flake) the aspect ratio will be high because the length is actually measuring the widest point of the flake, that which is often referred to as "breadth."

Elongation, on the other hand, measures the skeleton length of the object against the mean fiber width. Skeleton length is determined by removing all pixels in an object except those that make up the midline. Mean fiber width measures the mean distance from all pixels in the object skeleton. Therefore, when a flake is "triangular" in shape—a shape very common to both the Liben Bore and Gogoshiis Qabe datasets—the skeleton length actually splits and creates a main arm with two branches similar to a "peace" symbol. As a result, triangular and even ovate shaped flakes can have high elongation values whereas the aspect ratio value might suggest completely otherwise.

In order to circumvent this problem, the X-feret and Y-feret values were divided similar to the aspect ratio. X-feret and Y-feret measures are useful in a situation such as this because they do not just measure the longest arc length within an object (i.e., "length"). Rather X-feret and Y-feret are measures of the two widest points on the X and Y axes and are thus sensitive to orientation. Since all flakes within the Gogoshiis Qabe (and Liben Bore) analysis were oriented platform down, the X-Y Feret ratio should indicate if the flakes from level 19 to level 36 are actually more elongated than the flakes from level 1 to level 16.

When plotted against the excavation levels, the X-Y feret ratio values indicate a pattern very similar to the aspect ratio suggesting that the elongation of flakes between levels 1 to 16 and levels 19 to 36 are not greatly different (Figure 4-12). The flakes between levels 19 to level 36 are actually slightly less elongated than flakes from level 1 to level 16 by an aspect ratio value difference of 0.128.

The distribution of values within the elongation graph, however, still suggests that there are underlying patterns within this data that have not been recognized. According to the elongation values, the flakes between levels 19 to level 36 are more triangular, or at least have a slightly greater width versus length, thereby creating a greater skeleton length and larger elongation value. Though the elongation measure may not be a good measure of actual elongation per se, this measure is still an accurate indication of the shape of these flakes. As a result, when the range and standard deviation of flake elongation values are compared between level 1 to level 16 and level 19 to 36 the results are striking.

According to these results, the range of elongation values between level 19 to level 36 (n = 26.399) is over twice as great as the range of elongation values between level 1 to level 16 (n = 13.867). This ratio is further supported by averaging the mean range of elongation values per excavation level. Furthermore, the standard deviation of elongation values between level 19 to level 36 is 69% greater (n = 2.338) than the standard deviation between level 1 to level 16 (n = 1.620). This suggests that there is greater variability in the overall shape of flakes between level 19 to level 36 in spite of the slightly greater roundness and less irregularity of shape compared from level 1 to level 16.

A t-test conducted on this data also shows that there is a statistical difference at a 0.05 confidence level between the inter-pattern mean values within the dataset in four out of five morphometrics measures (Table 4-3). According to this test, there is a statistical difference between the mean values between excavation level 1 to level 16 (pattern 1) and excavation level 19 to level 36 (pattern 2).

Furthermore, the results of a cluster analysis on the GQ data using the standard deviation values per excavation level for the formfactor, roundness, elongation, and aspect ratio group the majority of levels from pattern two independent of pattern one at a rescaled cluster case distance of 4 (Figure 4-13). Fourteen out of seventeen excavation levels categorized morphometrically within pattern two do in fact group within cluster two whereas eight out of thirteen levels classified morphometrically within group one also group within cluster one. Only eight out of thirty morphometrically analyzed excavation levels do not share similar morphometrics and cluster analysis results.

Finally, the shape of flakes between levels 19 to 36 suggests an ideal type qualitatively different from the ideal type underlying the lithic technological system in level 1 to level 16. Due to similarities in the formfactor, roundness and aspect ratios between these two time periods, the ideal types must not have been greatly different. However, there must have been a great enough change to the lithic technological system around level 19 to create more solidarity within the shape of flakes between level 1 to level 16.

**Understanding the Gogoshiis Qabe Data**

According to Brandt (1988), the Gogoshiis Qabe assemblage actually represents the transition from the Eibian LSA to the Bardaale LSA-Neolithic industry. This shift occurs with the environmental change from cool, hyperarid conditions of the Pleistocene to warm and humid Holocene conditions (Brandt 1988). Brandt specifically identifies this transition at Level 19.

The similar identification of two patterns separated at a similar excavation level shows that the application of morphometrics was again able to determine technological change within an archaeological site using only flake debitage even though morphometrics on the Gogoshiis Qabe data was not as successful as the Liben Bore analysis. For instance, technological changes within the Liben Bore dataset were much more pronounced than those identified at Gogoshiis Qabe. This can be accepted especially if technological changes are more gradual rather than punctuated.

Thus, the discussion of Gogoshiis Qabe is significant for two reasons. First, the GQ analysis once again shows the validity of the morphometrics method for identifying technological change within the archaeological record. Second, the unique nature of the GQ data bring to bear certain deficiencies or assumptions within the morphometrics method that warrant explanation. Specifically, a deficiency of the morphometrics method rests on an underlying assumption that the archaeological deposits within a morphometrics analysis represent a continuous deposition of archaeological and geological materials over time. This assumption was noted in the Liben Bore analysis, but warrants further discussion.

Gradual and punctuated technological changes can be obfuscated or created within a morphometrics dataset by differing rates of archaeological and sedimentary deposition. It is important to note here that the application of this type of morphometrics analysis implies an archaeological sequence with a continuous rate of sedimentary and archaeological deposition over time with few, if any, abrupt changes in the rates of deposition. Keep in mind that this assumption does not preclude that differential rates of cultural or sedimentary deposition do occur and can distort the distribution of a dataset. It merely points out that abrupt changes in the sedimentary deposition at a site should be clearly identifiable whereby a period of rapid sedimentary deposition should show an equalized morphometrics distribution with few, if any abrupt changes.

On the other hand a period of slow sedimentary deposition should show a very distinct demarcation between the morphometrics values of artifacts. This demarcation corresponds to the much coarser temporal resolution, and collection of archaeological materials, represented in the period with slow sedimentary deposition versus other periods with more refined temporal resolution of archaeological materials.

At Liben Bore, there is no evident distinction in changes to the rate of archaeological or geologic deposition at that site. Due to the consistently fluctuating morphometrics values throughout the entire Liben Bore sequence, this suggests that there was continuous sedimentary and archaeological deposition over the entirety of the Liben Bore sequence creating uniformity in the frequency of archaeological materials and temporal resolution.

Gogoshiis Qabe suggests otherwise. Although archaeological materials were recovered in excavation level 17 and level 18, the abrupt nature of this division as shown in the statistical analyses between pattern one and pattern two, which correlates with a major sedimentary and environmental shift as noted by Brandt (1988), suggests the possibility for either slow sedimentary depositions or dis-continuous archaeological deposition during this restricted period of time. If there is a gap in the deposition of archaeological materials then one can only expect to see significant technological changes between the two patterns (i.e., level 1 to level 16 and level 19 to level 36) separated by a large span of time and significant changes to the environment. However, as the shape of flakes remain similar in many respects throughout the entire Gogoshiis Qabe sequence, this suggests other, as yet unknown, factors homogenizing the morphology of flakes within each lithic technological systems operating in this area through time.

## Conclusion

This chapter has been able to show that the morphometrics method is capable of identifying technological changes and technological variations within the lithic technological systems at Gilgel Gibe and Gogoshiis Qabe. It is hypothesized that these shifts correlate to equivalent changes in the ideal types within the technological systems. At Liben Bore, computer assisted morphometry has been able to identify three statistically different morphological patterns within the dataset indicative of technological change whereas at Gogoshiis Qabe, the results were similar and identified two statistically different patterns within the dataset correlated with environmental and sedimentary changes.

Thus not only does computer assisted morphometrics work when applied to flakes, but it is also fast. The analysis of 1,810 flakes for the Gilgel Gibe analysis took less than three weeks while the analysis of 1,809 flakes for the Gogoshiis Qabe analysis took less than two weeks. Therefore, a morphometrics analysis could theoretically operate concurrent with an excavation with minor extra expenditure of time. This would afford a significant advantage towards understanding the nature of a site in the process of excavation versus knowing these difference after excavation has finished and the artifacts are being analyzed in a laboratory. Furthermore, the application of morphometrics is also capable of providing significant insight into the character of archaeological deposits in previously studied, or unstudied, archaeological sites and even regions. The point I must stress here is that morphometrics is by no means a standalone method, but in conjunction with CST, the application of this theoretical and methodological package provides significant advantages towards understanding Stone Age archaeological sites in a timely, cost-effective manner. In so doing, archaeologists may be able to better tackle the spatial and temporal immensity of Stone Age archaeology within the Horn of Africa and impart a much more firm foothold towards understanding the complex sequence of archaeology within this region.

Table 4-1 T-test results of the inter-period differences in the mean values for formfactor, roundness, aspect ratio, elongation, and X-feret and Y-feret. Each trend was compared against the other two. The results of this test suggest that there is no statistical difference between the mean values for trend 1 and trend 2, there is a small difference between mean values in trend 1 and trend 3, and the mean values for trend 2 are statistically different than each of the other two trends. Bold values indicate statistical difference.

| | **Roundness** | **Elongation** | **Aspect Ratio** | **Formfactor** | **X-Feret / Y-Feret** |
|---|---|---|---|---|---|
| **T1/T2** | 0.188 | 0.509 | 0.101 | 0.398 | 0.261 |
| **T2/T3** | **1.54E-05** | 0.520 | **9.75E-05** | **0.005** | **0.003** |
| **T1/T3** | **0.036** | 0.949 | **0.051** | 0.120 | 0.207 |

Alpha Value = 0.05
Null Hypothesis: No Statistically Significant Difference in mean value.

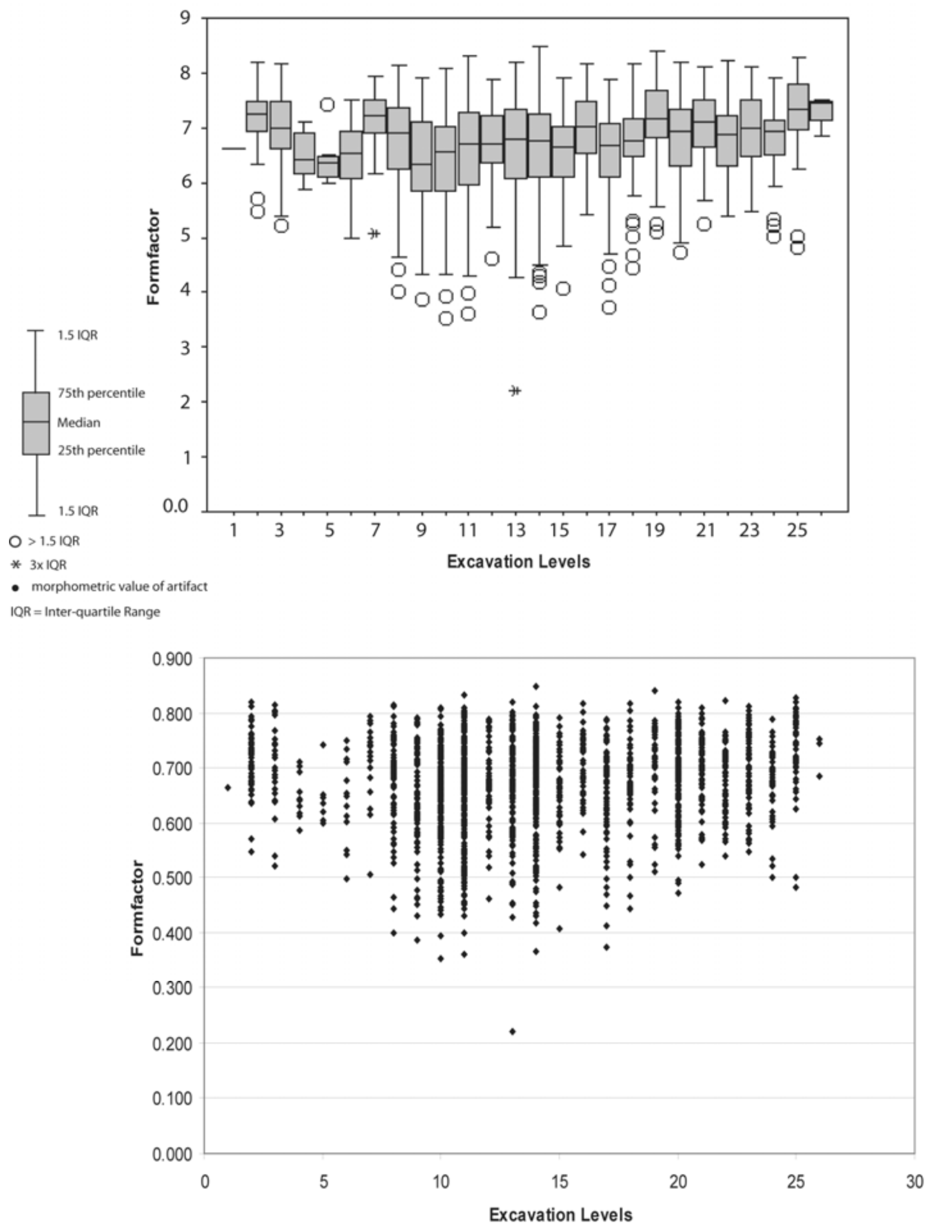
Table 4-2 Averaged standard deviation of the formfactor, aspect ratio, and roundness values organized per excavation level time period.

| | **Roundness** | **Formfactor** | **Aspect Ratio** |
|---|---|---|---|
| **Period 1** | 0.112 | 0.060 | 0.387 |
| **Period 2** | 0.134 | 0.088 | 0.530 |
| **Period 3** | 0.111 | 0.067 | 0.335 |

Table 4-3 T-test results of the inter-period differences in the mean values for formfactor, roundness, aspect ratio, elongation, and X-feret and Y-feret. The results of the test show that trend one (excavation level 1 to level 16) is statistically different from trend two (excavation level 19 to level 36) in four out of the five morphometric measure results.

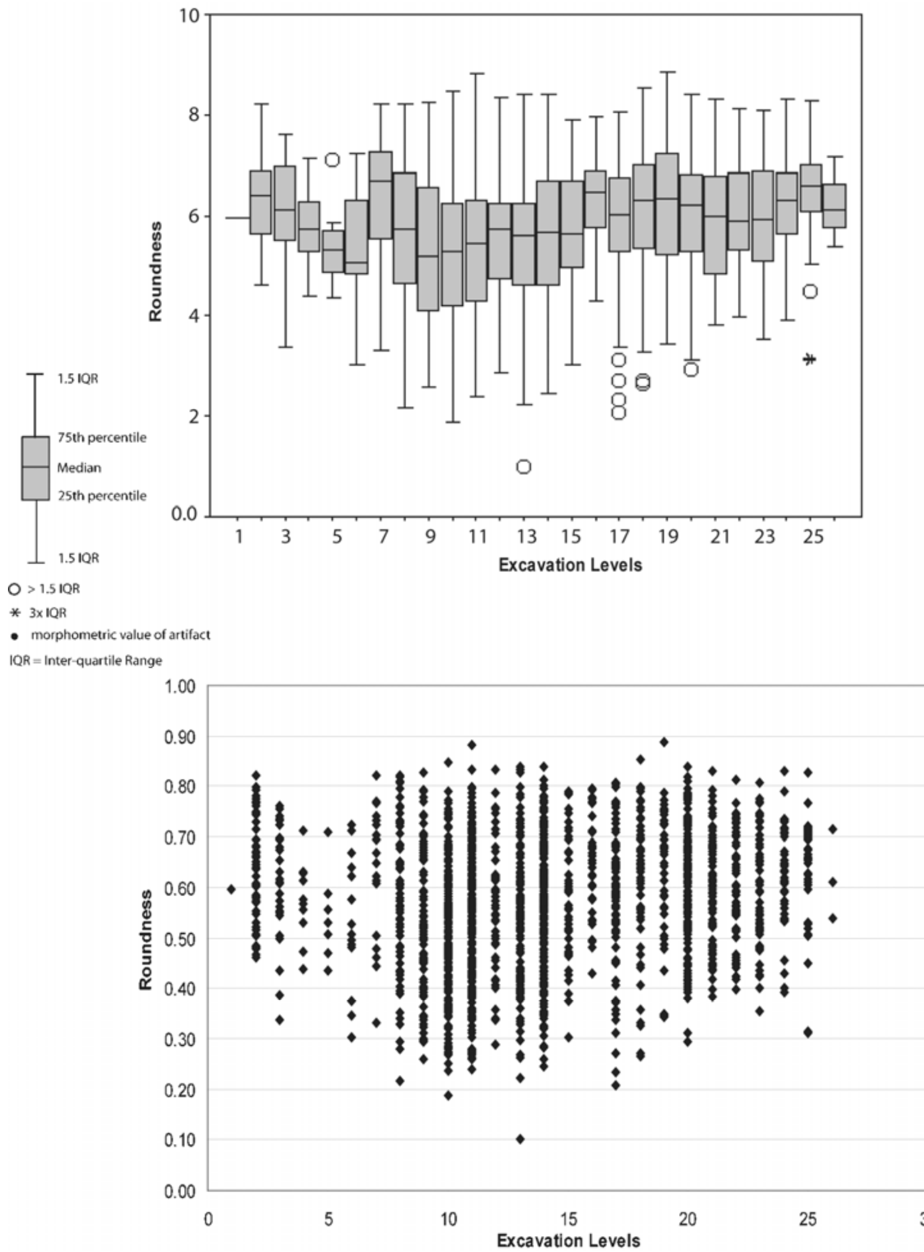
| | **T1/T2** |
|---|---|
| **X- Feret and Y-Feret** | **0.001** |
| **Formfactor** | **0.022** |
| **Roundness** | **0.002** |
| **Aspect Ratio** | **0.002** |
| **Elongation** | 0.423 |

Alpha Value = 0.05
Null Hypothesis: No Statistically Significant Difference in mean value



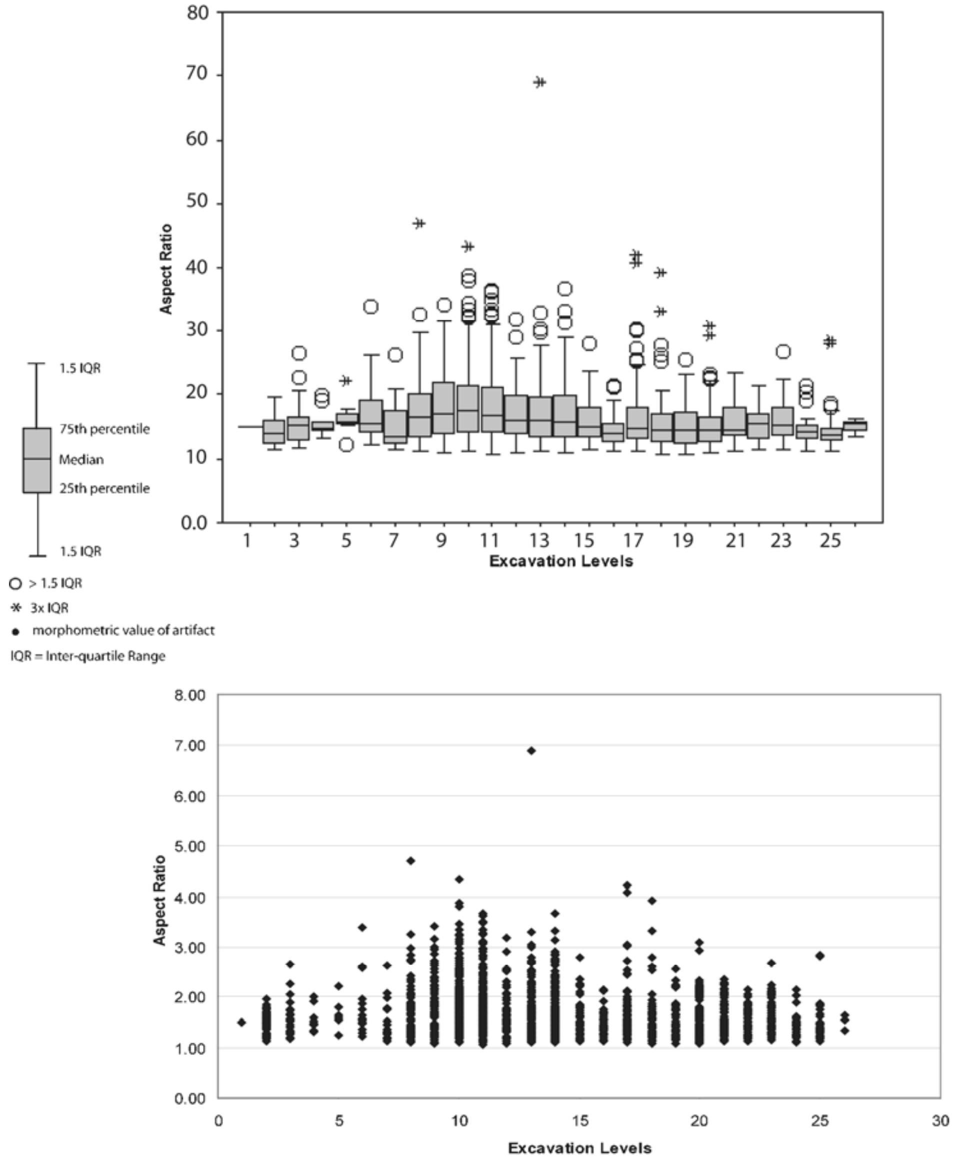

| Level | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | 1 | 63 | 27 | 10 | 7 | 15 | 19 | 67 | 89 | 204 | 228 | 51 | 136 | 184 | 50 | 38 | 88 | 55 | 42 | 160 | 70 | 56 | 56 | 43 | 47 | 3 |

Figure 4-1 Morphometric formfactor values of the Liben Bore flakes organized by the level of excavation. According to these graphs, the flake shape at Liben Bore became more irregular between level 16 and level 8. Lower levels of excavation correspond with greater excavation level numbers. The top graph is a box-and-whisker plot representing the mean, standard deviation, first and third quartiles of the formfactor data. Circles in this graph correspond to outliers whereas asterisks represent extreme values. The lower graph represents the raw formfactor data points used to create the box-and-whisker graph.



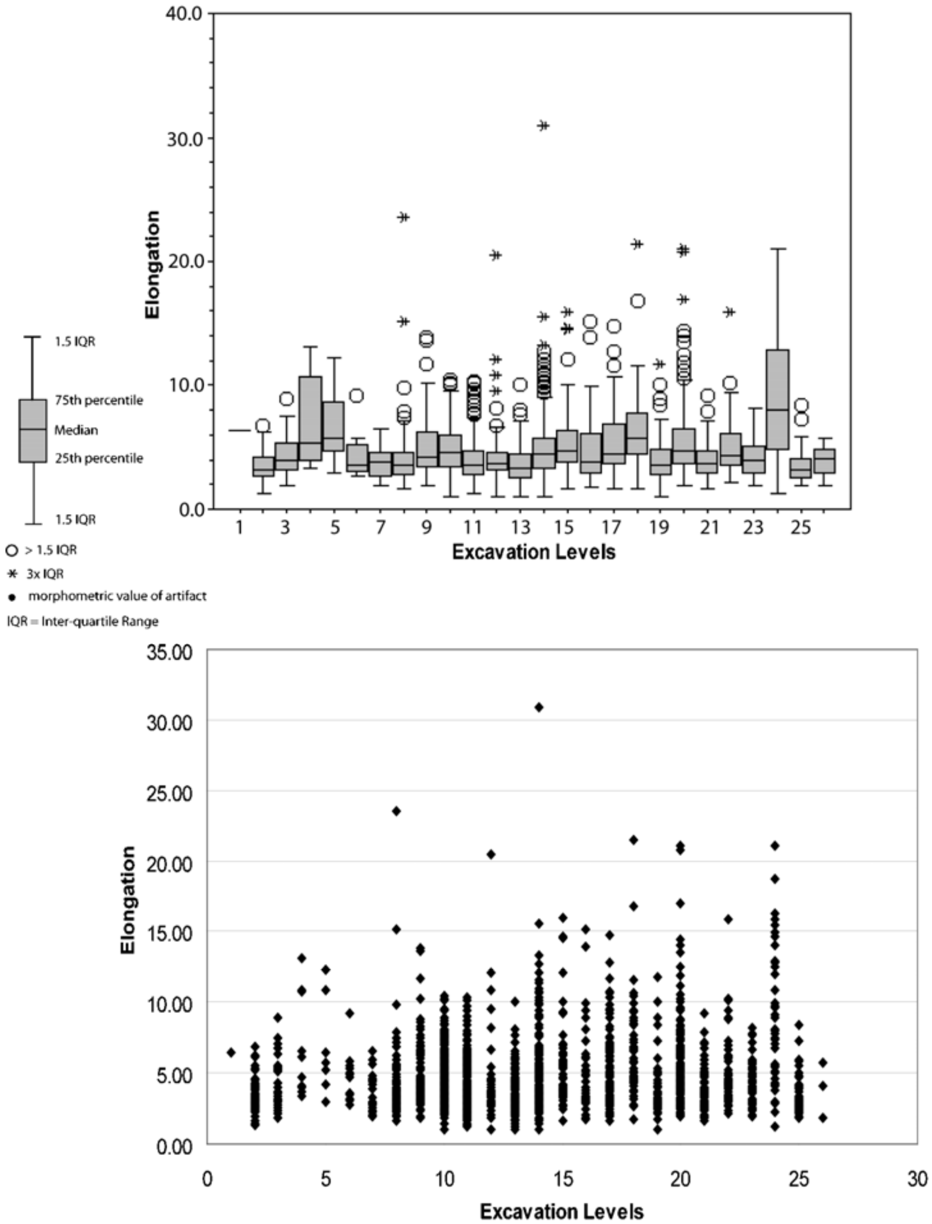

| Level | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | 1 | 63 | 27 | 10 | 7 | 15 | 19 | 67 | 89 | 204 | 228 | 51 | 136 | 184 | 50 | 38 | 88 | 55 | 42 | 160 | 70 | 56 | 56 | 43 | 47 | 3 |

Figure 4-2 Morphometric roundness values of the Liben Bore flakes organized by the level of excavation. According to these graphs, the flake shape at Liben Bore became less round between level 15 and level 8. Lower levels of excavation correspond with greater excavation level numbers. The top graph is a box-and-whisker plot representing the mean, standard deviation, first and third quartiles of the roundness data. Circles in this graph correspond to outliers whereas asterisks represent extreme values. The lower graph represents the raw roundness data points used to create the box-and-whisker graph.



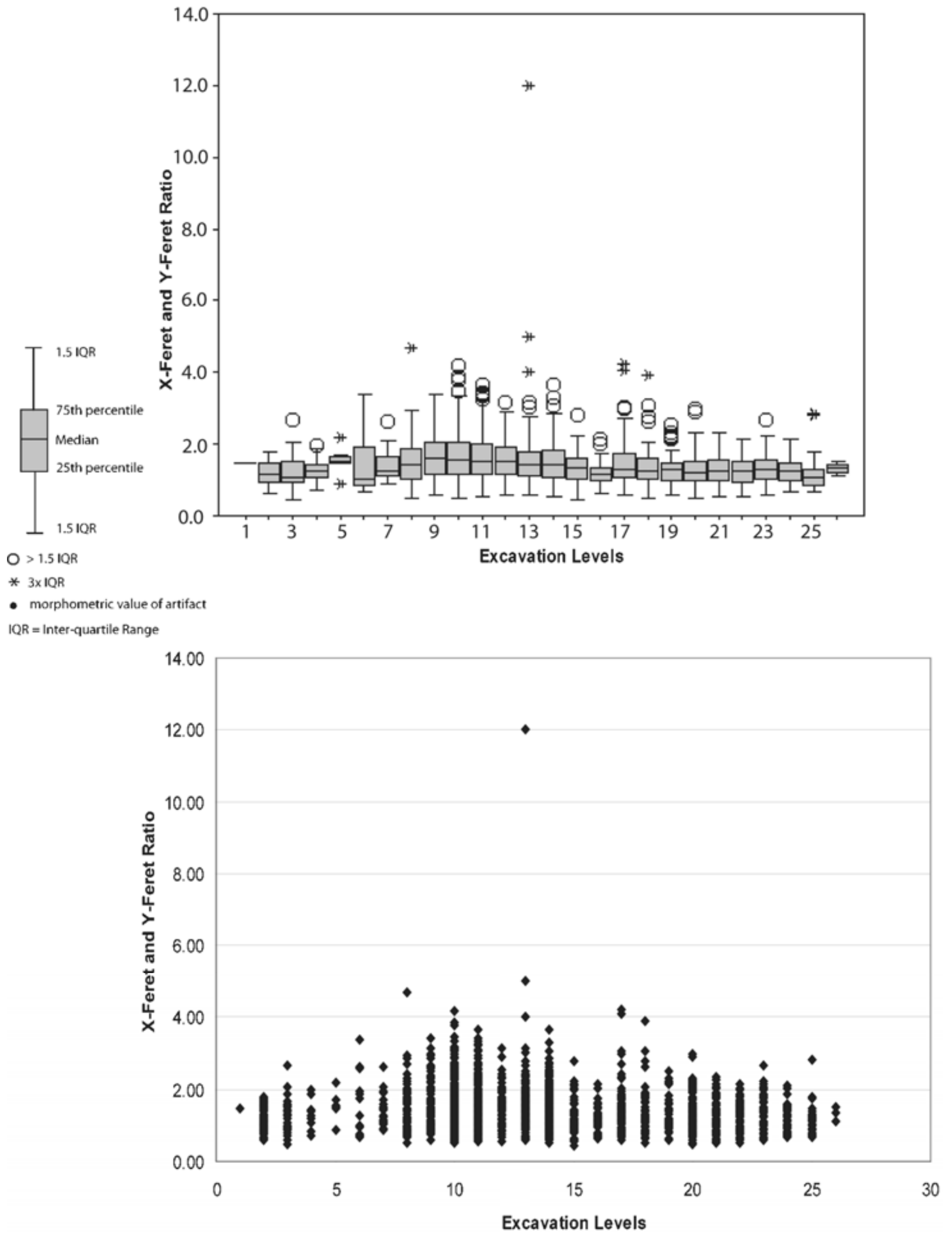

| Level | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | 1 | 63 | 27 | 10 | 7 | 15 | 19 | 67 | 89 | 204 | 228 | 51 | 136 | 184 | 50 | 38 | 88 | 55 | 42 | 160 | 70 | 56 | 56 | 43 | 47 | 3 |

Figure 4-3 Morphometric aspect ratio values of the Liben Bore flakes organized by the level of excavation. According to these graphs, flake shape between level 15 and level 8 became more elongated at Liben Bore. Lower levels of excavation correspond with greater excavation level numbers. The top graph is a box-and-whisker plot representing the mean, standard deviation, first and third quartiles of the aspect ratio data. Circles in this graph correspond to outliers whereas asterisks represent extreme values. The lower graph represents the raw aspect ratio data points used to create the box-and-whisker graph.



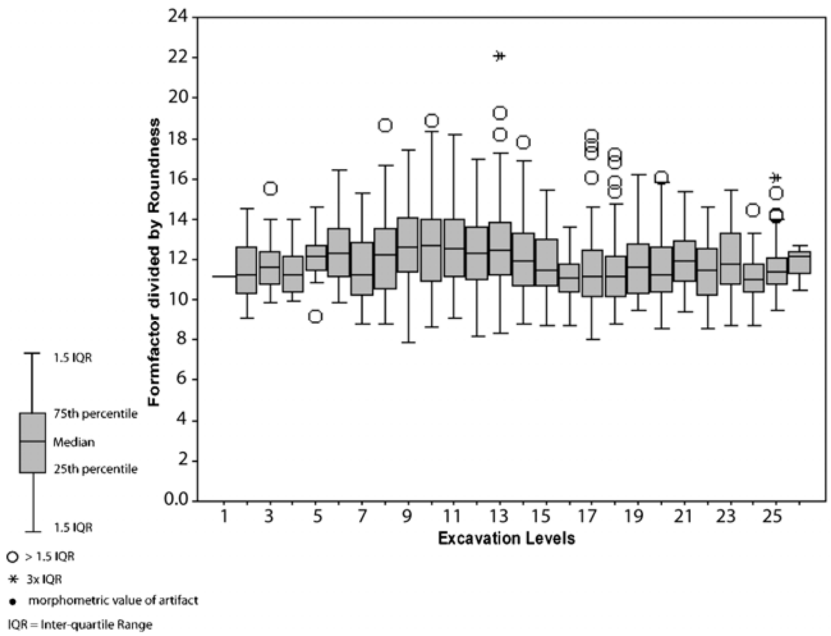

| Level | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | 1 | 63 | 27 | 10 | 7 | 15 | 19 | 67 | 89 | 204 | 228 | 51 | 136 | 184 | 50 | 38 | 88 | 55 | 42 | 160 | 70 | 56 | 56 | 43 | 47 | 3 |

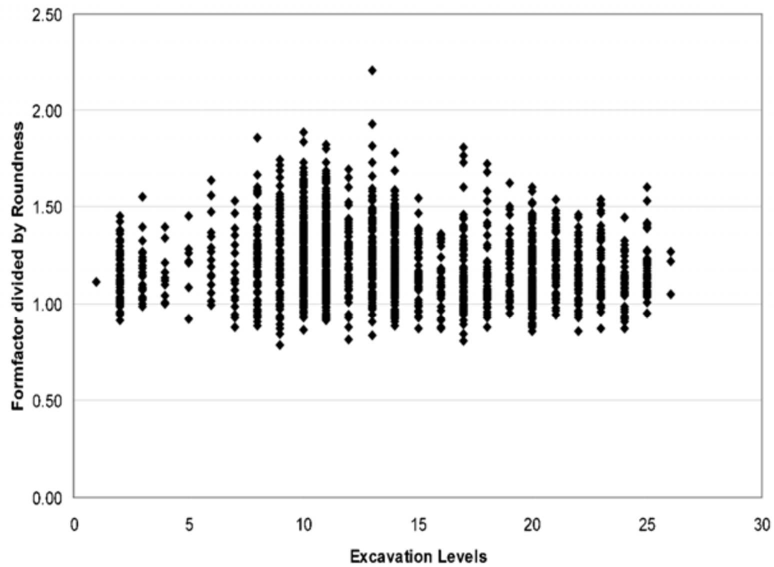
Figure 4-4 Morphometric elongation values of the Liben Bore flakes organized by the level of excavation. According to these graphs, flake shape between level 15 and level 8 became more elongated at Liben Bore. Lower levels of excavation correspond with greater excavation level numbers. The top graph is a box-and-whisker plot representing the mean, standard deviation, first and third quartiles of the elongation data. Circles in this graph correspond to outliers whereas asterisks represent extreme values. The lower graph represents the raw elongation data points used to create the box-and-whisker graph.




| Level | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | 1 | 63 | 27 | 10 | 7 | 15 | 19 | 67 | 89 | 204 | 228 | 51 | 136 | 184 | 50 | 38 | 88 | 55 | 42 | 160 | 70 | 56 | 56 | 43 | 47 | 3 |

Figure 4-5 Morphometric X-Feret and Y-Feret ratio values of the Liben Bore flakes organized by the level of excavation. According to these graphs, flake shape between level 15 and level 8 became more elongated at Liben Bore. Lower levels of excavation correspond with greater excavation level numbers. The top graph is a box-and-whisker plot representing the mean, standard deviation, first and third quartiles of the X-Feret and Y-Feret ratio data. Circles in this graph correspond to outliers whereas asterisks represent extreme values. The lower graph represents the raw X-Feret and Y-Feret ratio data points used to create the box-and-whisker graph.




| Level | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | 1 | 63 | 27 | 10 | 7 | 15 | 19 | 67 | 89 | 204 | 228 | 51 | 136 | 184 | 50 | 38 | 88 | 55 | 42 | 160 | 70 | 56 | 56 | 43 | 47 | 3 |

Figure 4-6 Irregularity (formfactor) divided by the roundness of the Liben Bore flakes organized by the level of excavation. These graphs suggest a trend towards more elongated and irregular flakes between level 15 to level 8. Lower levels of excavation correspond with greater excavation level numbers. The top graph is a box-and-whisker plot representing the mean, standard deviation, first and third quartiles of the Formfactor divided by Roundness ratio data. Circles in this graph correspond to outliers whereas asterisks represent extreme values. The lower graph represents the raw Formfactor divided by Roundness ratio data points used to create the box-and-whisker graph.

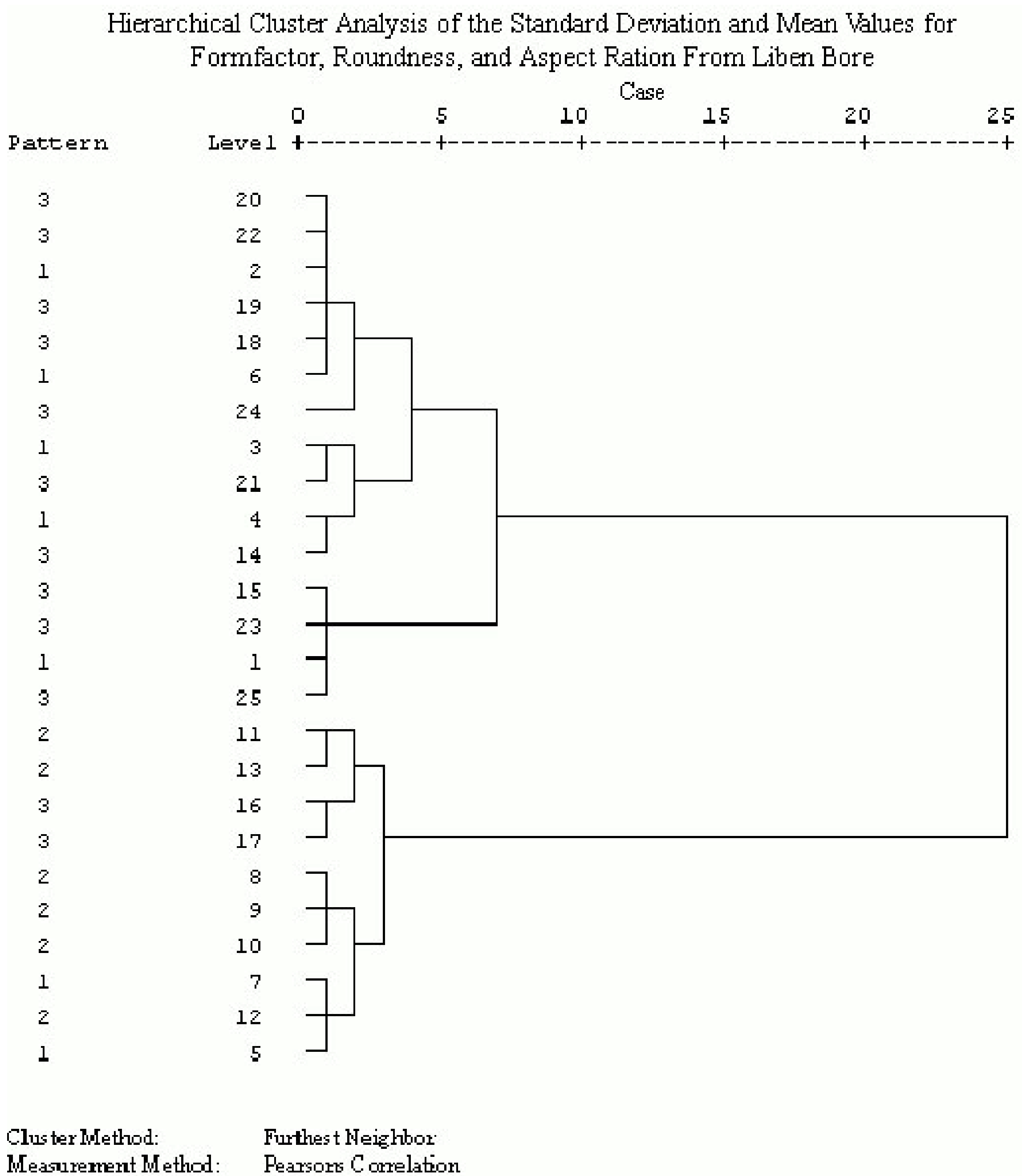
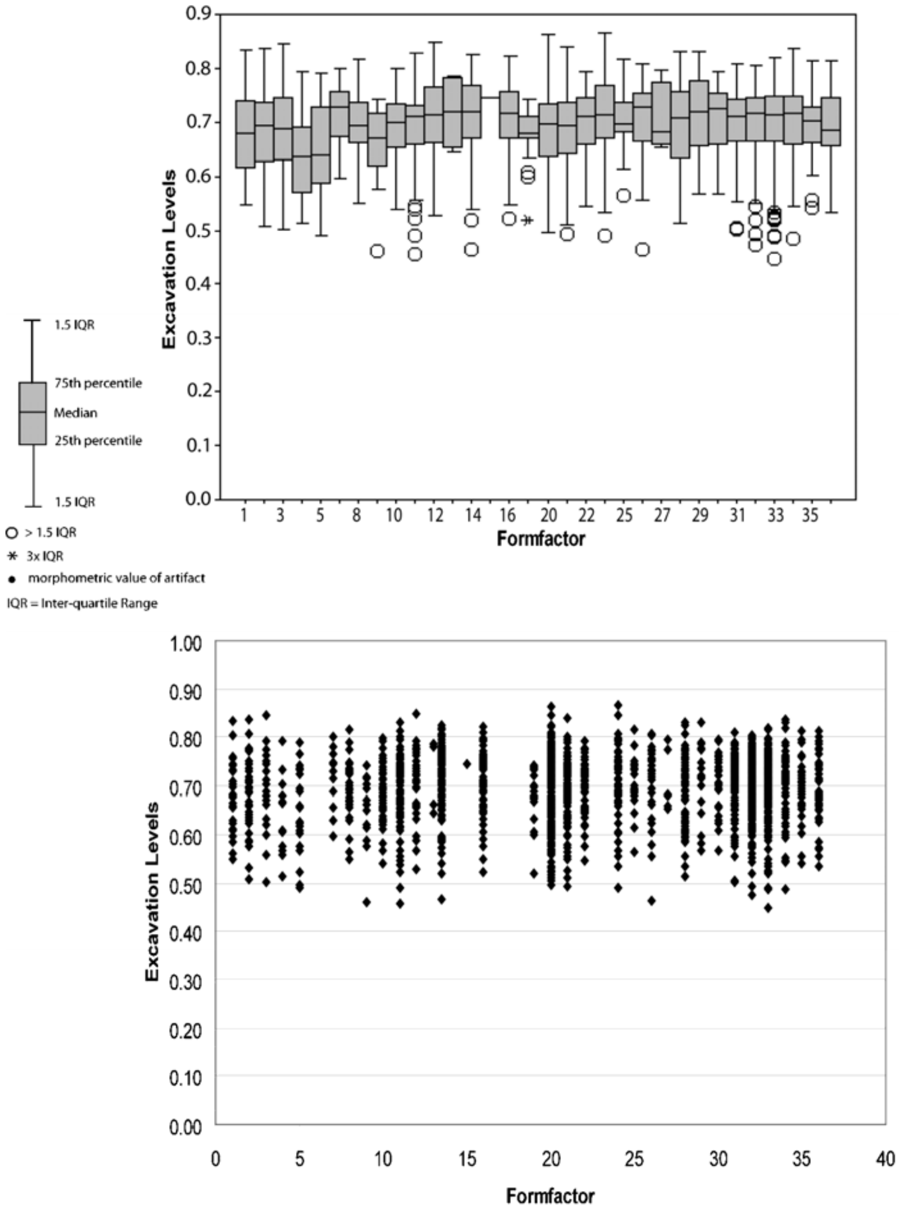
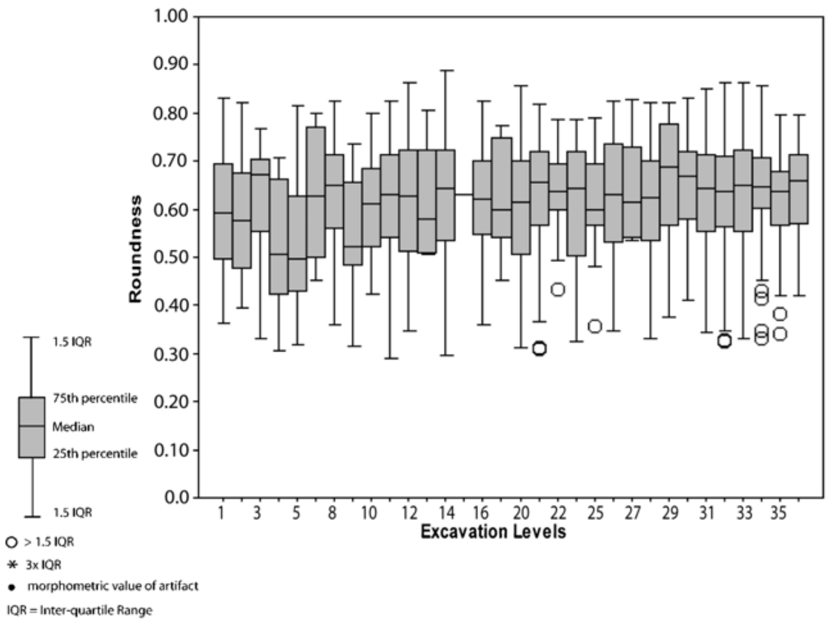


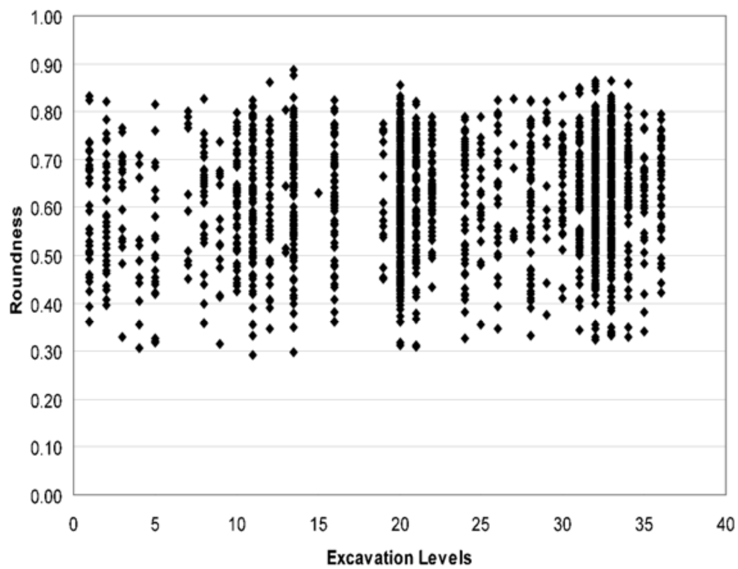

Figure 4-7 A hierarchical cluster analysis using the mean and standard deviation values per excavation level for formfactor, roundness, and aspect ratio from Liben Bore. The graph shows that excavation levels identified into pattern two (excavation level 9 to level 14) mostly group independently of excavation levels identified into pattern one and pattern three. In this graph "pattern" refers to the three identified patterns discussed in the text.




| Level | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | 31 | 34 | 21 | 12 | 20 | 11 | 29 | 15 | 50 | 87 | 35 | 4 | 89 | 1 | 58 | 20 | 247 | 100 | 52 | 51 | 20 | 28 | 6 | 62 | 16 | 30 | 90 | 251 | 204 | 63 | 32 | 39 |

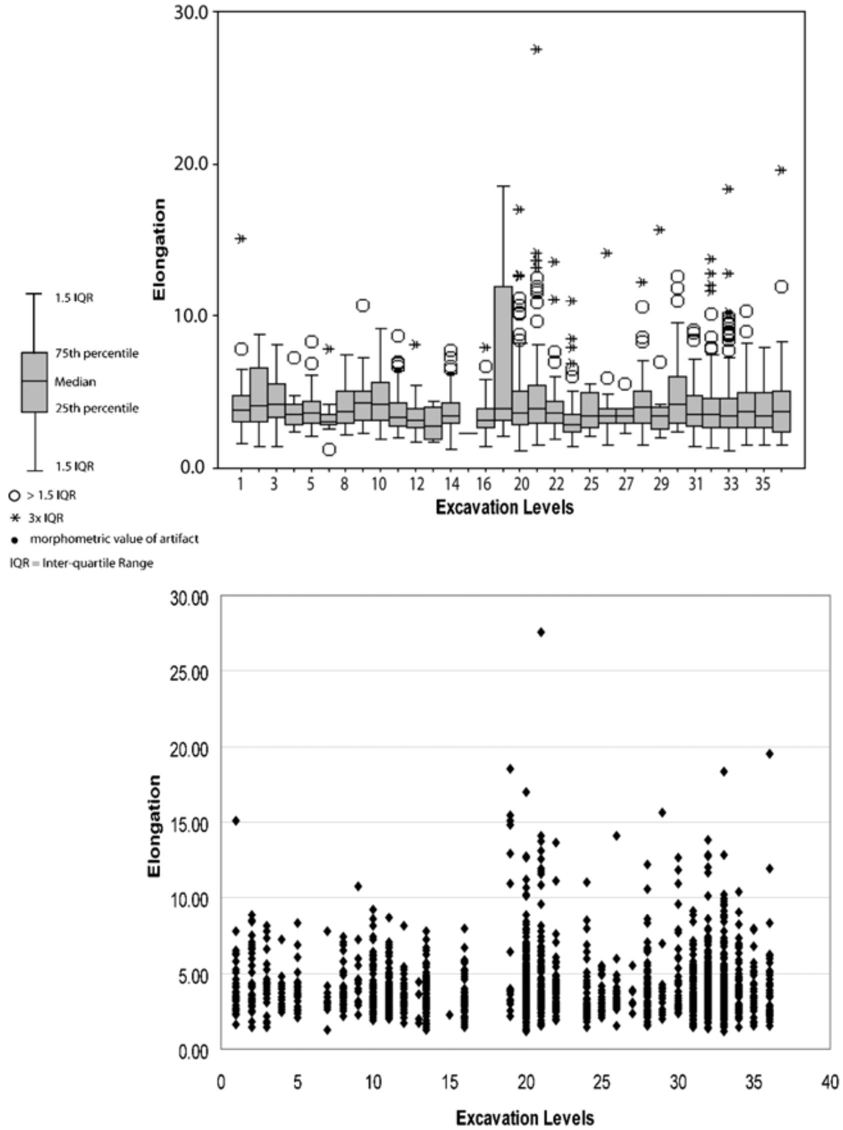
Figure 4-8 Morphometric formfactor values of the Gogoshiis Qabe flakes organized by the level of excavation. According to these graphs, flake irregularity fluctuated minimally at Gogoshiis Qabe. Lower levels of excavation correspond with greater excavation level numbers. The top graph is a box-and-whisker plot representing the mean, standard deviation, first and third quartiles of the formfactor data. Circles in this graph correspond to outliers whereas asterisks represent extreme values. The lower graph represents the raw formfactor data points used to create the box-and-whisker graph.



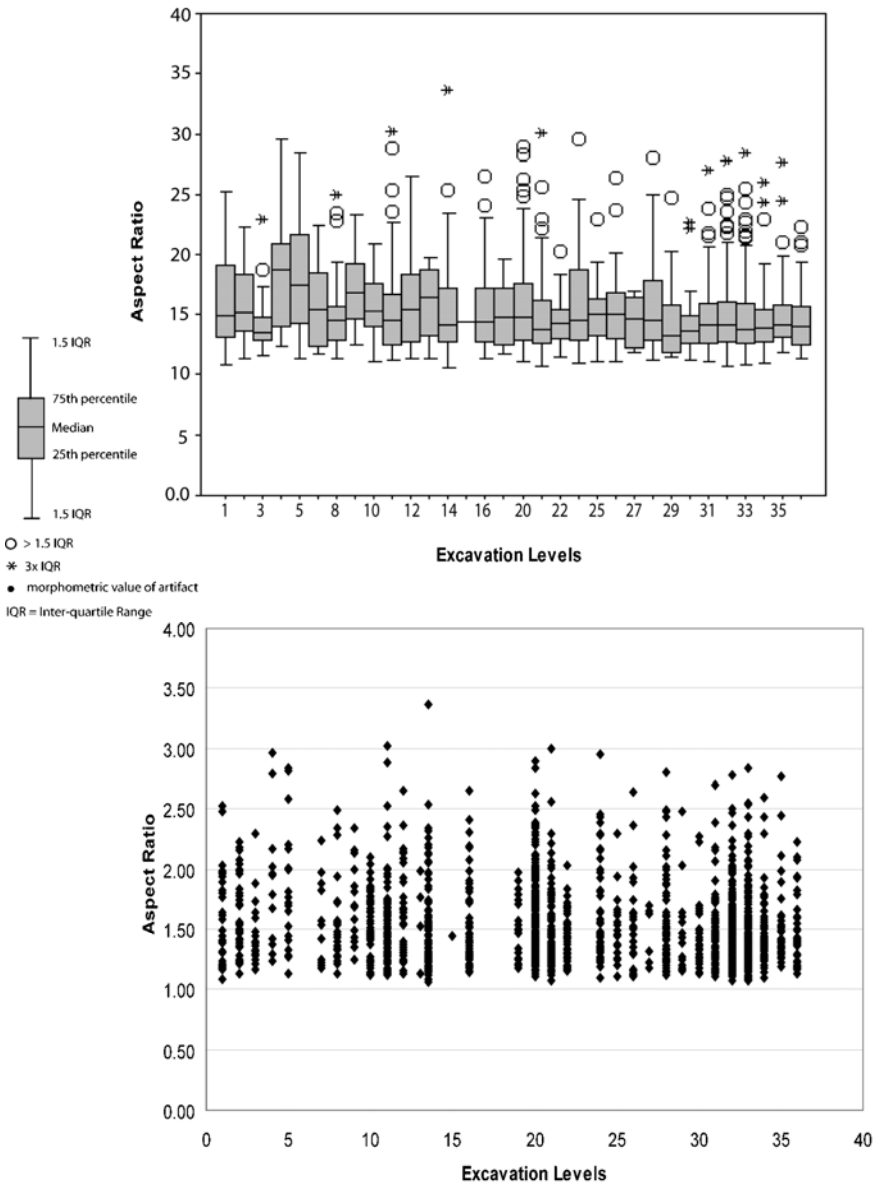

| Level | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | 31 | 34 | 21 | 12 | 20 | 11 | 29 | 15 | 50 | 87 | 35 | 4 | 89 | 1 | 58 | 20 | 247 | 100 | 52 | 51 | 20 | 28 | 6 | 62 | 16 | 30 | 90 | 251 | 204 | 63 | 32 | 39 |

Figure 4-9 Morphometric roundness values of the Gogoshiis Qabe flakes organized by the level of excavation. According to these graphs, flake roundness fluctuated minimally at Gogoshiis Qabe. Lower levels of excavation correspond with greater excavation level numbers. The top graph is a box-and-whisker plot representing the mean, standard deviation, first and third quartiles of the roundness data. Circles in this graph correspond to outliers whereas asterisks represent extreme values. The lower graph represents the raw roundness data points used to create the box-and-whisker graph.



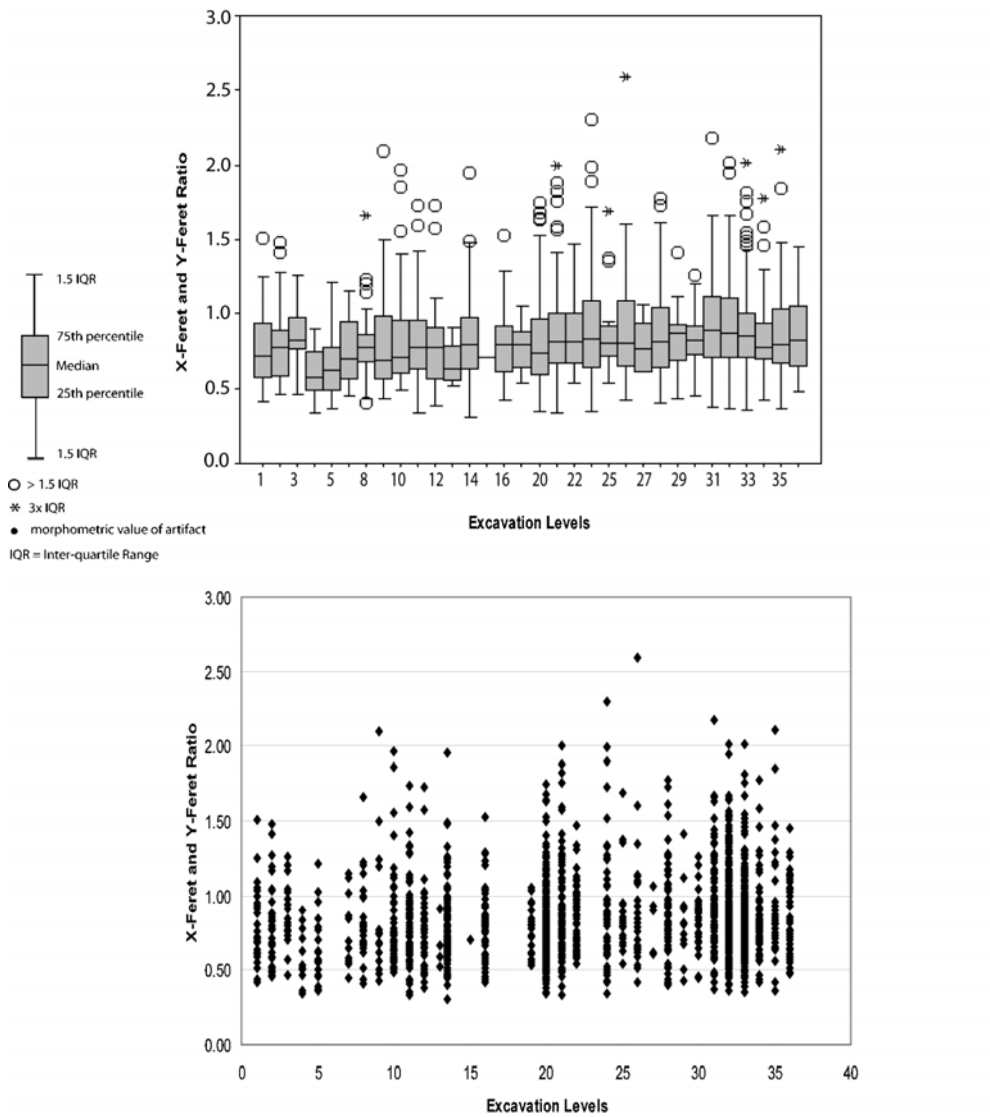

| Level | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | 31 | 34 | 21 | 12 | 20 | 11 | 29 | 15 | 50 | 87 | 35 | 4 | 89 | 1 | 58 | 20 | 247 | 100 | 52 | 51 | 20 | 28 | 6 | 62 | 16 | 30 | 90 | 251 | 204 | 63 | 32 | 39 |

Figure 4-10 Morphometric elongation values of the Gogoshiis Qabe flakes organized by the level of excavation. According to these graphs, flake elongation appears to be greater between level 36 to level 19 at Gogoshiis Qabe. Lower levels of excavation correspond with greater excavation level numbers. The top graph is a box-and-whisker plot representing the mean, standard deviation, first and third quartiles of the elongation data. Circles in this graph correspond to outliers whereas asterisks represent extreme values. The lower graph represents the raw elongation data points used to create the box-and-whisker graph.




| Level | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | 31 | 34 | 21 | 12 | 20 | 11 | 29 | 15 | 50 | 87 | 35 | 4 | 89 | 1 | 58 | 20 | 247 | 100 | 52 | 51 | 20 | 28 | 6 | 62 | 16 | 30 | 90 | 251 | 204 | 63 | 32 | 39 |

Figure 4-11 Morphometric aspect ratio values of the Gogoshiis Qabe flakes organized by the level of excavation. These graphs contradict the trend for greater elongation between level 36 to level 19 as shown in figure 15. Here, flake length appears to remain relatively constant throughout the entire Gogoshiis Qabe sequence. Lower levels of excavation correspond with greater excavation level numbers. The top graph is a box-and-whisker plot representing the mean, standard deviation, first and third quartiles of the aspect ratio data. Circles in this graph correspond to outliers whereas asterisks represent extreme values. The lower graph represents the raw aspect ratio data points used to create the box-and-whisker graph.




| Level | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 19 | 20 | 21 | 22 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count | 31 | 34 | 21 | 12 | 20 | 11 | 29 | 15 | 50 | 87 | 35 | 4 | 89 | 1 | 58 | 20 | 247 | 100 | 52 | 51 | 20 | 28 | 6 | 62 | 16 | 30 | 90 | 251 | 204 | 63 | 32 | 39 |

Figure 4-12 Morphometric X-Feret and Y-Feret ratio values of the Gogoshiis Qabe flakes organized by the level of excavation. These graphs support figure 16 by also showing that the elongation of flakes remained fairly constant over time at Gogoshiis Qabe. Lower levels of excavation correspond with greater excavation level numbers. The top graph is a box-and-whisker plot representing the mean, standard deviation, first and third quartiles of the X-Feret and Y-Feret ratio data. Circles in this graph correspond to outliers whereas asterisks represent extreme values. The lower graph represents the raw X-Feret and Y-Feret ratio data points used to create the box-and-whisker graph.

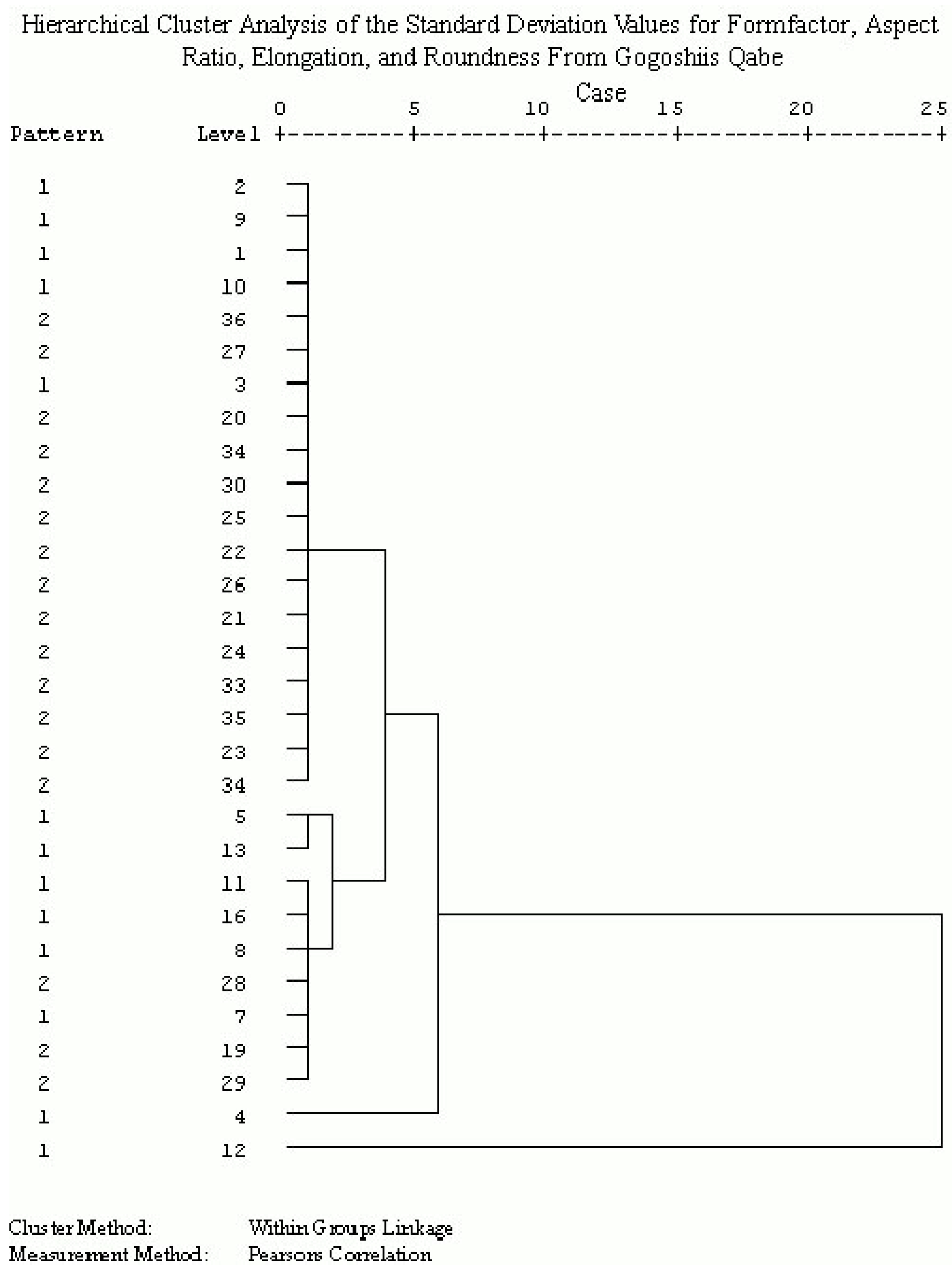



Figure 4-13 A hierarchical cluster analysis using the standard deviation values per excavation level for formfactor, roundness, elongation, and aspect ratio from Gogoshiis Qabe. The graph shows that excavation levels identified into pattern one (excavation level 1 to level 16) group independently of excavation levels identified into pattern two (excavation level 19 to level 36).

# CHAPTER 5
# CONCLUSIONS

This thesis focused on the application of Complex systems theory (CST) to interpret the process of technological change as it is observed in the prehistoric archaeological record of the Horn of Africa.  The impetus for this thesis was based in reaction to perceived deficiencies in the predominant application of culture historical methodology in current African Stone Age archaeological research and existing theories of technological change.

The recognized deficiencies in culture history include limitations to interpret data within the culture historical framework and the non-dynamic and discontinuous conception of time presented by culture historical typologies and essentialism. Deficiencies noted within contemporary studies of technological change include an over-reliance on using discrete events to explain changes over time in a technological system without adequately describing the actual processes involved (cf. Van der Leeuw 1989:3), scalar differences between the varied ideas of technological change, and a lack of discussion concerning unintentional technological changes.

As a result, I have relied on eight primary theoretical aspects of CST within this thesis to derive specific expectation regarding the identification and interpretation of technological change in the African Stone Age archaeological record.  These eight theoretical aspects include an opens systems model, non-linearity, determinism, sensitivity to initial conditions, critical path networks, contingency, emergence, and self-organization.  The expectations I have derived from CST within this thesis include an overall conception of continuous technological change with periods of punctuated changes, multi-scalar dynamics including the ability to theorize on the existence of shared social-technological ideas (ideal types) and how these relate within long term technological systems, and the ability to integrate theoretically material culture and non-material thoughts and actions of past people.

I have appended several other theoretical ideas onto the existing complex systems model in order to more precisely account for the actions and ideas of people within a theory of technological change. First, I have assumed an essentialist position advocating a mind-body dichotomy between the ideas in people's heads and their subsequent actions. In contrast to culture historical essentialism I assume that there are underlying essential ideas that direct our actions in creating technological products, but I reject the ability to know the exact ideal characteristics of an object now or in the past. By rejecting the ability to ever observe or define the essential qualities of an object I hope to distance myself from culture historical essentialism by attempting to measure instead the variation of many objects around a hypothesized, but unattainable, ideal type thereby creating a bridge between thoughts and actions. In this way I hope also to find common ground between diametrically opposed essentialist and materialist theoretical positions.

Second, I have assumed that technological changes occur intentionally and unintentionally. In my theorization of CST in chapter 2 and my application of certain aspect of CST in chapter 4 I ignore many other internal and external systemic factors that may cause technological change and instead argue that technological change is located in the changes to cognitively-based ideal types. More precisely, I argue that technological change occurs due to a combination of intentional and unintentional events that can serve to alter the trajectory of a technological system through the knowledge to identify their potential and successfully incorporate them into a technological system. This idea incorporates the punctuated events of directed and purposeful action (i.e., intentional change) in association with the constant acquisition of unanticipated techniques, tool characteristics, tool types, or technological knowledge in general acquired during the directed and purposeful events of intentional technological change (i.e., unintentional change).

In summation of this thesis, I feel confident to conclude with two points. First, a morphometrics method using computer assisted shape analysis of flake debitage can be used to identify technological change in the archaeological record. Second, CST, as modified within this thesis to explore on certain parameters and explanation, can be applied usefully to the archaeological record to interpret the process of technological change.

The application of computer assisted morphometry to analyze lithic debitage in the archaeological record is still in its infancy, and the results of my morphometrics analysis at Liben Bore and Gogoshiis Qabe pose many new directions for future research. For instance, is there an observable difference in the flake morphometry between primary, secondary, or tertiary flakes in the archaeological record? How might style affect the adoption of unanticipated variations thereby affecting the ideal type? Does raw material affect the morphology of flake shape in spite of shared properties of chonchoidal fracture? Could a morphometrics analysis even be used to identify style in the form of flakes within the archaeological record?

Within this thesis I have had to assume that many of these questions will not have a direct influence on technological change. However, this does not belittle the recognition of their possible significance within a theory of technological change, nor does it affect my conclusion about morphometrics in general. In this thesis I have merely set out in part to demonstrate that computer assisted shape analysis can or cannot be used to identify technological change through time by analyzing how flake shape varies within an archaeological sequence. As an initial study, I feel confident to conclude that morphometrics does indeed identify changes through time.

However, identifying technological change through time was only half of this thesis' objective. The identified changes had to be interpreted as well in order to make them useful to archaeology. The application of CST, as I advocate it here, can provide a useful explanation of the process of technological change identified in the archaeological record. Using expectation from a complex systems model I have been able to offer a minimal explanation of how the technological systems at both Liben Bore and Gogoshiis Qabe changed through time without any evidence that facilitates why the changes occurred in the first place.

Furthermore the complex systems model brought together materialized actions and cognitive ideas and situated them within a multi-scale continuous and dynamic conception of time and change. And, it is here that I think CST may have the most to offer archaeological research in the future. When associated with a conception of ideal types, CST provides a useful model to posit a relationship between ideas and actions, individuals and groups, and shorter periods of time within much greater spans of time. Using a complex systems model we do not have to restrain ourselves to typologies that imply synchronicity.  Instead we can begin to explore the many levels of variation operating continuously through time within a complex system that serve to create technological, social, and even behavior changes within people. In the short section that follows I intend to posit how CST, as it is applied here, may be able to provide an alternative way to explain the development of modern human behavior, a direction for future research I intend to pursue.

The epistemological implications of the modern human origins debate include Eurocentrism, materialism and culture-historical essentialism, but herald a much greater impact on the discipline itself by re-defining key concepts such as “modern behavior” (cf. Henshilwood et al. 2001; Henshilwood and Marean 2003; McBrearty and Brooks 2000:534; Wadley 2001).  Current trends within this debate seek to move beyond simple normative and direct-historical trait-list approaches reminiscent of the culture-historical roots of European and African archaeology towards a more social approach advocating intangible, socially-produced behavior as well as material culture  (for example see Deacon and Deacon 1999:101-102; Henshilwood and Marean 2003:635; McBrearty and Brooks 2000:491-492; Mitchell 2002:104-105).  As a result, the application of CST as a tool for the identification of cognitive ideal types and intentional and unintentional changes might be able to provide salient advantages towards answering key questions about the development of technology and behavior within this debate.

First, recognition of both intentional and unintentional changes and how these changes are adopted into a technological system through the critical path and contingency to transform the technological system can render obsolete the necessity of a strict dichotomy between “punctuated” and “gradualist” models within the debate (cf. Brooks et al. 1995; Henshilwood et al. 2001; Henshilwood and Marean 2003:630; Klein 1999; Kusimba 2003:117; McBrearty and Brooks 2000:454; Milo 1998:99; Shea 2003; Thompson et al. 2004; Yellen et al. 1995; Milo 1998). Instead a complex systems model assumes that both processes must work together to propel the trajectory of technological systems, and the behavior, actions, and knowledge of technological agents in new and unforeseen directions.

Second, a complex theory model may be able to describe more accurately the interaction between material culture and behavior within this debate, thereby disqualifying certain current traits recognized as modern human behavior and possibly even moving beyond a culture historical trait list approach. The reason for this is found in the ideal type. The ideal type, and a study of the variation around these ideal types, is a link between the material record and intangible behavior. The transition from a technological system with little or no formal object definition to a technology with clearly pre-defined ideas that influence the overall forms of objects over vast geographic areas and time periods suggests the adoption of specific ideological principles.

Precisely, these principles manipulate behavior by elevating the form of an object to that of "symbol" thereby transcending regional specialization. If symbolization and standardization of tool forms does in fact herald in part the foundation of modern human behavior as others have suggested (cf. Deacon and Deacon 1999:101-102; Henshilwood and Marean 2003; Klein 1999:512; McBrearty and Brooks 2000:491-492; Mitchell 2002:104-105; Wadley 2001) then the advent of the Acheulian "handaxe" may be the first tangible evidence for the development of modern human behavior.

This is just one example of possible future research for CST but is by no means the limits of this research. The applicability of both CST and morphometrics for archaeological research is much more diverse. Complex systems theory already has been used be other researchers to explain social change within archaeological contexts (cf. Bentley and Maschner 2003; Van der Leeuw and McGlade 1997). Yet the complex systems model is still cutting-edge theorization of systems theory, chaos, and non-linearity. As the literature on these diverse concepts increases, this should in turn open up many new avenues of theorizing how people behaved and acted in the past.

However, computer assisted morphometry might have more practicality to mainstream archaeology. The expediency, reliability, cost-effectiveness, and standardization of morphometrics can play a significant role in future lithic analysis methodology. Refinement of morphometrics techniques can lend this method very useful for identifying the character of archaeological deposits during an excavation and even using this method as a tool to correlate the morphological trends at one site with one or more other sites. Thus, morphometrics can become just the method essential to Horn of African archaeology that provides a foothold on understanding the spatial and temporal enormity of Stone Age assemblages within this area. Only time will tell though. Regardless, I intend to pursue both CST and computer assisted morphometry in the hopes of advancing archaeological knowledge and practice in order to contribute to the story of humanity.

APPENDIX A
AN EXPERIMENT ON TECHNOLOGICAL PROCESS USING STONE TOOLS

## Introduction

A practical experiment was conducted during the Fall of 2003 to investigate the process of intentional and unintentional technological change within an experimental archaeological setting as interpreted using a CST. This experiment enlisted nine volunteers with no prior experience making stone tools. The lack of lithic tool production experience was essential to ensure a contemporary de novo lithic technology with little influence from prior archaeological knowledge as to how stone tools have been made prior and a relatively even beginning point to compare each of the three groups against. This project was undertaken to observe whether:

1. Technological change occurs primarily through unintentional variations incurred through intentional technological production.
2. Intentional and goal-oriented developments follow a pre-planned route of research and technology while unintentional variations may alter the trajectory of technological research, development and implementation in new and unforeseen ways.
3. Experiential knowledge plays a vital role in the identification and implementation of unintentional variation within a technological system. In particular, agents with low experiential knowledge of a technology will not grasp the full significance of certain unintentional variations until a substantial experiential knowledge base (i.e., critical path) is achieved.

These three project goals were tested by observing the actions of each group member during each task and noting how their behavior changed, or did not change, between tasks and series. Each task was designed to be cumulative thereby allowing the knowledge acquired in task one to also be applied to task two. However, each task was also distinctly different thereby forcing group members to create new solutions for each task. The ability to recognize intentional and unintentional variations and note their influence on a group's developed technological system hinged on my greater experience producing, using, and studying stone tools. Through my knowledge, I was able to identify the accidental production of tool forms or the accidental use of tool production techniques based on my prior experience with similar situations and examples from the archaeological record, and observe if the group member identified the usefulness of the unintentional variation or not. For example, if a group member accidentally produced a flake during a task requiring them to cut through a piece of leather, I observed if the group member identified this potentially useful tool and how they incorporated it within their technological system. In later tasks I was able to observe how group members further utilized flakes, for example, in terms of their ideal tool types and actual tool production and if the group members had sufficient knowledge to create more flakes or were unable to sustain the tool type.

The observations and interpretations made within this project rest on several underlying assumptions. These assumptions are:

1. Participants prior knowledge will not affect the results of their ability to create and sustain a lithic technology because their lack of knowledge to produce stone tools. However, prior knowledge may limit the choices perceived available to each group (i.e., to chop though a piece of wood you need an axe-like tool).

2. Ideas direct actions. Shared ideas create similarity within tool forms and tool use.

3. Technological change results primarily from intentional and unintentional variations recognized during the process of technological production. The adoption of these variations changes the ideal type and technological system in general.

4. Technological change may or may not occur through other processes but this is inconsequential to the effect of intentional and unintentional changes.

5. Modern-day experimental technological production should replicate comparable real-world archaeological technological production for both intentional and unintentional technological change.

The experiment consisted of each group independently conducting a series of 4 tasks that were repeated twice in sequence (Series 1 and Series 2). Each task was designed so that every group could apply the knowledge gained from the prior task to the next task. The specific tasks for each group included the following:

1. Develop an implement to cut through a section of leather.
2. Develop an implement to chop through a 2 inch thick diameter oak branch.
3. Develop an implement to inscribe fine, parallel lines onto a piece of wood.
4. Develop of an implement to bore a hole in a section of wood.

The rules for the experiment were simple and required that each group initially fill out a questionnaire asking what they intended to produce, why they wanted to produce a particular design and how they conceived the tool manufacturing process. Furthermore, each group was also required to submit a scale drawing of the intended final outcome of the tool(s) with a brief explanation of its particular hypothesized morphology and function. This information was thought to be useful to compare a group's intentions with the final tools produced. However, the drawings of a group's ideal tool were frequently much too generalized to be much use in comparison with the actual tool(s) produced. Furthermore, the tool(s) produced during the task were frequently modified, thereby creating inconsistency in the ability to compare ideal tool form drawings against the end-products. As a result, I found that my direct conversations with group members about their ideal tool and how they intend to make the tool were much more informative and useful for identifying their ideal types and how these change through time though intentional and unintentional variations.

The methodology was straightforward and consisted of giving each group a collection of variably-sized quartzite and chert cobbles. While the participants were told the common name of each rock, caution was taken not to use descriptive or functional terminology such as “core”, “hammerstone” or “flake” and thus bias the participant’s conceptions of the “proper” functions of the supplied materials. In addition to the quartzite and chert stones, other raw materials available to each group included a 26cm elk antler baton, a 15cm white tail deer antler tine and a 28cm x 18cm piece of leather.

**Series 1**

**Task 1: Cutting a Piece of leather**

The first task was to cut a large piece of leather using only the stone tools provided. All three groups decided to rely initially only upon naturally sharp edges of the chert instead of attempting to secondarily manufacture a sharp edge. Frequently, a large rock was used as an anvil to support a cutting tool from above. Alternately, a large rock was also situated on the ground and the leather simply rubbed over an upward facing sharp edge. Most importantly, one group eventually began to experiment with flaking chert after experimenting with an unintentionally produced flake. But while this group seemed to grasp the importance of flaking raw materials to produce sharp edges, they could not duplicate the sharp flakes through their random and haphazard smashing two stones together. Therefore, they reverted back to a simple hammer and anvil cutting technique. It was only toward the end of this task that the same group found a sharp flake unintentionally produced during the hammer and anvil technique and swiftly and successfully scored the leather with the distal end of the flake.

While two groups still did not recognize and utilize a flake tool technique, the recognition and utilization by the third group demonstrated that the unintentional production of tool variations can alter the conception of the ideal tool and how they go about accomplishing a task.

**Task 2: Chopping through a Branch**

The next task was designed to build on experiential knowledge gained from the previous task and required each group to chop through a 5cm (2 inch) thick branch of oak. All three groups clearly noted their influence with the image of an axe as the pattern of choice because of its sharp bifacial blade, high mobility and the mechanical force it afforded to chop through wood. A second group began to recognize the properties and value of flakes during this task. However, like the group in task one, this second group lacked the knowledge to consistently produce flakes. Flakes were still a novelty produced only by accident.

**Task 3: Inscribe a Series of Lines into Wood**

This task required each group to score a series of crosshatched and zigzag lines into a piece of wood. As in past experiments, all groups initially chose the simplest solution by utilizing readily available material of naturally pointed stones. This process quickly failed to produce desired results so all groups eventually reverted to lessons learned in previous tasks and sought additional stones for flaking sharp edges and points. It was during this process of attempted flake production that one group's quartz nodule they used as a hammerstone shattered. The quartz shatter produced predominantly non-flake angular debris with numerous sharp corners and edges. This group quickly discovered that the angular debris from the quartz boulder provided an excellent tool for inscribing the wood and shifted their focus from using and producing flakes to using non-flaked angular debris initially made unintentionally.

Up until this point I have emphasized the usefulness and unintentionally produced nature of flake materials. However, the example from task three clearly shows that flakes are not the only useful unintended variation but just another variation nonetheless. Interestingly, in this task, the most successful final tool was unintentionally produced while trying to produce flakes. What followed was the important discovery that rough, angular and pointed pieces of quartz could also be successfully utilized for the required task at hand instead of expending time and energy on the precise production of flakes.

**Task 4: Drill a Hole through a Piece of Wood**

The requirement for this task was to drill a hole of any diameter through a 0.5cm piece of wood. Similar to past experiments, the participants were equally influenced by their knowledge of modern drilling technology and immediately set out to produce a drill-like stone tool that fit the hand well and could be applied in a spinning motion. Two groups began experimenting with flaking chert nodules in attempts to produce thin, drill-like stone tools representative of their preconceived ideal tool form. The first group accidentally produced their flake and created a successful tool from it whereas the second group, which had up until now not utilized flake technology, began to experiment with creating and using flakes. The third group unsuccessfully completed this task because their hammering method split the wood in two.

Most groups began this task with a clear-cut ideal tool form in mind and quickly set about its manufacture. It was only after repeated unsuccessful attempts to make the tool that the focus was then shifted to utilizing the resulting flake debitage instead. While the manufacture of these ultimately successful flakes was originally intentional, their final utility was not initially recognized until later. It was again observed that unintentional variations and usage of manufactured products could be successfully applied to accomplish the task at hand.

**Summary of Series 1**

At the conclusion of Series 1, the technological systems of all groups had progressed significantly in both the design and implementation of stone tools. Each group had developed a flake-based technology that allowed the rudimentary manufacture and modification of tool edges. While functionally-driven, goal-oriented tasks were the motivation for each group, it was equally clear that the tool designs of each group also reflected the intention of the task and the prior knowledge of the group members.

Through direct observation and conversation with participants during each task, experiential knowledge seemed to provide each group the ability to ultimately recognize and utilize unintended outcomes during intentional production that they otherwise may have missed earlier. It was observed that the frequency to recognize useful unintended variations increased as group members acquired more direct knowledge of stone tools. This in turn enabled them to identify and either implement or reject coincidental and unintended variations.

## Series 2

Series 2 consisted of identical tasks from the previous series and was designed to allow direct observation of the importance of experiential knowledge and how it may influence the recognition and ultimate application of unintended outcomes. All groups initially expressed confidence in using stone tools to complete the required tasks.

Sharp flake production was the dominant objective for cutting the leather and wood although one group still attempted to reproduce an unusual triangular-shaped tool with a hook that was unintentionally created in a previous task. After considerable effort and numerous tool failures from breakage, this group eventually discarded the hooked stone tool idea and reverted back to simple flake technology to successfully accomplish the cutting tasks. It was observed that the identification of an earlier unintended variation (the triangular flake) clearly influenced the intentional production of the technology and facilitated rapid change of the ideal type conception for this group even if the produced tool was eventually proven unsuccessful. This unstable and perturbative process ultimately led to the emergent development of a similar tool form that might not have been pursued had the initial conditions been slightly different. Similar albeit less original variants were also utilized in the drilling and scoring tasks as all groups simply relied upon their past experience to reproduce stone implements found acceptable in the previous series.

## Conclusion

The primary objective of this experiment was to investigate whether technological change through unintentional variations can be directly observed and documented. In addition, this project observed the influence of increasing experiential knowledge in the identification and implementation of unintentional variations within a technological system.

Each group consistently relied on a pre-planned ideal tool type to accomplish each task but the actual manufactured product was rarely similar in design. The reasons for this possibly relate to the low manufacturing skill level of the participants combined with their inability to recognize and utilize unintended tool variants to better accomplish the tasks. As the knowledge base of the technological producers increased, the ability to recognize unintended outcomes also increased thereby altering the overall trajectory of the technological system.

# APPENDIX B
# MATHEMATICAL FORMULAE

| | |
|---|---|
| Formfactor | $4\Pi A / P^2$ |
| Roundness | $4A / \Pi L^2$ |
| Elongation | skeleton length / mean fiber width |
| Aspect Ratio | $L / B$ |
| Formfactor Divided by Roundness | $\Pi^2 AL^2 / AP^2$ |

Where:

A = Area

B = Breadth

L = Length

P = Perimeter

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